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Ichthyofauna from Santos-São Vincente upper estuary: a study before and during fire at Santos port terminal

Ictiofauna do alto estuário de Santos-São Vicente: um estudo antes e durante o incêndio no terminal portuário de Santos

Ictiofauna del estuario alto de Santos-São Vicente: un estudio antes y durante el incendio en la terminal portuaria de Santos

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Abstract

Studies accounting the ichthyofauna composition of the Santos-São Vincente estuary-bay and Bertioga channel complex (SSEBBC) are scarce, even with its high ecological and economical importance. In this sense, the present study performed a checklist of the ichthyofauna from the SSEBBC aiming to report the distribution, diet, habitat, economic importance, and conservation status of the collected fish species. Twenty-four (24) monthly collecting campaigns were conducted between March 2013 and February 2015. In each survey, four locations around Bagres Island were sampled with the aid of the Terminal Químico de Aratú S.A. (TEQUIMAR) between April 2nd and 10th of 2015. A total of 172 fish specimens were collected, where 50.6% were carnivorous; 35.5% were marine-estuarine; 44.2% with high occidental Atlantic Ocean distribution; 44.8% were a high important food resource. Regarding the conservation status, these fish species were classified as "low-worries" in 76.2% for the global evaluation; 95.3% in national evaluation; and 55.2% in São

Paulo State evaluation. Moreover, 53 new fish species were catalogued for the Santos-São Vincente estuary-bay, where 12 were collected during the field monitoring and 41 during the fire monitoring. Fifty-eight (58) fish species collected during the field campaigns were categorized like "insufficient data"; 3 as alien species (*Oreochromis niloticus*, *Opsanus beta* e *Butis koilomatodon*); and there was a rare record of *Megalops atlanticus* in São Paulo State. Besides of the high anthropization, the studied area presented high fish species richness and should be monitored to ensure the fish species conservation status.

Keywords: Checklist; Geographic distribuction; Diet; Aquatic habitat; Economic importance; Conservation.

Resumo

Apesar da importância ecológica e econômica do complexo baía-estuário de Santos-São Vicente e canal de Bertioga, ainda são incipientes os estudos sobre a composição da ictiofauna na região alta do complexo. Assim, o presente estudo teve como objetivo listar as espécies de peixes da região do alto estuário de Santos-São Vicente, relatando a distribuição, dieta, tipos de habitats, importância econômica e status de conservação. Para cumprir este objetivo foram realizadas 24 campanhas mensais entre março de 2013 e fevereiro de 2015, em quatro pontos distintos, utilizando rede de espera com esforço de captura padronizado. Também foram recolhidos peixes mortos durante o incêndio que acometeu o Terminal Químico de Aratú S.A. (TEQUIMAR) entre 2 e 10 de abril de 2015. No total, foram registradas 172 espécies, predominantemente carnívoras (50,6%), marinha-estuarinas (35,5%), com ampla distribuição no Oceano Atlântico Ocidental (44,2%), com importância econômica para alimentação (44,8%) e categorizadas como "pouco preocupante" na avaliação global (76,2%), nacional (95,3%) e estadual (55,2%). O presente estudo registrou 53 espécies ainda não catalogadas para o alto estuário de Santos-São Vicente, sendo 12 através do monitoramento e 41 do incêndio. Também foram observadas 58 espécies categorizadas como "dados deficientes" e três espécies exóticas (*Oreochromis niloticus*, *Opsanus beta* e *Butis koilomatodon*), além de um raro registro de *Megalops atlanticus* no estado de São Paulo. Apesar da elevada antropização, a área de estudo apresenta uma grande riqueza de peixes e deve ser monitorada adequadamente para garantir a conservação das espécies.

Palavras-chave: Inventário; Distribuição geográfica; Dieta; Habitats aquáticos; Importância econômica; Conservação.

Resumen

A pesar de la importancia ecológica y económica del complejo bahía-estuario Santos-São Vicente y del canal Bertioga, los estudios sobre la composición de la ictiofauna en la región alta del complejo son aún incipientes. Así, el presente estudio tuvo como objetivo enumerar las especies de peces en la región del estuario alto de Santos-São Vicente, informando la distribución, dieta, tipos de hábitats, importancia económica y estado de conservación. Para lograr este objetivo, se realizaron 24 campañas mensuales entre marzo de 2013 y febrero de 2015, en cuatro puntos diferentes, utilizando una red de espera con un esfuerzo de captura estandarizado. También se recolectaron peces muertos durante el incendio que afectó al Terminal Químico de Aratú S.A. (TEQUIMAR) entre el 2 y el 10 de abril de 2015. En total se registraron 172 especies, predominantemente carnívoras (50,6%), marino-estuarinas (35, 5%), con amplia distribución en el Atlántico Occidental (44,2%), con importancia económica para la alimentación (44,8%) y categorizada como “poca preocupación” en el global (76,2%), nacional (95,3%) y estatal (55,2%). El presente estudio registró 53 especies aún no catalogadas para el estuario alto de Santos-São Vicente, 12 por monitoreo y 41 por incendio. También se observaron 58 especies categorizadas como "datos deficientes" y tres especies exóticas (*Oreochromis niloticus*, *Opsanus beta* y *Butis koilomatodon*), además de un registro raro de *Megalops atlanticus* en el estado de São Paulo. A pesar de la alta antropización, el área de estudio tiene una gran riqueza de peces y debe ser monitoreada adecuadamente para asegurar la conservación de las especies.
Palabras clave: Inventario; Distribución geográfica; Dieta; Hábitats acuáticos; Importancia económica; Conservación.

1. Introduction

Historically, coastal regions play a strategic role in a country’s economic development and population growth, mainly as a result of the construction of ports and terminals in these regions (Barletta et al., 2010; Blaber & Barletta, 2016; Barletta & Lima, 2019). In Brazil, more than half of the metropolitan regions are in estuarine areas (CETESB, 2001). However, as the country’s economic development is not based on a sustainable economic model that considers the ecological importance of such areas (Kennish, 1990), these ecosystems are exposed to different impacts due to industrialization and urbanization.

Estuaries consist of a mosaic of habitats, including salt marshes, mangroves, tidal creeks and water columns (Miranda et al., 2002), and provide food, protection against predators and environmental conditions that favor the growth and survival of various organisms in their initial stages. The distribution of organisms in estuaries is influenced mainly by the salinity, temperature and dissolved oxygen (Spach et al., 2004; Barletta et al., 2010) but also depends on life-cycle stage and can vary seasonally. The nekton community consists mainly of immature individuals from transient saltwater, freshwater and anadromous species (Weinstein & Brooks, 1983), which use estuaries as feeding and nursery grounds as well as for reproductive migration (Yáñes-Arancibia, 1986; Vendel et al., 2003). Estuaries are therefore responsible for connectivity between different habitats (Sheaves, 2005) and for the renewal of demographic groups (Barletta et al., 2010).

Despite the undeniable importance of estuaries for fish species, there is a dearth of studies on their species composition in Brazil (Silveira et al., 2010), which can lead to underestimation of the biodiversity (Barletta et al., 2010) even in areas that can be easily reached, such as those in metropolitan regions (Vilar & Joyeux, 2018). In many cases, Brazilian estuaries underwent extensive modifications before they were studied (Barletta et al., 2010; Silveira et al., 2010; Catelani et al., 2014; Marceniuk et al., 2017; Vilar & Joyeux, 2018; Barletta & Lima, 2019), as did Brazilian coastal reef environments (Pinheiro et al., 2015).

Although the upper Santos-São Vicente estuary is of considerable economic importance, only five studies (Luederwaldt, 1919; Paiva-Filho et al., 1987; Braga, 2013; Santos et al., 2015; Souza, 2017) of the composition and ecological interactions of its ichthyofauna have been published to date. However, in other areas of the Santos-São Vincente estuary-bay and Bertioga channel complex (SSEBBC), several studies have been carried out (Vazzoler, 1970; Paiva-Filho, 1982; Paiva-Filho & Schmiegelow, 1986; Paiva-Filho et al., 1987; Paiva-Filho & Toscano, 1987; Ribeiro-Neto, 1989; Giannini & Paiva-Filho, 1990; Lopes et al., 1993; Ribeiro-Neto, 1993; Giannini & Paiva-Filho, 1995; Fagundes et al., 2007; Schmidt et al., 2008; Rocha, 2009; Barbanti et al, 2013; Dias et al., 2014; Rocha & Dias, 2015; Santos et al., 2015; Caetano, 2016; Dias et al., 2017; Carminatto et al., 2020; Rotundo, 2020).

Historically, due to the petrochemical industry and port activities, the SSEBBC was influenced by several events which were responsible for the impacts to the biodiversity and human health. According to Poffo (2011), from 1951 to 2016, fourteen events can be highlighted: 1951: fire in the oil tanker "Cerro Gordo"; 1974: fire in the oil tanker "Guaporé"; 1974: fire on the ship "Ais Georgius", carrying sodium nitrate; 1974: leaking of 3,450 tons of toluene; 1984: fire caused by the rupture of a gasoline duct in the port region, resulting in 93 deaths; 1984: leaking of 550,000 liters of oil fuel from the "Gisela" vessel; 1991: fire at two containers of vinyl acetate and acrinolitrile; 1994: leaking of diesel fuel from the "Norma" vessel; 1998: leaking of 40,000 liters of oil fuel fron the "Elisabeth Rickmers" and "Smyrmi" vessels; 1998: fire during the shipment of the tank truck full of dicyclopentadiene; 2008: leaking of 1,000 liters of oil fuel with fire of the ship "Rio Blanco"; 2013: Fire at the sugar terminal "COPERSUCAR", were 180,000 tons of sugar were burned and drained to the estuary; 2014: fire at the Rumo Logística sugar terminal "TEAG"; 2016: fire at the Localfrio containers terminal, were 20 tons of sodium dichloroisocyanurate dihydrate were burned.

Therefore, the present study provides information of the ichthyofauna aiming to report the distribution, diet, habitat, economic importance, and conservation status of the fish species collected at SSEBBC, a little-studied and high impacted area of the center coast of the São Paulo State, Brazil.Use o parágrafo como modelo

2. Material and Methods

The study area is in the Santos-São Vicente upper estuary region in the SSEBBC. At SSEBBC is located the port of Santos, the largest in Latin America, which processes cargo from the largest petrochemical center in Brazil (Cubatão). Together, the port and petrochemical center are responsible for a wide range of anthropogenic impacts to this region (CETESB, 1978, 1981, 2001, 2008; Milanelli, 2003; Medeiros & Bícego, 2004; Zaroni, 2006; Martins et al., 2008; Siqueira et al., 2012; Brandão et al., 2015).

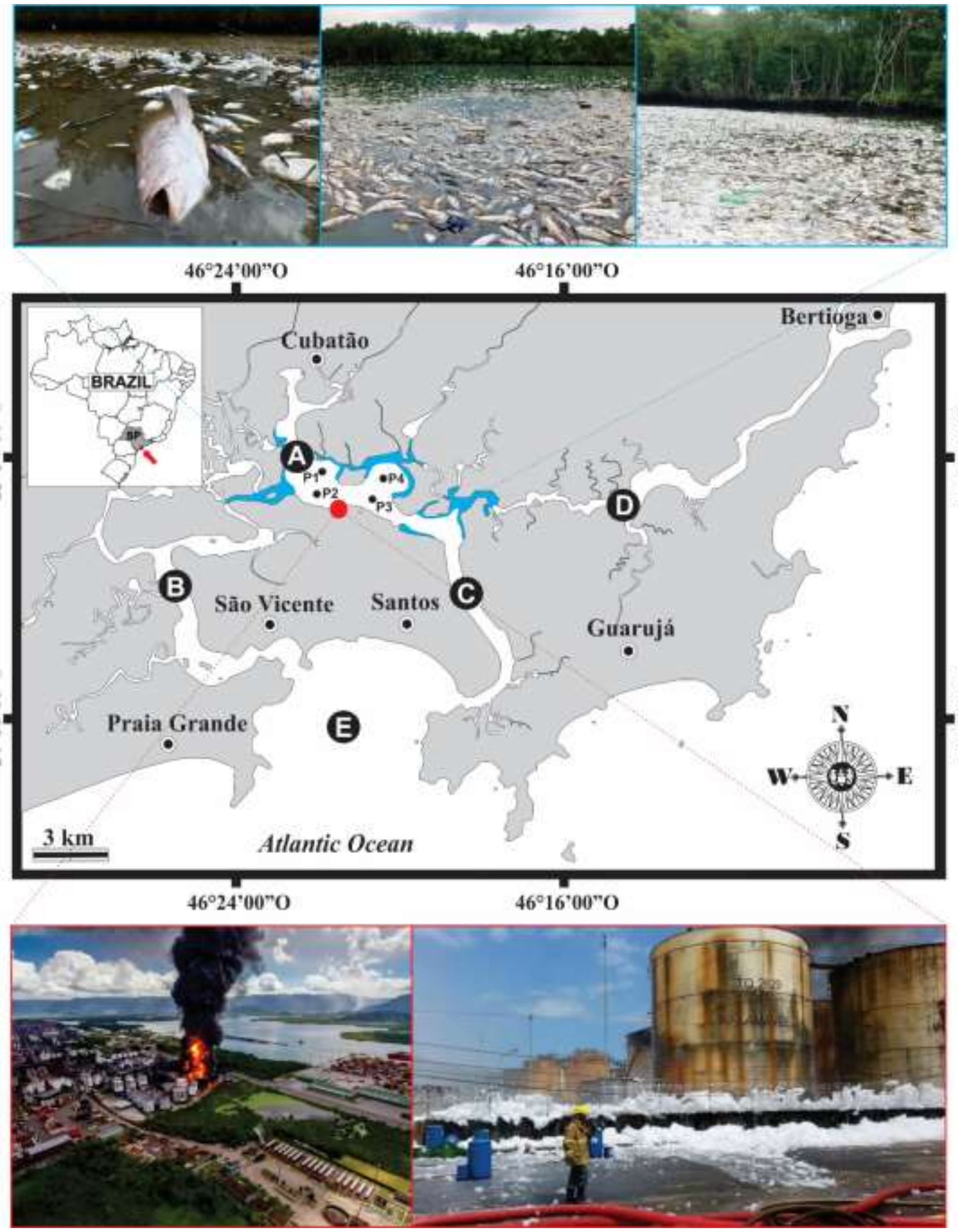
The monitoring was carried out through twenty-four monthly collecting campaigns, which were conducted between March 2013 and February 2015. In each survey, four locations around Bagres Island were sampled (Figure 1). The (mean) geographic coordinates of each location are P1 (23S 54'30"; 46W 21'38"), P2 (23S 54'55"; 46W 21'39), P3 (23S 54'57"; 46W 20'25") and P4 (23S 54'30"; 46W 20'17"). After collection, fish specimens were sacrificed by immersion in a saturated clove-oil solution and then stored in ice and transported to the laboratory at the Santa Cecília University Zoological Collection (AZUSC).

In 2015, between April 2nd and 15th, occurs the biggest fire already registered in an industrial area of Brazil. This fire happened at the Terminal Químico de Aratú S.A. – TEQUIMAR, a private company, located at the Santos-São Vicente estuary (Figure 1). This incident burned eight tanks of gasoline A, anhydrous alcohol ANP, and diesel fuel S10 (≈23,306m^3) (Almeida, 2018). The foam generating liquid- Aqueous Film-Forming Foam (AFFF) was used to control the fire, 426,000 liters of several brands of AFFF; 4,000 liters of Cold fire®; and 4,000 liters of F-500® were used to contain the fire (Figure 1). Moreover, water from the estuary (more than 500 million of liters) was used to contain the fire, togethers with the AFFFs, which drained the all the hazards compounds present in the AFFFs composition (i.e. solvents, additive compounds, perfluorinated, hydrocarbon-based surfactants, perfluorooctane sulfonic acids and perfluorooctanoic acids) back to the estuary complex. This contaminants caused the mortality of fish species and other organisms probably due to (i) the mode of action of the AFFFs, which decreases de dissolved oxygen of the water due the creation and a layer under water with prevents the oxygen to penetrates, while increases the water temperature, and (ii) the toxicity of the AFFFs composition (Borges, 2015; Fontes, 2016; Chinellato, 2017). The specimens from the fire were collected in the entire region of the upper Santos-São Vicente estuary using liftnet and casting net with the help of local fishermen. Subsequently, they were transported to the AZUSC for identification and biometry.

Fishes were identified according to Figueiredo & Menezes (1978, 1980, 2000), Fischer (1978), Menezes & Figueiredo (1980, 1985), Cervigón et al. (1992), Carvalho-Filho (1999), Carpenter (2002), Fischer et al. (2004), Marceniuk (2005), Leis (2006), Sampaio & Nottingham (2008), Carvalho-Filho et al. (2010), Gomes et al. (2010), Macieira et al. (2012), Menezes et al. (2015), Marceniuk et al. (2016), Silva et al (2018), Marceniuk et al. (2019a,b), Mercedes-Azpelicueta et al. (2019), Carvalho et al. (2020), Marceniuk et al. (2020) and Petean et al. (2020). Higher level classification follows Nelson et al. (2016), whereas classification at genus and species levels follow Fricke et al. (2020). Voucher specimens of the species collected during the study were deposited in the regional collection of fish from the Atlantic Forest coast of the AZUSC, in the city of Santos-SP, Brazil.

The biogeographic distribution, which followed Floeter et al. (2008), Luiz Jr et al. (2008), Passos et al. (2012) and Rotundo et al. (2019), was based on the following classification: circumtropical (CT); trans-Atlantic (TA): both sides of the Atlantic; Western

Figure 1. Santos-São Vincente estuary-bay and Bertioga channel complex (SSEBBC) showing the four sampling locations (P1-P4) in the Santos-São Vicente high estuary; A. Upper Santos and São Vicente estuary; B. São Vicente channel; C. Santos channel; D. Bertioga channel; E. Santos bay; Red circle: fire area (TEQUIMAR); Blue: dead fish collection area.



Source: Map: authors, upper: Willian Schepis (Ecofaxina Institute); lower left: Sergio Furtado (G1), right: Fire Department of the Military Police of the São Paulo State.

Atlantic (WA): northern and southwestern Atlantic; Southwestern Atlantic (SWA): from northern Brazil to Argentina; Argentinean Province (Ar): the area between Rio de Janeiro in Brazil and Argentina; Caribbean (Ca): from Florida to Venezuela; Brazilian Province (Br): the area between the Orinoco Delta in Venezuela and Santa Catarina in Brazil; Eastern Pacific (EP); and not applicable (NA) in the case of species with a typically freshwater distribution.

Based on Froese & Pauly (2020), species were classified according to their feeding habits as carnivorous (CAR), invertivorous (INV), omnivorous (OMN), piscivorous (PIS) or planktivorous (PLA). They were also classified in terms of their habitats according to Fricke et al. (2020) as marine (M), brackish (B) or freshwater (F). Species used as ornamental fishes were identified following Monteiro-Neto et al. (2003), Sampaio & Nottingham (2008) and Gurjão & Lotufo (2018).

The conservation status of each species was checked in the International Union for Conservation of Nature (IUCN) (IUCN 2020), the list of threatened species in Brazil (Brasil, 2014) and the list of threatened species in the São Paulo State (São Paulo, 2014).

3. Results

Monitoring

Eighty-three (83) species belonging to 32 families, 20 orders and 2 classes were recorded (Table 1). Osteichthyes accounted for 98.8% of the species, and Chondrichthyes for only 1%.

The order representing the greatest number of families was the Perciformes (7), followed by the Pleuronectiformes (3), Anguilliformes, Clupeiformes, Scorpaeniformes and Tetraodontiformes (2). The family representing the greatest number of species was the Sciaenidae (14), followed by the Carangidae (12), Gerreidae (6) and Ariidae (5), which together accounted for 44.6% of all the species recorded. In monitoring, 5252 specimens were captured, and the five most abundant were *M. curema* (n=1392), *D. rhombeus* (n=501), *G. genidens* (n=373), *M. furnieri* (n=242) and *M. martinicensis* (n=234), which together accounted for 54% of all the specimens.

The majority (49.4%) of the species recorded have a distribution along the Western Atlantic coast (WA), followed by Ca+Br (14.5%), Ca+SWA (9.6%), TA (7.2%), Br+Ar

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(4.8%), CT (3.6%), WA+EP and Br (2.4% each). Only one species was found in each of the categories NA, Ca, SWA, Ca+WA and TA+EP.

Table 1. Class, order, family and species organized according to Nelson et al. (2016); monitoring relative abundance (RA); Fire; 1: Luederwaldt (1919); 2: Paiva-Filho et al. (1987); 3: Braga (2013); 4: Santos et al. (2015); 5: Souza (2017); type of habitat (HB): freshwater (F), brackish water (B) and marine (M); diet (Di): carnivorous (CAR), detritivorous (DET), invertivorous (INV), omnivorous (OMN), piscivorous (PIS) and planktivorous (PLA); geographic distribution (GD): circumtropical (CT), trans-Atlantic (TA), Western Atlantic (WA), Southwestern Atlantic (SWA), Argentinean Province (Ar), Caribbean (Ca), Brazilian Province (Br), not applicable (NA) and Eastern Pacific (EP); conservation status according to Brazilian state legislation (SMA), Brazilian federal legislation (MMA) and the International Union for Conservation of Nature (IUCN): data deficient (DD), endangered (EN), not evaluated (NE), needs management action (NMA), least concern (LC), near threatened (NT), critically threatened (CR) and vulnerable (VU); economic importance ($): food (FD), ornamental fishes (ON) and no commercial value (N); vouchers (AZUSC); first time registered in the study area (*); invasive species (#).

Class/Order/ Family/ Specie	RA	Fire	1	2	3	4	5	HB	Di	GD	IUCN	MMA	SMA	$	Voucher
CHONDRICHTHYES															
TORPEDINIFORMES															
Narcinidae															
Narcine brasiliensis (Olfers, 1831)*		x						M	INV	WA	DD	LC	DD	O	448
PRISTIFORMES															
Rhinobatidae															
Pseudobatos horkelii (Müller & Henle, 1841)*		x						M	CAR	Ar	CR	CR	LC	F	4415
MYLIOBATIFORMES															
Dasyatidae															
Hypanus berthalutzae Petean, Naylor & Lima, 2020*	0.11							BM	CAR	WA	DD	LC	LC	O	3356
Hypanus guttatus (Bloch & Schneider, 1801)*		x						M	CAR	Ca+Br	DD	LC	LC	O	4367
Myliobatidae															
Aetobatus narinari (Euphrasen, 1790)*		x						BM	INV	CT	NT	LC	DD	N	4515

Class/Order/ Family/ Specie	**RA**	**Fire**	**1**	**2**	**3**	**4**	**5**	**HB**	**Di**	**GD**	**IUCN**	**MMA**	**SMA**	**$**	**Voucher**
<u>OSTEICHTHYES</u>															
ELOPIFORMES															
Elopidae															
Elops smithi McBride, Rocha, Ruiz-Carus & Bowen, 2010	0.59	x	x			x	x	M	CAR	WA	DD	LC	LC	F	4314, 4416
Megalopidae															
Megalops atlanticus Valenciennes, 1847*		x						FBM	PIS	WA	VU	VU	LC	FO	4680
ALBULIFORMES															
Albulidae															
Albula vulpes (Linnaeus, 1758)	0.10	x					x	M	CAR	WA	NT	LC	LC	N	4106, 4421
ANGUILLIFORMES															
Muraenidae															
Gymnothorax funebris Ranzani, 1839*		x						M	CAR	WA	LC	LC	LC	O	4681
Gymnothorax ocellatus Agassiz, 1831*	0.08	x						M	CAR	Ca+SWA	LC	LC	LC	O	4107, 4455
Ophichthidae															
Myrophis punctatus Lütken, 1852*		x						FBM	CAR	WA	LC	LC	LC	N	4473
Ophichthus gomesii (Castelnau, 1855)	0.17	x				x		M	CAR	WA	LC	LC	LC	N	4431
Congridae															
Conger orbignianus Valenciennes, 1837*		x						M	CAR	WA	LC	LC	LC	F	4454
CHARACIFORMES															

Class/Order/ Family/ Specie	RA	Fire	1	2	3	4	5	HB	Di	GD	IUCN	MMA	SMA	$	Voucher
Erythrinidae															
Hoplias malabaricus (Bloch, 1794)			x					F	CAR	NA	LC	LC	LC	FO	
CLUPEIFORMES															
Engraulidae															
Anchoa filifera (Fowler, 1915)*		x						BM	CAR	Ca+Br	LC	LC	DD	F	4684
Anchoa spinifer (Valenciennes, 1848)		x				x	x	FBM	CAR	Ca+Br+EP	LC	LC	DD	F	4375
Anchoa tricolor (Spix & Agassiz, 1829)		x					x	BM	CAR	SWA	LC	LC	DD	F	4624
Anchovia clupeoides (Swainson, 1839)*		x						M	PLA	Ca+Br	LC	LC	LC	F	2141
Anchoviella lepidentostole (Fowler, 1911)		x				x		FBM	CAR	Br	LC	LC	NT	F	4398
Cetengraulis edentulus (Cuvier, 1829)	0.59	x	x			x	x	M	PLA	Ca+Br	LC	LC	LC	F	3116, 4374
Lycengraulis grossidens (Spix & Agassiz, 1829)		x				x	x	FBM	CAR	Br+Ar	LC	LC	LC	F	5915
Clupeidae															
Brevoortia pectinata (Jenyns, 1842)*		x						M	INV	Ar	LC	LC	LC	F	2956
Harengula clupeola (Cuvier, 1829)	0.55	x				x	x	M	PLA	WA	LC	LC	LC	F	3795, 4396
Opisthonema oglinum (Lesueur, 1818)	0.21	x				x	x	BM	CAR	WA	LC	LC	NT	F	3748, 4378
Sardinella aurita Valenciennes, 1847		x				x		BM	PLA	Ar	DD	LC	DD	F	4439
SILURIFORMES															
Callichthyidae															
Callichthys callichthys (Linnaeus, 1758)			x					F	OMN	NA	NE	LC	LC	O	

Class/Order/ Family/ Specie	RA	Fire	1	2	3	4	5	HB	Di	GD	IUCN	MMA	SMA	$	Voucher
Ariidae															
Aspistor luniscutis (Valenciennes, 1840)	3.71	x	x			x	x	BM	OMN	Br	NE	LC	DD	F	4119, 4386
Bagre bagre (Linnaeus, 1766)*	0.15	x						BM	CAR	Ca+Br	LC	LC	DD	F	4223, 4388
Cathorops spixii (Agassiz, 1829)	3.07	x	x			x	x	FBM	CAR	Ca+Br	NE	LC	LC	F	4140, 4372
Genidens barbus (Lacepède, 1803)	1.64	x				x	x	BM	CAR	Br+Ar	NE	EN	DD	F	2795, 4371
Genidens genidens (Cuvier, 1829)	7.10	x	x	x		x	x	BM	CAR	Br+Ar	LC	LC	DD	F	4114, 4381
AULOPIFORMES															
Synodontidae															
Synodus bondi Fowler, 1939		x				x	x	M	OMN	WA	LC	LC	LC	N	4425
BATRACHOIDIFORMES															
Batrachoididae															
Batrachoides surinamensis (Bloch & Schneider, 1801)							x	BM	CAR	Ca+Br	LC	LC	LC	O	
Opsanus beta (Goode & Bean, 1880)#	0.32	x				x	x	FBM	CAR	Ca	LC	LC	LC	N	4118, 4426
Porichthys porosissimus (Cuvier, 1829)		x					x	M	INV	Ar	LC	LC	NT	O	4403
GOBIIFORMES															
Eleotridae															
Butis koilomatodon (Bleeker, 1849)#*		x						FBM	CAR	EP	NE	LC	LC	N	3121
Dormitator maculatus (Bloch, 1792)*		x						BM	OMN	WA	LC	LC	LC	O	4459
Eleotris pisonis (Gmelin, 1789)*		x						FBM	CAR	WA	LC	LC	LC	O	4466

Class/Order/ Family/ Specie	RA	Fire	1	2	3	4	5	HB	Di	GD	IUCN	MMA	SMA	$	Voucher
Guavina guavina (Valenciennes, 1837)*		x						FBM	OMN	WA	LC	LC	LC	O	5662
Gobiidae															
Awaous tajasica (Lichtenstein, 1822)*		x						FBM	OMN	WA	LC	LC	LC	O	4471
Bathygobius soporator (Valenciennes, 1837)		x	x			x		M	INV	TA	LC	LC	LC	O	4460
Ctenogobius shufeldti (Jordan & Eigenmann, 1887)*		x						FBM	OMN	WA	LC	LC	LC	O	5912
Ctenogobius smaragdus (Valenciennes, 1837)*		x						FBM	OMN	WA	LC	LC	LC	O	4627
Ctenogobius stigmaticus (Poey, 1860)					x			M	OMN	WA	LC	LC	LC	N	
Gobionellus oceanicus (Pallas, 1770)	0.27	x	x		x	x	x	FBM	INV	WA	LC	LC	LC	O	2796, 4465
Gobionellus stomatus Starks, 1913					x			B	CAR	WA	NE	LC	LC	O	
MUGILIFORMES															
Mugilidae															
Mugil brevirostris Miranda Ribeiro, 1915*	0.06							FBM	OMN	WA	NE	LC	LC	O	4511
Mugil curema Valenciennes, 1836	26.50	x				x	x	FBM	OMN	TA+EP	LC	LC	DD	F	3798, 4390
Mugil liza Valenciennes, 1836	0.86	x	x			x	x	FBM	OMN	WA	DD	LC	NMA	F	4231, 4392
CICHLIFORMES															
Cichlidae															
Geophagus brasiliensis (Quoy & Gaimard, 1824)	0.02	x	x			x		FB	OMN	NA	NE	LC	LC	F	3918, 4457
Oreochromis niloticus (Linnaeus, 1758)#*		x						FB	OMN	NA	LC	LC	LC	FO	4451
BLENNIIFORMES															

Class/Order/ Family/ Specie	RA	Fire	1	2	3	4	5	HB	Di	GD	IUCN	MMA	SMA	$	Voucher
Blenniidae															
Hypleurochilus fissicornis (Quoy & Gaimard, 1824)*		x						M	INV	SWA+EA	LC	LC	LC	O	5918
Labrisomidae															
Labrisomus nuchipinnis (Quoy & Gaimard, 1824)							x	M	INV	TA	LC	LC	LC	O	
ATHERINIFORMES															
Atherinopsidae															
Atherinella brasiliensis (Quoy & Gaimard, 1825)		x				x		BM	OMN	Ca+Br	LC	LC	LC	F	4400
Odontesthes argentinensis (Valenciennes, 1839)*		x						FBM	OMN	Br+Ar	LC	LC	LC	F	4469
BELONIFORMES															
Hemiramphidae															
Hyporhamphus roberti (Valenciennes, 1847)*		x						BM	OMN	WA+EP	LC	LC	DD	F	4712
Hyporhamphus unifasciatus (Ranzani, 1841)		x	x			x		BM	OMN	WA+EP	LC	LC	DD	F	4685
Belonidae															
Strongylura marina (Walbaum, 1792)	0.15	x	x			x		FBM	OMN	WA	LC	LC	DD	F	3800, 4370
Strongylura timucu (Walbaum, 1792)*	0.15							FBM	PIS	WA	LC	LC	DD	F	3576
CYPRINODONTIFORMES															
Anablepidae															
Jenynsia lineata (Jenyns, 1842)*		x						FB	OMN	Br+Ar	NE	LC	LC	O	5916
Poeciliidae															

Class/Order/ Family/ Specie	**RA**	**Fire**	**1**	**2**	**3**	**4**	**5**	**HB**	**Di**	**GD**	**IUCN**	**MMA**	**SMA**	**$**	**Voucher**
Poecilia vivipara Bloch & Schneider, 1801*		x						FBM	OMN	Br+WA	NE	LC	LC	O	5913
CARANGIFORMES															
Carangidae															
Caranx bartholomaei Cuvier, 1833		x				x		M	CAR	WA	LC	LC	LC	F	4568
Caranx crysos (Mitchill, 1815)	0.08	x	x			x		BM	CAR	TA	LC	LC	LC	F	4376, 4376
Caranx hippos (Linnaeus, 1766)	0.21	x	x			x	x	FBM	CAR	TA	LC	LC	LC	F	3725, 4423
Caranx latus Agassiz, 1831	0.13	x						FBM	CAR	TA	LC	LC	LC	F	4402
Caranx lugubris Poey, 1860			x					M	CAR	CT	LC	LC	LC	F	
Chloroscombrus chrysurus (Linnaeus, 1766)	0.38	x					x	BM	PLA	TA	LC	LC	LC	F	4404
Citharichthys arenaceus Evermann & Marsh, 1900		x					x	FBM	CAR	WA	LC	LC	DD	N	4683
Hemicaranx amblyrhynchus (Cuvier, 1833)	1.60	x	x				x	M	CAR	WA	LC	LC	LC	F	4103, 4447
Oligoplites palometa (Cuvier, 1832)*	2.19	x						FBM	CAR	Ca+Br	LC	LC	LC	F	4224, 4389
Oligoplites saliens (Bloch, 1793)	1.28	x	x			x		BM	CAR	Ca+SWA	LC	LC	LC	FO	4104, 4433
Oligoplites saurus (Bloch & Schneider, 1801)	0.99	x				x	x	FBM	CAR	WA	LC	LC	LC	F	3690, 4385
Selene setapinnis (Mitchill, 1815)	0.84	x					x	BM	CAR	WA	LC	LC	NT	F	4377, 4377
Selene vomer (Linnaeus, 1758)	0.95	x				x	x	BM	CAR	WA	LC	LC	NT	FO	3689, 4399
Trachinotus carolinus (Linnaeus, 1766)	0.78	x	x			x	x	BM	CAR	WA	LC	LC	LC	FO	4317, 4379
Trachinotus falcatus (Linnaeus, 1758)*	0.25	x						BM	CAR	WA	LC	LC	LC	F	2817, 4422
ISTIOPHORIFORMES															

Class/Order/ Family/ Specie	**RA**	**Fire**	**1**	**2**	**3**	**4**	**5**	**HB**	**Di**	**GD**	**IUCN**	**MMA**	**SMA**	**$**	**Voucher**
Sphyraenidae															
Sphyraena guachancho Cuvier, 1829*		x						M	PIS	TA	LC	LC	DD	F	4452
PLEURONECTIFORMES															
Paralichthyidae															
Citharichthys macrops Dresel, 1885	0.19	x					x	M	INV	WA	LC	LC	DD	N	4679
Citharichthys spilopterus Günther, 1862	0.40	x	x			x	x	FBM	OMN	WA	LC	LC	DD	N	3687, 4458
Etropus crossotus Jordan & Gilbert, 1882	0.40	x	x			x	x	BM	OMN	WA+EP	LC	LC	DD	N	3118, 4468
Etropus longimanus Norman, 1933							x	M	CAR	Ar	NE	LC	DD	N	
Paralichthys brasiliensis (Ranzani, 1842)*		x						BM	CAR	SWA	NE	LC	NT	F	3723
Paralichthys orbignyanus (Valenciennes, 1839)		x					x	BM	CAR	Ar	DD	LC	NT	F	4682
Syacium micrurum Ranzani, 1842							x	M	INV	WA	LC	LC	DD	F	
Achiridae															
Achirus declivis Chabanaud, 1940)	0.13	x	x			x	x	FBM	CAR	WA	LC	LC	DD	N	3727, 3652
Achirus lineatus (Linnaeus, 1758)	0.13	x	x			x	x	FBM	INV	WA	LC	LC	DD	O	3731, 4464
Catathyridium garmani (Jordan, 1889)							x	BM	CAR	Br+Ar	NE	LC	DD	O	
Trinectes microphthalmus (Chabanaud, 1928)	0.21	x				x		BM	INV	WA	LC	LC	DD	N	3218, 4472
Trinectes paulistanus (Miranda Ribeiro, 1915)	0.04	x				x	x	FBM	INV	Ca+Br	LC	LC	DD	N	3734, 4461
Cynoglossidae															
Symphurus diomedeanus (Goode & Bean, 1885)							x	M	INV	WA	LC	LC	LC	N	

Class/Order/ Family/ Specie	RA	Fire	1	2	3	4	5	HB	Di	GD	IUCN	MMA	SMA	$	Voucher
Symphurus plagusia (Bloch & Schneider, 1801)		x					x	BM	INV	WA	LC	LC	LC	F	5433
Symphurus tessellatus (Quoy & Gaimard, 1824)	0.38	x	x			x	x	BM	INV	WA	LC	LC	DD	N	3666, 4462
SYNGNATHIFORMES															
Syngnathidae															
Bryx dunckeri (Metzelaar, 1919)*		x						M	CAR	WA	LC	LC	LC	O	4467
Microphis lineatus (Kaup, 1856)*		x						FBM	CAR	WA	NE	LC	LC	O	4463
Hippocampus reidi Ginsburg, 1933		x	x					M	PLA	WA	NT	VU	NMA	O	4444
Pseudophallus mindii (Meek & Hildebrand, 1923)*		x						FB	CAR	Ca+Br	DD	LC	LC	N	4470
Syngnathus folletti Herald, 1942*		x						M	OMN	SWA	LC	LC	LC	N	4133
Fistulariidae															
Fistularia petimba Lacepède, 1803*		x						M	CAR	TA	LC	LC	LC	F	4478
Dactylopteridae															
Dactylopterus volitans (Linnaeus, 1758)		x	x				x	M	CAR	TA	LC	LC	LC	O	3954
SCOMBRIFORMES															
Trichiuridae															
Trichiurus lepturus Linnaeus, 1758	2.99	x	x			x	x	BM	CAR	CT	LC	LC	LC	F	3750, 4443
Scombridae															
Scomberomorus brasiliensis Collette, Russo & Zavala-Camin, 1978*		x						M	PIS	Ca+Br	LC	LC	DD	F	4366
Stromateidae															

Class/Order/ Family/ Specie	**RA**	**Fire**	**1**	**2**	**3**	**4**	**5**	**HB**	**Di**	**GD**	**IUCN**	**MMA**	**SMA**	**$**	**Voucher**
Peprilus xanthurus (Quoy & Gaimard, 1825)		x					x	M	CAR	WA	LC	LC	DD	F	4413
TRACHINIFORMES															
Uranoscopidae															
Astroscopus y-graecum (Cuvier, 1829)*		x						M	PIS	WA	LC	LC	DD	F	4450
PERCIFORMES															
Polynemidae															
Polydactylus oligodon (Günther, 1860)	0.08	x					x	BM	OMN	WA	LC	LC	LC	FO	3125, 2303
Polydactylus virginicus (Linnaeus, 1758)	0.42	x				x	x	BM	OMN	WA	LC	LC	LC	FO	2854, 4678
Centropomidae															
Centropomus parallelus Poey, 1860	1.45	x				x	x	FBM	CAR	WA	LC	LC	NT	F	4110, 4382
Centropomus undecimalis (Bloch, 1792)	0.63	x				x	x	FBM	CAR	WA	LC	LC	NT	F	4108, 4387
Gerreidae															
Diapterus auratus Ranzani, 1842	1.35	x					x	FBM	INV	WA	LC	LC	DD	F	4120, 4409
Diapterus rhombeus (Cuvier, 1829)	9.54	x	x			x	x	FBM	INV	Ca+Br	LC	LC	LC	F	4203, 4394
Eucinostomus argenteus Baird & Girard, 1855	0.04	x					x	FBM	INV	WA+EP	LC	LC	LC	N	3735, 4395
Eucinostomus gula (Quoy & Gaimard, 1824)	0.06	x	x			x	x	FBM	OMN	WA	LC	LC	DD	N	4414
Eucinostomus melanopterus (Bleeker, 1863)	0.15	x			x	x	x	FBM	INV	TA	LC	LC	LC	F	3682, 4393
Eugerres brasilianus (Cuvier, 1830)*	0.06	x						M	INV	WA	LC	LC	DD	F	3732, 4373
Serranidae															

Class/Order/ Family/ Specie	RA	Fire	1	2	3	4	5	HB	Di	GD	IUCN	MMA	SMA	$	Voucher
Diplectrum radiale (Quoy & Gaimard, 1824)	0.61	x	x	x		x	x	BM	CAR	WA	LC	LC	LC	O	4109, 4428
Epinephelus itajara (Lichtenstein, 1822)*		x						BM	CAR	WA	VU	CR	NMA	F	4417
Epinephelus marginatus (Lowe, 1834)		x		x			x	M	CAR	WA+EP	VU	VU	NMA	FO	4368
Mycteroperca acutirostris (Valenciennes, 1828)		x					x	M	CAR	Ca+Br	LC	LC	LC	FO	4424
Rypticus randalli Courtenay, 1967		x					x	M	CAR	Ca+Br	LC	LC	LC	O	5919
Pomatomidae															
Pomatomus saltatrix (Linnaeus, 1766)	0.19	x					x	BM	CAR	CT	VU	LC	NT	F	2861, 4380
Chaetodontidae															
Chaetodon striatus Linnaeus, 1758*		x						M	INV	WA	LC	LC	LC	O	5262
Haemulidae															
Anisotremus surinamensis (Bloch, 1791)*		x						M	INV	WA	DD	LC	LC	O	4418
Conodon nobilis (Linnaeus, 1758)	1.52	x					x	FBM	OMN	WA	LC	LC	DD	FO	3172, 4369
Genyatremus luteus (Bloch, 1790)	0.84	x					x	BM	INV	Ca+Br	DD	LC	DD	F	4456, 4456
Haemulon atlanticus Carvalho, Marceniuk, Oliveira & Wosiacki, 2020*		x						M	INV	Ca+SWA	LC	LC	LC	O	4453
Haemulopsis corvinaeformis (Steindachner, 1868)	0.06	x	x				x	BM	CAR	Ca+SWA	LC	LC	LC	O	2832, 4432
Orthopristis rubra (Cuvier, 1830)	0.61	x					x	BM	INV	Ca+SWA	LC	LC	NT	FO	4407
Rhonciscus crocro (Cuvier, 1830)				x		x		FBM	CAR	WA	DD	LC	LC	F	
Lutjanidae															
Lutjanus analis (Cuvier, 1828)		x	x					FBM	CAR	WA	NT	LC	NMA	F	5914

Class/Order/ Family/ Specie	RA	Fire	1	2	3	4	5	HB	Di	GD	IUCN	MMA	SMA	$	Voucher
Lutjanus cyanopterus (Cuvier, 1828)*		x						BM	CAR	WA	VU	VU	NMA	F	5408
Lutjanus synagris (Linnaeus, 1758)	0.13	x					x	M	CAR	WA	NT	LC	LC	O	4419
Pristigasteridae															
Chirocentrodon bleekerianus (Poey, 1867)		x					x	BM	CAR	Ca+Br	LC	LC	LC	N	4411
Pellona harroweri (Fowler, 1917)		x				x	x	BM	PLA	Ca+Br	LC	LC	LC	F	4412
SCORPAENIFORMES															
Scorpaenidae															
Scorpaena brasiliensis Cuvier, 1829	0.08	x					x	M	CAR	WA	LC	LC	LC	O	3275, 4474
Scorpaena isthmensis Meek & Hildebrand, 1928*		x						M	CAR	WA	LC	LC	LC	O	4473
Scorpaena plumieri Bloch, 1789	0.02	x					x	M	CAR	WA	LC	LC	LC	O	4440
Triglidae															
Prionotus punctatus (Bloch, 1793)	0.48	x				x	x	BM	CAR	Ca+SWA	LC	LC	LC	FO	2837, 4441
Prionotus nudigula Ginsburg, 1950							x	M	CAR	Ar	NE	LC	DD	FO	
MORONIFORMES															
Ephippidae															
Chaetodipterus faber (Broussonet, 1782)	2.57	x	x		x	x	x	FBM	INV	WA	LC	LC	LC	FO	4141, 4408
ACANTHURIFORMES															
Sciaenidae															
Bairdiella goeldi Marceniuk, Molina, Caires, Rotundo, Wosiacki & Oliveira, 2019	0.36	x	x			x	x	BM	CAR	Ca+Br	LC	LC	DD	F	3685, 4391

Class/Order/ Family/ Specie	RA	Fire	1	2	3	4	5	HB	Di	GD	IUCN	MMA	SMA	$	Voucher
Ctenosciaena gracilicirrhus (Metzelaar, 1919)							x	M	INV	Ca+Br	LC	LC	LC	N	
Cynoscion acoupa (Lacepède, 1801)	1.31	x				x	x	FBM	CAR	Ca+WA	LC	LC	DD	F	4117, 4677
Cynoscion guatucupa (Cuvier, 1830)		x					x	M	CAR	Ca+WA	NE	LC	NMA	F	5917
Cynoscion jamaicensis (Vaillant & Bocourt, 1883)*	0.42	x						BM	CAR	Ca+SWA	LC	LC	NT	F	4449
Cynoscion leiarchus (Cuvier, 1830)	0.51	x				x		BM	CAR	Ca+Br	LC	LC	DD	F	2839, 4446
Cynoscion microlepidotus (Cuvier, 1830)	0.53	x				x	x	BM	CAR	WA	LC	LC	DD	F	4289, 4383
Cynoscion virescens (Cuvier, 1830)*	1.33	x						BM	CAR	Ca+Br	LC	LC	NT	F	2826, 4473
Isopisthus parvipinnis (Cuvier, 1830)		x				x	x	BM	CAR	Ca+Br	LC	LC	LC	FO	4434
Larimus breviceps Cuvier, 1830	1.33	x					x	FBM	CAR	Ca+Br	LC	LC	LC	F	2823, 4397
Macrodon atricauda (Günther, 1880)	0.69	x					x	BM	CAR	Br+Ar	NE	LC	NMA	F	4225, 4384
Menticirrhus martinicensis (Cuvier, 1830)	4.46	x	x			x	x	FBM	CAR	WA	LC	LC	NT	FO	4204, 4365
Menticirrhus gracilis (Cuvier, 1830)		x	x					BM	INV	WA	LC	LC	NT	F	4364
Micropogonias furnieri (Desmarest, 1823)	4.61	x	x			x	x	FBM	CAR	Ca+SWA	LC	LC	NMA	FO	3729, 4405
Paralonchurus brasiliensis (Steindachner, 1875)	0.74	x	x				x	BM	INV	Ca+SWA	LC	LC	NT	FO	2820, 4403
Pogonias courbina (Lacepède, 1803)	0.02	x						FBM	CAR	WA	LC	EN	NMA	F	4287, 4287
Stellifer brasiliensis (Schultz, 1945)		x	x				x	BM	OMN	Br	LC	LC	LC	N	4410
Stellifer punctatissimus Meek & Hildebrand, 1925							x	M	CAR	Ca+Br	LC	LC	DD	N	
Stellifer rastrifer (Jordan, 1889)	0.11	x	x	x			x	BM	OMN	Br+Ar	LC	LC	LC	N	3726, 4401
Stellifer stellifer (Bloch, 1790)							x	BM	OMN	Br	DD	LC	DD	N	

Class/Order/ Family/ Specie	**RA**	**Fire**	**1**	**2**	**3**	**4**	**5**	**HB**	**Di**	**GD**	**IUCN**	**MMA**	**SMA**	**$**	**Voucher**
Umbrina canosai Berg, 1895							x	BM	INV	Ar	NE	LC	NT	F	
Umbrina coroides Cuvier, 1830*	0.27							BM	INV	WA	LC	LC	LC	F	4586
SPARIFORMES															
Lobotidae															
Lobotes surinamensis (Bloch, 1790)*	0.15	x						FBM	CAR	CT	LC	LC	DD	F	4427
Sparidae															
Archosargus probatocephalus (Walbaum, 1792)			x					FBM	INV	WA	LC	LC	LC	F	
Archosargus rhomboidalis (Linnaeus, 1758)*		x						BM	OMN	WA	LC	LC	LC	FO	3744
LOPHIIFORMES															
Ogcocephalidae															
Ogcocephalus vespertilio (Linnaeus, 1758)		x	x				x	M	INV	Ca+SWA	LC	LC	LC	O	4445
TETRAODONTIFORMES															
Monacanthidae															
Monacanthus ciliatus (Mitchill, 1818)							x	M	OMN	WA	LC	LC	LC	FO	
Stephanolepis hispida (Linnaeus, 1766)*		x						M	OMN	TA	LC	LC	LC	FO	4435
Tetraodontidae															
Lagocephalus laevigatus (Linnaeus, 1766)	0.57	x	x			x		BM	CAR	TA	LC	LC	DD	FO	3684, 4438
Sphoeroides greeleyi Gilbert, 1900	0.15	x	x	x			x	BM	INV	Ca+Br	LC	LC	DD	O	4105, 4406
Sphoeroides spengleri (Bloch, 1785)		x					x	BM	INV	TA	LC	LC	DD	O	4429

Class/Order/ Family/ Specie	RA	Fire	1	2	3	4	5	HB	Di	GD	IUCN	MMA	SMA	$	Voucher
Sphoeroides testudineus (Linnaeus, 1758)	0.76	x			x	x	x	BM	INV	WA	LC	LC	DD	O	4209, 4420
Sphoeroides tyleri Shipp, 1972	0.13						x	M	INV	Br	LC	LC	DD	O	5197
Diodontidae															
Chilomycterus spinosus (Linnaeus, 1758)	0.11	x	x		x	x	x	M	INV	SWA	LC	LC	DD	O	3728, 4442

Source: Authors.

The feeding habits of the specimens were as follows: carnivorous (55.4%), invertivorous (24.1%), omnivorous (15.7%), planktivorous (3.6%) and piscivorous (1.2%).

Based in the distribution of habitats, 44.6% recorded inhabit estuarine and marine environments, 37.3% move between freshwater, estuarine and marine environments, 16.9% inhabit only marine environments and one species inhabits freshwater and estuarine environments.

The economic importance of the species was as follows: 51.8% are used for food, 16.9% are only used as ornamental fishes, and 15.7% are used for food and as ornamental fishes, and no commercial value.

Considering the IUCN assessments at the global level (IUCN, 2020), 84.3% of the species are classified as “least concern”, 7.2% as “not assessed”, 4.8% as “data deficient”, 2.4% as “near threatened” and 1.2% as “vulnerable”. Based on Brazilian federal legislation (MMA, 2014), 97.6% of the species are classified as “least concern” and only 2.4% are classified as “near threatened”. According to state legislation (São Paulo, 2014), 45.8% of the species recorded are classified as “least concern”, 36.1% as “data deficient”, 13.2% as “near threatened” and 4.8% as “needing management action”.

Fire

One hundred and forty and eight (148) species were recorded, belonging to 55 families, 30 orders and 2 classes (Table 1), 97.3% of Osteichthyes and 2.7% of Chondrichthyes.

The order representing the greatest number of families was the Perciformes (9), followed by the Anguilliformes, Pleuronectiformes, Scombriformes, Syngnathiformes and Tetraodontiformes (3). The family representing the greatest number of species was the Sciaenidae (17), followed by the Carangidae (14), Engraulidae (7), Haemulidae and Gerreidae (6), which together accounted for 34.7% of all the species recorded.

In total fire, 1574 specimens were collected, it was not possible to quantify the total number of specimens. However, based on the material collected and discarded in the landfill (approximately 9 tons), a total of 12.5 tons of dead aquatic organisms were estimated, mostly fish (Borges, 2015).

The majority (43.9%) of the species recorded have a distribution along the Western Atlantic coast (WA), followed by Ca+Br (15.5%), TA (8.1%), Ca+SWA (6.8%), Br+Ar (4.7%), Ar and WA+EP (3.4% each), CT and SWA (2.7% each), Br (2.0%), Ca+WA (1.4%).

Only one species was found in each of the categories Ca, EP, NA, Br+WA, SWA+EA, TA+EP and Ca+Br+EP.

The feeding habits of the specimens were as follows: carnivorous (52.0%), invertivorous (20.9%), omnivorous (19.6%), planktivorous (4.7%) and piscivorous (2.4%).

Based in the distribution of habitats, 37.2% recorded inhabit estuarine and marine environments, 30.4% move between freshwater, estuarine and marine environments, 29.7% inhabit only marine environments and 2.7% inhabits freshwater and estuarine environments.

The economic importance of the species was as follows: 84.3% are used for food, 43.4% are used for food and as ornamental fishes, 26.5% have no commercial value and 24.1% are only used as ornamental fishes.

Considering the IUCN assessments at the global level (IUCN, 2020), 79.1% of the species are classified as “least concern”, 7.4% were “not assessed”, 6.1% as “data deficient”, 3.4% as “near threatened”, 3.4% as “vulnerable” and 0.7% as “critically threatened”. Based on Brazilian federal legislation (MMA, 2014), 94.6% of the species are classified as “least concern”, 2.7% as “vulnerable”, 1.4% as “near threatened” and 1.4% as “critically threatened”. According to state legislation (São Paulo, 2014), 54.1% of the species recorded are classified as “least concern”, 28.4% as “data deficient”, 10.8% as “near threatened” and 6.8% as “needing management action”.

Total area

One hundred and seventy-two (172) species belonging to 59 families, 31 orders and 2 classes were recorded (Table 1). Osteichthyes accounted for 97.1% of the species and 2.9% as Chondrichthyes.

The order representing the greatest number of families was the Perciformes (8), followed by the Anguilliformes, Pleuronectiformes, scombriformes, Syngnathiformes and Tetraodontiformes (3). The family representing the greatest number of species was the Sciaenidae (22), followed by the Carangidae (15), Engraulidae, Gobiidae, Haemulidae and Paralichthyidae (7) and Gerreidae (6), which together accounted for 42.5% of all the species recorded.

The majority (44.2%) of the species recorded have a distribution along the Western Atlantic coast (WA), followed by Ca+Br (15.1%), TA (7.6%), Ar (4.7%), Ca+SWA (5.8%), Br+Ar (4.7%), Br and CT (2.9% each), SWA (2.3%), WA+EP (2.9%) and Ca+WA (1.2%).

Only one species was found in each of the categories Ca, EP, NA, Br+WA, SWA+EA, TA+EP and Ca+Br+EP.

The feeding habits of the specimens were as follows: carnivorous (50.6%), invertivorous (22.7%), omnivorous (19.8%), planktivorous (4.1%) and piscivorous (2.9%).

Based in the distribution of habitats, 35.5% recorded inhabit estuarine and marine environments, 32.0% inhabit only marine environments, 28.5% move between freshwater, estuarine and marine environments, 2.3% inhabits freshwater and estuarine environments, 1.2% inhabit only freshwater environments and 0.6% inhabit only estuarine environments.

The economic importance of the species was as follows: 44.8% are used for food, 25.6% are only used as ornamental fishes, 16.3% have no commercial value and 13,4% are used for food and as ornamental fishes.

Considering the IUCN assessments at the global level (IUCN, 2020), 76.2% of the species are classified as “least concern”, 10.5% were “not assessed”, 7.0% as “data deficient”, 2.9% as “near threatened”, 2.9% as “vulnerable” and 0.6% as “critically threatened”. Based on Brazilian federal legislation (MMA, 2014), 95.3% of the species are classified as “least concern”, 2.3% as “vulnerable”, 1.2% as “critically threatened” and 1.2% as “near threatened”. According to state legislation (São Paulo, 2014), 55.2% of the species recorded are classified as “least concern”, 29.1% as “data deficient”, 9.9% as “near threatened” and 5.8% as “needing management action”.

4. Discussion

According to Vieira & Musick (1994), Andrade-Tubino et al. (2008) and Vilar et al. (2013), families Sciaenidae, Carangidae, Engraulidae and Ariidae are the most important families in relation to the number of species and abundance in Brazilian estuarine and coastal systems. The findings of the monitoring performed in the present study corroborates with the importance of Sciaenidae both in terms of the number of species represented (17%) and species abundance (16.3%); *M. furnieri* and *M. martinicensis* together accounted for 10% of the specimens caught. Similarly, Carangidae had high richness (13.3%) and abundance (9.7%), like Ariidae (6% and 15.7%, respectively); in the study by Dias et al. (2017) in the Bertioga channel, the same estuarine complex studied here, *C. spixii* was the most abundant species recorded.

The importance of Gerreidae and Mugilidae in the present study is noteworthy: although only a few species from the latter were observed (3.6%), the abundance was high

(27.4%), as was also the case for Gerreidae, which accounted for six species (7%) and 11.2% of the specimens caught. These results are similar to those of other studies carried out in the same estuarine complex: Vazzoler (1970), Paiva-Filho (1982), Paiva-Filho et al. (1987) and Giannini & Paiva-Filho (1990).

Only five studies had previously been carried out in the study area: Luederwald (1919) collected 42 species of fish in the mangroves of the region, using gill nets, longlines, traps over and casting net; Paiva-Filho et al. (1987) collected 76 specimens from 5 families and 6 species using traps over a 12-month period (1985-1986); Braga (2013) collected 264 specimens of fish, belonging to 7 species, using beam trawl, between June 2009 and December 2011; Santos et al. (2015) captured 1738 specimens belonging to 28 families and 55 species using gill nets (mesh sizes 12, 24, 40 and 60 mm between opposite knots) in two periods (March & August) in 2010; and Souza (2017) conducted monthly collections between July 2010 and June 2012, using otter trawl at nine points (Santos, São Vicente and Bertioga estuarine channels, and the Santos-São Vicente high estuary region), collected 89 species. As in the monitoring of the present study, with the exception of Engraulidae, the families with the greatest richness in the studies carried in the region, were Sciaenidae, Carangidae, Achiridae, Ariidae and Engraulidae. This difference in the richness of Engraulidae can be attributed to the small size of the species in this family and the mesh size used, which account for the few species from this family caught in our study and their low abundance.

Comparing the results of the present monitoring with Luederwald (1919), we observed that twelve species were not registered in the monitoring: *Archosargus probatocephalus*, *Bathygobius soporator*, *Callichthys callichthys*, *Caranx lugubris*, *Dactylopterus volitans*, *Hippocampus reidi*, *Hoplias malabaricus*, *Hyporhamphus unifasciatus*, *Lutjanus analis*, *Menticirrhus gracilis*, *Ogcocephalus vespertilio* and *Stellifer brasiliensis*. The Jaccard index indicated that composition similarity was low (33.68%). Although only two species recorded in the study by Paiva-Filho et al. (1987) were not observed in the monitoring of the present study [*Epinephelus marginatus* (Lowe, 1834) and *Rhonciscus crocro* (Cuvier, 1830)] the Jaccard index indicated that composition similarity was low (4.71%). Composition similarity with the study by Braga (2013) was 5.88%, and only two species in that study were not recorded in the monitoring of the present study (*Ctenogobius stigmaticus* and *Gobionellus stomatus*). The Jaccard index indicated that composition similarity was high (51.06%) with Santos et al. (2015), and eleven species in that study were not recorded in the monitoring of the present study (*Anchoa spinifer*, *Anchoviella lepidentostole*, *Atherinella brasiliensis*, *Bathygobius soporator*, *Caranx bartholomaei*, *Hyporhamphus unifasciatus*, *Isopisthus*

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parvipinnis, *Lycengraulis grossidens*, *Pellona harroweri*, *Sardinella brasiliensis* and *Synodus bondi*. These differences can be attributed to the different mesh sizes of the gill nets used and the different sampling efforts. Composition similarity with the study by Souza (2017) was high (53.04%), and only two species in that study were not recorded in the monitoring of the present study (*Ctenogobius stigmaticus* and *Gobionellus stomatus*).

The monitoring of the present study added 12 species and collections during the fire added 41 species, totaling 53 new records to the local ichthyofauna, highlighting the importance of faunistic studies even in areas that are relatively easily reached or where there is considerable human activity.

Generally, estuarine ichthyofauna is dominated by only a few species (Kennish, 1986), as indicated by the monitoring of the present study, in which only five species accounted for 52.2% of all the specimens caught: *M. curema*, *D. rhombeus*, *G. genidens*, *M. furnieri* and *M. martinicensis*. A similar dominance was reported by Santos et al. (2015) in the same area but with different species; only *D. rhombeus* was common to both studies. Overall, the richness and abundance reported in the present study agree with the patterns observed in other Brazilian estuaries reported by Araújo et al. (1998), Azevedo et al. (1999), Schwarz Jr. et al. (2006, 2007), Carvalho-Neto & Castro (2008), Schmidt et al. (2008), Barletta et al. (2010), Silveira et al. (2010), Catelani et al. (2014), Marceniuk et al. (2017), Vilar & Joyeux (2018) and Barletta & Lima (2019).

In their summary of existing knowledge on Brazilian estuarine fishes, Vilar & Joyeux (2018) analyzed 27,891 records, corresponding to 796 species in 425 genera, 144 families and 33 orders. They identified a variation in richness along a latitudinal gradient in which two regions: Northeast (-4° to -5°) and Southeast (-22° to -23°), were of particular note and pointed out that estuaries in metropolitan regions, such as Guanabara Bay (RJ), suffered severe degradation before they were well studied. Compared with other Brazilian estuaries in economically active and easily reached areas, the SSEBBC has been relatively little studied.

The following studies of ichthyofauna in the complex have been carried out to date: Vazzoler (1970), Paiva-Filho (1982), Paiva-Filho & Schmiegelow (1986), Paiva-Filho et al. (1987), Paiva-Filho & Toscano (1987), Ribeiro-Neto (1989), Giannini & Paiva-Filho (1990), Lopes et al. (1993), Ribeiro-Neto (1993), Giannini & Paiva-Filho (1995), Fagundes et al. (2007), Schmidt et al. (2008), Rocha (2009), Barbanti et al. (2013), Garrone-Neto et al. (2013), Dias et al. (2014), Rocha & Dias (2015), Santos et al. (2015), Caetano (2016), Dias et al. (2017), Carminatto et al. (2020) and Rotundo (2020). A total of 244 species were recorded in these studies (including the present study): 74 in the São Vicente estuary channel, 172 in the upper-estuary region, 127 in the Bertioga channel and 193 in Santos bay (Figure 1).

This richness (n=244) is similar to that observed by Passos et al. (2012) in the Paranaguá estuary in the state of Paraná (n=213), and 59.43% of the species found in the studies were common to both complexes. The high richness in the SSEBBC and Paranaguá estuary complex (Passos et al., 2012) agrees with the richness reported by Vilar & Joyeux (2018) for estuarine fishes at a latitude of -24°. The composition similarity between the SSEBBC and Macaé estuary in the state of Rio de Janeiro (Catelani et al., 2014), was low (32.39%). Total species composition similarity between the SSEBBC and Laje de Santos State Marine Park (Luiz Jr et al., 2008) both of which are in the Argentinean zoogeographic region (Caires, 2014), was low (17.25%). As observed between the SSEBBC and the coastal region (excluding estuaries) extending from the state of Rio de Janeiro to the state of Santa Catarina (Rotundo et al., 2019), was low (48.48%). This indicates the existence of ichthyofauna that has adapted to estuarine areas, even those which have high connectivity with the adjacent coastal marine environment (Able 2005; Andrade-Tubino, 2008; Vasconcelos et al., 2011; Murray et al., 2018; Obolewski et al., 2018).

When assessing the richness and composition of estuarine fishes, it is important to consider the number of species that are endemic to the zoogeographic province in which the estuary is located. In general, the large number of species in tropical estuaries is a direct result of the number of species in the adjacent coastal environments. However, a sampling design that considers the nyctohemeral and seasonal behavior of diadromous species is essential (Kennish, 1990; Vieira & Musick, 1993, 1994; Vasconcelos et al., 2011). We found that 4.65% and 2.91% of the ichthyofauna in the SSEBBC consists of species endemic to the Argentinean and Brazilian zoogeographic provinces, respectively. The importance of the Argentinean zoogeographic province in the diversity of marine and estuarine fishes was also observed in Laje de Santos State Marine Park (Luiz Jr et al., 2008), in the Paranaguá estuary complex (Passos et al., 2012) and in the marine coastal region between Rio de Janeiro and Santa Catarina (Rotundo et al., 2019). However, species from the Argentinean province did not contribute significantly to diversity in the present study or the study in Araçá Bay in São Sebastião, in the state of São Paulo (Lamas et al., 2016).

The richness of the marine-estuarine ichthyofauna in the state of São Paulo can generally be attributed to the influence of the oscillation of the Subtropical Convergence between the warm waters of the Brazil Current and the cold waters of the Malvinas Current; the upwelling system which causes South Atlantic Central Water (SACW) to flow over the platform during the summer and spring, reaching the coastal area with a thermocline between 10 and 15 m, and recede during the winter, to be replaced by Tropical Water (TW); the significant inflow of water from continental drainage; and the large width and gentle slope of the continental platform composed of muddy sediment. Because of these characteristics, the region represents the southernmost point at which tropical species are found and the northernmost point at which temperate species are found (Pires-Vanin et al., 1993; Matsuura, 1995; Castro & Menezes, 1998; Menezes et al., 2003; Braga & Niencheski, 2006; Castro et al., 2006; Castro et al., 2008; Amaral & Nallin, 2011).

According to Karr (1981) and Araujo et al. (2003), communities in which top carnivore species are well represented have a healthy composition since top carnivore species are replaced by omnivores as the quality of the environment declines. This was corroborated by the present study as a variety of stressors and impacts have been reported in the Santos-São Vicente upper estuary region (CETESB, 1978, 1981, 2001; Milanelli, 2003; Medeiros & Bícego, 2004; Zaroni, 2006; Siqueira et al., 2012), where only 2.91% of the species are piscivorous (top carnivores) and 19.77% omnivorous.

According to Blaber (2000), around 80% of estuarine species are carnivorous and few of these are specialists. This was also observed in the present study as the majority of the species (50.58%) have (generalist) carnivorous feeding habits, 2.91% are piscivorous and 22.67% are invertivorous. The absence of herbivorous species may be a result of reduced plant cover due to sediment suspension following dredging operations in the channel used by port shipping, as observed by Barletta et al. (2016) in the Paranaguá estuary complex.

As expected, we found that most (66.86%) species to inhabit the estuarine environment; 31.98%, however, are exclusively marine species. The presence of marine species in an estuarine environment can be explained by the fact that seawater from the adjacent continental platform flows toward the upper estuary, generally through the lower part of the water column. This is the farthest point at which marine species are found (Barletta et al., 2010). The uppermost parts of an estuary reached by marine and continental waters therefore have the greatest richness (Barletta-Bergan et al., 2002). However, this pattern was not observed when we examined the records of species in the different parts of the SSEBBC as the greatest richness was in the Santos bay region. This can be explained by the different sampling efforts in the various parts of the complex.

Estuaries are known to be important spawning and nursery areas that also provide protection for countless fish and invertebrate species and are essential for the survival of traditional fishers (Barletta & Costa, 2009; Barletta et al., 2010). This relationship becomes clear when we consider the percentage of commercially important species in the CBESSB: 83.72% are used for food and ornamentation. Although studies have shown the water, sediment and even fishes in the SSEBBC to be contaminated, this complex is considered a natural breeding ground for fishes in southeastern Brazil and also plays an important role in artisanal fishing (CETESB, 1978, 1981, 2001; Paiva-Filho et al., 1987; Milanelli, 2003; Medeiros & Bícego, 2004; Zaroni, 2006; Hortellani et al., 2008; Siqueira et al., 2012; Torres et al., 2015; Rotundo, 2020).

In total species composition of the SSEBBC, 58 species, are classified as data deficient (DD), being that 12 species at the global level (IUCN 2020) and 50 at state legislation (São Paulo 2014); the majority of these (75.86%) are commercially important. A lack of information on some of these species tends to mean that these are classified as DD when they may in fact need to be included in conservation programs (Howard & Bickford, 2014; Bland et al., 2015; Luiz Jr et al., 2016). Various research groups are therefore seeking different ways of efficiently assessing the extinction risk when basic data are not available. Nevertheless, regardless of whichever approach is adopted, there appears to be a consensus that many species currently classified as DD are really at some risk of extinction but are not protected by conservation programs or legislation (Jennings et al., 1999; Good et al., 2006; Brito, 2010; Morais et al., 2013; Sousa-Baena et al., 2014; Howard & Bickford, 2014; Bland et al., 2015; Jetz & Freckleton, 2015; Luiz Jr et al., 2016).

The present study highlighted the occurrence of *Megalops atlanticus* (Megalopidae), a specie categorized as "vulnerable" according to the Brazilian Federal legislation (MMA, 2014) and by the global level (IUCN, 2020). This is an important record, once as observed by Garrone-Neto & Rodrigues (2018), there are few reports of this specie for São Paulo State, were this was the first time that this specie is reported in the estuarine system of the São Paulo State.

If we also consider the 33 species classified in some threat category, we find that 19.18% of the species recorded in the present study require special attention by researchers and government to ensure their conservation. The need for special attention is made all the more pressing and its solution more complex because port activities in the SSEBBC are expanding rapidly, mainly as a result of the offshore exploitation of petroleum in the pre-salt layer and significant population growth in the Baixada Santista metropolitan region (Santos et al., 2015).

A further concern in relation to conservation is the presence of *Opsanus beta* (Gulf toadfish), a species that may have been introduced in ballast water (Caires et al., 2007). This species, which is originally from the Gulf of Mexico (Collette, 2002), became established in the SSEBBC (Tomás et al., 2012), where it formed a stable population, and has also been reported in the Paranaguá estuary (Caires et al., 2007).

We also highlighted the presence of the mud sleeper *Butis koilomatodon* (Eleotridae) in the region. This fish species is native from the Indo-Pacific Ocean region (Froese & Pauly, 2020), where was firstly describe on the western Atlantic Ocean in Venezuela by Lasso-Alcalá et al. (2005) and posteriorly along the Brazilian Coast (Hercos, 2006; Cunningham & Gondolo, 2009; Macieira et al., 2012; Soares et al., 2012; Contente et al., 2016; Bonfim et al., 2017; Guimarães et al., 2017). The current record represents the south limit of its distribution in the Brazilian Coast, extending in 127.2 km from the Contente et al. (2016) record at Araçá Bay (São Sebastião – SP).

In addition to the two mentioned fish species, the Nile Tilapia *Oreochromis niloticos* (Cichlidae) was also recoded at SSEBBC. This fish species is native from the Nile river bay but have high geographical distribution due its wide utilization in aquaculture (Watanabe et al., 2002), been considered a potential plague (Ogutu-Ohwayo & Hecky, 1991). In Brazil, this fish species was introduced in 70's in the northeast region, were it was used to populate the dams and reduced the starvation of this poor population (Castagnolli, 1996). Currently, Nile Tilapia is the most cultivated fish species, representing 24% of the total Brazilian production (MPA, 2012).

The stabilization of exotic species is related not only to their life-history but also to the characteristics of the environment, these species being more likely to survive in degraded areas (Ricciardi & Atkinson, 2004; Milardi et al., 2018). Invasive species can cause not only habitat changes, but also changes in nutrient cycles and energy transfer, as well as competition, predation, disease transmission and genetic impacts, factors that, whether combined or not, cause local native species to become extinct (Gallardo et al., 2016; Arndt et al., 2018). The high number of alien species in this region corroborates with Teixeira & Creed (2020) which observed a high number of invasive species (73) in São Paulo State in relation to other regions in Brazilian coast.

5. Final Considerations

Although the fire caused high ecological losses, the non-selective nature of the mortality causer (the use of the AFFFs), together with the nature of the exposure to the AFFFs (acute exposure) at SSEBBC (see Fontes, 2016) lead to high mortality of the fish species habiting the Santos-São Vicente estuarine system, allowing the researchers to register fish species that was not collected before, improving the knowledge regarding the ichthyofauna composition. Forty-one (41) fish species were firstly catalogued for this region. In this sense, we suggest that the SSEBBC be monitored constantly with a view to supporting conservation and handling measures as the area is of considerable ecological (MMA, 2002a,b), economic and social importance for the whole region along the central coast of the state of São Paulo.

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