Building a baseline: a survey of the composition and distribution of the ichthyofauna of Guanabara Bay, a deeply impacted estuary

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Biodiversity baselines are essential subsidies to evaluate how environmental changes and human impacts affect the special and temporal patterns of communities. This information is paramount to promote proper conservation and management for historically impacted environments such as Guanabara Bay, in southeastern Brazil. Here, we propose an ichthyofaunal baseline for this bay using gathered past data from 1889 to 2020, including literature records, scientific collections, biological sampling, and fisheries landing monitoring. A total of 220 species (203 teleosts and 17 elasmobranchs), distributed in 149 genera (136 teleosts and 13 elasmobranchs) and 72 families (61 teleosts and 11 elasmobranchs) were recorded, including the first record of a tiger-shark, *Galeocerdo cuvier*, in Guanabara Bay. Although the employed sampling effort was sufficient to represent the ichthyofauna in the middle and upper estuary, the Chao2 estimator indicates an even greater richness regarding the bay as a whole. Evidence of reduced abundance and probable local extinction over the decades was found, supporting the importance of implementing management and conservation strategies in the area. The ichthyofaunal distribution analyses revealed that areas close to conservation units are richer compared to their surroundings, indicating that this is an effective strategy to mitigate human impacts in the bay.

Keywords: Brazil, Inventory, Scientometric review, Species density, Tropical estuary.

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Esforços de caracterização da biodiversidade são subsídios essenciais para avaliar como mudanças ambientais e impactos antrópicos afetam os padrões espaciais e temporais das comunidades. Essas informações são essenciais para promover conservação e manejo adequados em ambientes historicamente impactados como a Baía de Guanabara, no sudeste do Brasil. Aqui, nós propomos uma linha de referência da ictiofauna dessa baía utilizando dados pretéritos de 1889 a 2020, incluindo registros de literatura, coleções científicas, coletas biológicas e monitoramento de desembarque pesqueiro. Um total de 220 espécies (203 teleósteos e 17 elasmobrânquios), distribuídas em 149 gêneros (136 teleósteos e 13 elasmobrânquios) e 72 famílias (61 teleósteos e 11 elasmobrânquios) foram registradas, incluindo o primeiro registro de tubarão-tigre, *Galeocerdo cuvier*, na Baía de Guanabara. Apesar do esforço amostral empregado ter sido suficiente para representar a ictiofauna do médio e alto estuário, o estimador Chao2 indicou uma riqueza ainda maior para a baía como um todo. Evidências de redução de abundância e de provável extinção local de táxons ao longo das décadas foram encontradas, corroborando a importância da implantação de medidas de manejo e conservação para a área. A análise da distribuição da ictiofauna revelou que áreas próximas a unidades de conservação são mais ricas em comparação ao seu entorno, indicando que essa é uma estratégia efetiva para mitigar os impactos antrópicos na baía.

Palavras-chave: Brasil, Densidade de espécies, Estuário tropical, Inventário, Revisão cientométrica.

INTRODUCTION

Estuaries are highly dynamic coastal environments that exhibit a wide range of salinity, nutrient, and temperature variations, providing habitats, resources, and shelter to a variety of species at different life cycle stages (Silva-Junior *et al*., 2016; Wolanski, Elliott, 2016). Estuaries function as important nursery and feeding areas (Corrêa, Vianna, 2015; Santos *et al*., 2015; Andrade *et al*., 2016; Mérigot *et al*., 2017; Gonçalves-Silva, Vianna, 2018b), which are essential for the maintenance of several marine fish stocks (Santos *et al*., 2020). Even though these environments are known to contain few strictly resident species (Andrade-Tubino *et al*., 2008; Vianna *et al*., 2012; Silva-Junior *et al*., 2016; Gonçalves-Silva, Vianna, 2018a), their ichthyofaunal diversity displays a rich taxonomic composition, including many species of economic interest and others at serious risk of extinction.

The Guanabara Bay is the second largest Brazilian estuary, located in the metropolitan region of the state of Rio de Janeiro, presenting significant historical, environmental, touristic, and scenic importance. The bay also comprises an essential part of Rio de Janeiro's economy, since it harbors a major port area and supports the most productive estuarine fisheries in the region (Prestrelo, Vianna, 2016). Guanabara Bay has historically suffered from a series of human impacts associated to huge solid waste, untreated domestic sewage, and persistent pollutant inputs, such as metals and hydrocarbons (Pereira *et al*., 2007; Rosenfelder *et al*., 2012; Silva-Junior *et al*., 2012, 2016; Hauser-Davis *et al*., 2019a; Paiva *et al*., 2021). Despite several impacts, this estuary is still ecologically relevant and is considered an area with the potential to become a priority for Brazilian conservation according to guidelines of the Brazilian National Biodiversity Commission (Teixeira-Leite *et al*., 2018).

Guanabara bay's ichthyofauna is historically a common target of scientific studies (*e.g*., Gomes *et al*., 1974; Toledo *et al*., 1983; Brum *et al*., 1995; Brum, 2000; Baêta *et al*., 2006; Vasconcellos *et al*., 2010; Mulato *et al*., 2015) as many research centers are located around the bay (*e.g*., Universidade Federal do Rio de Janeiro, Universidade Federal do Estado do Rio de Janeiro, Universidade Federal Fluminense, Universidade do Estado do Rio de Janeiro). However, knowledge on several aspects of the bay's biodiversity was dispersed over the years in different literature, hindering a more comprehensive understanding of the bay's fish diversity. Reliable and informative inventories are important to promote the conservation and adequate management of natural areas (Reis-Filho *et al*., 2010; Silveira *et al*., 2010; Sreekanth *et al*., 2020), in addition to providing a baseline to assess how environmental changes and human impacts affect temporal community variations (Sheaves, 2006). Vianna *et al.* (2012) made a first attempt to gather past knowledge of the bay's ichthyofauna by developing a list of local species, but most of the information they recovered was not based on published articles that went through proper critical peer-review. In addition, since 2012 new research initiatives that monitor experimental collections and fishing landings carried out by research groups (*e.g*., Laboratório de Biologia e Tecnologia Pesqueira – BioTecPesca/UFRJ, Universidade Federal do Rio de Janeiro) have promoted a considerable increase in knowledge concerning the ichthyofauna of the bay.

The aim of this study is therefore to develop a baseline of Guanabara Bay's ichthyofauna, to achieve a better understanding of the composition, distribution, and richness of fish species in the bay. The use of reliable past data (*e.g*., articles published in indexed journals, voucher specimens deposited in ichthyological collections, biological samplings and fishing landings monitored by BioTecPesca/UFRJ) make this inventory a basis for comparison for future studies. It also potentially reveals changes in species composition that have already taken place throughout history.

MATERIAL AND METHODS

Study area. The Guanabara Bay (22°59'02.20"S – 22°40'23.66"S; 43°01'26.53"W – 43°17'26.08"W) is a semi-enclosed tropical estuary located on the southeastern coast of Brazil, in the state of Rio de Janeiro, covering 384 km^2, with an average volume of 1.87 x 10^9 m^3 of water, and a 4,080 km^2 drainage basin with maximum depth of 50 m in the central channel (Meniconi *et al*., 2012; Silva-Junior *et al*., 2016). It is characterized by seasonal salinity variations influenced by a connection with oceanic waters, the local rainfall regime, and tides. During the low rainfall period (June to August), the water column is more homogeneous, with little temperature and salinity variations, becoming vertically stratified during the rainy season (December to March), with the appearance of upwelling areas due to the penetration of the South Atlantic Central Water (SACW) that enters the estuary through its saline wedge (Valentin *et al*., 1999; Silva-Junior *et al*., 2016).

The bay is categorized into three compartments (*sensu* Silva-Junior *et al*., 2016; Souza, Vianna, 2022): (i) the lower estuary, corresponding to the central channel and its banks, comprising the area suffering the greatest influence of the oceanic waters that enter the bay; (ii) the middle estuary, consisting of an intermediate transition area between the more saline waters of the lower estuary and the more brackish waters of the upper estuary, and (iii) the upper estuary, the innermost bay region under greater influence of continental waters from the local hydrographic basin.

The Guanabara Bay entrance was defined as the shortest distance between the east and west coasts (limit line, from the point of Forte São José, 22°56'24.41"S 43° 09'06.66"W to the point of Fortaleza de Santa Cruz da Barra, 22°56'16.97"S 43°08'06.30"W). Therefore, all records external to this line were considered as outside the estuarine region and were not included in our inventory. The bay was also divided into quadrants using the Quantum GIS (QGIS) software version 3.16.5 according to the same grid applied by the fishing landing monitoring efforts in Guanabara Bay (Prestelo, Vianna, 2016) (Fig. 1).

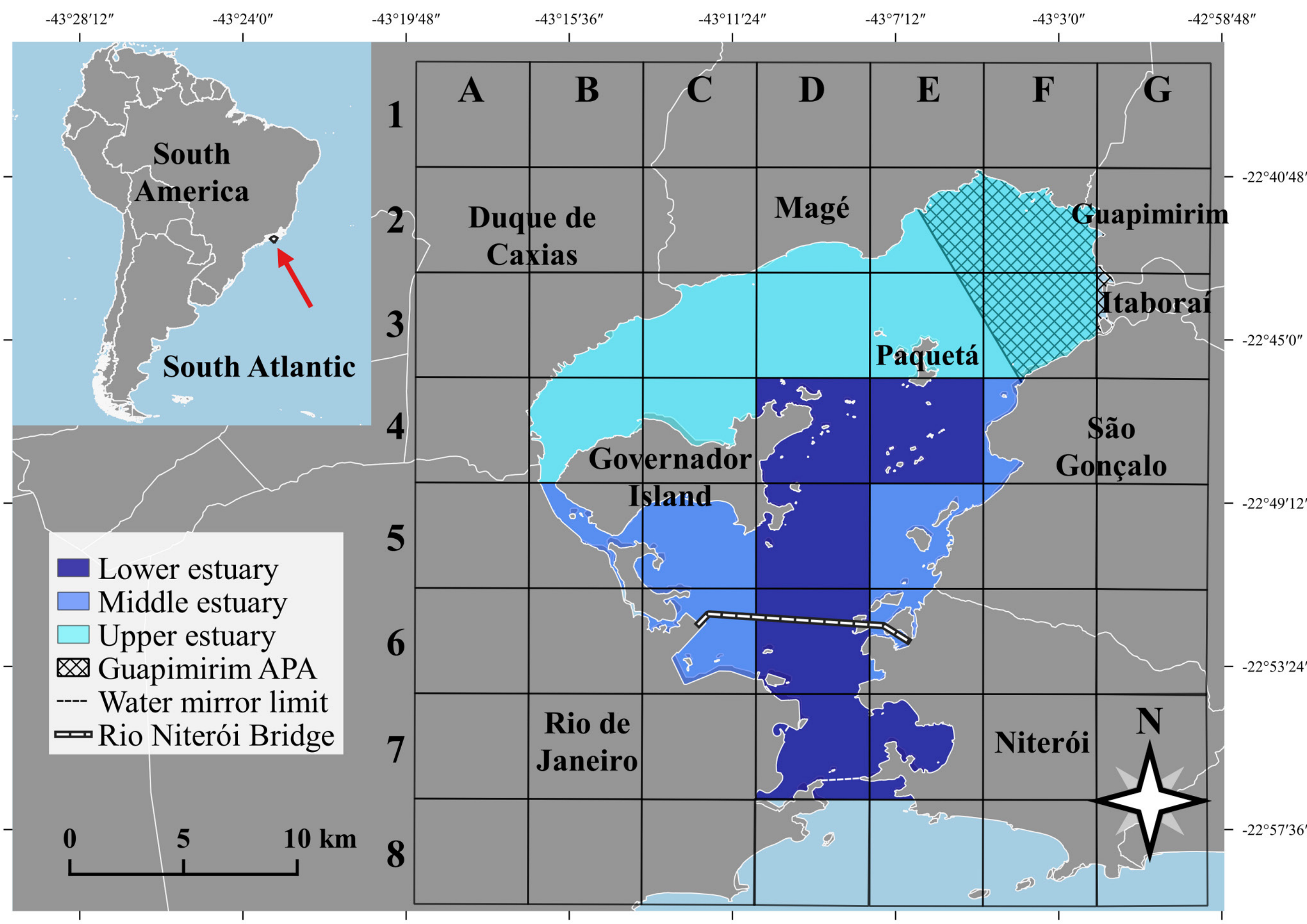

FIGURE 1 | Guanabara Bay map, Rio de Janeiro, divided into five km x five km quadrants. Different shades of blue indicate which estuary compartment (upper, middle or lower) the quadrant belongs to.

Data compilation. Different strategies were employed to gather ichthyofaunal records in the Guanabara Bay. First, we made a compilation of scientific literature concerning the bay's ichthyofauna. A scientometric analysis was carried out at the Web of Science, SciELO and Scopus portals, covering articles from all available years, *i.e.*, from 1921 to March 23, 2021. The search method applied two keyword fields linked by the connectors "AND" and "OR", the first referring to the study location (Guanabara Bay) and the second to the study group (ichthyofauna) (Tab. 1). We added to the scientometric analysis results other published articles that were previously known by the authors. Then, data from two sets of fish samplings carried out by BioTecPesca/UFRJ were added to the database. These bottom trawl samplings were carried out from 2005 to 2007 at quadrants C3, C5, D5, D7, E3, E5 and E7; and from 2013 to 2015 at quadrants C5 and D5. In addition, the records of species identified in two artisanal fishing landing monitoring programs at Guanabara Bay based on different commercial fishing gear (also carried out by BioTecPesca/UFRJ) were considered, the first in 2009 and 2010, and the second in 2013 and 2014.

Historical records were obtained from the online databases of the fish collections of Museu de Zoologia da Universidade de São Paulo, São Paulo (MZUSP) (records available online at https://mz.usp.br/pt/laboratorios/ictiologia/ accessed on July 30, 2020) and the Museu Nacional, Universidade Federal do Rio de Janeiro, Rio de Janeiro (MNRJ) (records available online at https://ipt.sibbr.gov.br/mnrj/resource?r= mnrj_ictiologia, accessed on July 30, 2020). In addition, we included to our data compilation the listings made by the BioTecPesca/UFRJ research group deposited at the Coleção de Peixes do Instituto de Biodiversidade e Sustentabilidade, Universidade Federal do Rio de Janeiro (NPM). The SpeciesLink Network (http://www.specieslink.net/) was used as another tool to compile records from several scientific collections. "Guanabara" was employed as keyword and the records were filtered by taxon to include only fishes, considering all reports until July 21, 2020. All lot numbers of species included in our database are available in Tab. **S1**.

Regardless of the strategy employed, records were considered only at the species level, with species without previous confirmed records in the state of Rio de Janeiro considered as doubtful records and not included in the baseline. Records at genus or family level were also not considered. Taxonomic classification (at species level and above) and species known distribution followed the Eschmeyer's Catalog of Fishes (Fricke *et al*., 2023). As this study comprised only the Guanabara Bay, records obtained

TABLE 1 | Keywords used in the scientometric search on fish at Guanabara Bay, Rio de Janeiro.

Keywords	
1º search field	"Guanabara bay" OR "Guanabara" OR "baía de Guanabara" OR "bahía de Guanabara"
"AND" 2º search field	"fish*" OR "teleost*" OR "elasmobran*" OR "pisces" OR "shark*" OR "ray*" OR "stingray*" OR "chondrichth*" OR "skate*" OR "bone fish*" OR "agnatha*" OR "osteichthy*" OR "actinopter*" OR "peixe*" OR "pesca*" OR "elasmobrânqui*" OR "tubar*" OR "raia*" OR "arraia*" OR "condrict*" OR "agnat*" OR "osteíct*" OR "pez" OR "tiburón" OR "tiburones" OR "raya*"

from local watershed rivers were not considered. Records from ichthyoplankton studies were also not included in our compilation. The historical baseline was built on data available until 2020, therefore we did not include records made after this year. However, we added the information of a few records made after this time-period in the Results section due to their ecological relevance. These include the first record of *Galeocerdo cuvier* (Perón & Lesueur, 1822) in Guanabara Bay and records of species that had not been recorded in the last decade (*Bagre bagre* (Linnaeus, 1766)) and *Rhizoprionodon lalandii* (Valenciennes, 1839)).

The selected records were used to build a baseline containing the currently valid name of the species, the year of the record, and the quadrant or quadrants where the species was recorded, if the information was available. When the exact year of collection was not indicated, the year of publication of the reference was considered as the date of the record. To generate a more complete inventory, the FishBase platform (https://www.fishbase.se) and specific literature on each species were used to obtain information on (i) feeding and functional guilds in the estuary (standardized according to Elliott *et al*., 2007) and (ii) habitat (standardized according to Silva-Junior *et al*., 2016). Finally, information on the extinction risk of each species was considered at both the global and Brazilian level, according to the IUCN Red List of Threatened Species (http://www.iucnredlist.org) and the Livro vermelho da fauna brasileira ameaçada de extinção (Subirá *et al*., 2018), respectively.

Data analysis. One of the main difficulties of studies that aim to assess the species richness of a given locality is to determine whether the employed sampling effort was sufficient to accurately estimate the richness (Schilling *et al*., 2012). As our study consisted on building a reference database using previously generated data, the number of sources consulted was considered as a unit of sampling effort. Thus, four absolute richness accumulation (S) curves by effort were constructed using the R software version 3.6.0, considering one for the bay as a whole and one for each of the three compartments of its estuary (low, medium and upper). In all cases, the random sample-based rarefaction method was used (Gotelli, Colwell, 2001) employing 100,000 permutations. In order to further understand the results of the curves, the non-parametric estimator for incidence data Chao2 was applied to each curve (Chao *et al*., 2009) which, in addition to allowing the verification of curve stabilization (reaching an asymptote), also provides a series of other information (Tab. 2). One of the advantages of using this estimator is the possibility to obtain "mg" values, since "g" values can be converted into percentages. In this context, if for a given "g" value extra collections are not necessary (null mg), then it is confirmed that the study in question was able to record the "g" of the percentage of total richness. A graph was also constructed for each rarefaction curve, where the x axis corresponds to "g" values and the y axis, to "mg" values.

Concerning the spatial richness distribution, accumulation of absolute richness (S) values of each water quadrant was plotted on the bay map employing the QGIS software version 3.16.5. As each quadrant has its own water surface area (discounting portions of land, such as islands and coastlines), species density (S/water surface area) was also calculated in each one of them to obtain comparable results.

Finally, considering the bay's history of environmental degradation and fishing exploitation, we expected the ichthyofaunal composition to change over the years.

TABLE 2 | Variables related to the non-parametric Chao2 estimator. The t, T, S obs, Q1 and Q2 values are used to calculate S est, q0, m and mg.

Variables	
t	Number of sources
T	Total number of incidences
S obs	Number of observed species
S est	Number of species estimated at the curve's asymptote
Q1	Number of simpletons (species recorded by only one source)
Q2	Number of dobletons (species recorded by only two sources)
q0	Probability of finding a new species if one more source was consulted
m	Number of extra sources necessary to obtain S obs = S est
mg	Number of extra sources necessary to obtain a proportion "g" of the estimated richness (S est), with "g" ranging from 0 (representing 0% of S est) to 1 (representing 100% of S est)

In this context, the temporal range of our baseline (1889 to 2020) was divided into decades to identify species that no longer occur in the bay, or that are at least rare now. We considered recent all records made from 2010 to 2020, because since 2010 there were no one-off impact events (*e.g.*, oil spills) that may have affected the ichthyofaunal composition. Therefore, for this study purposes, the 10 years period between 2010 and 2020 (last decade) represent the recent state of the bay.

RESULTS

Ichthyofauna richness and composition. The scientometric analysis resulted in a total of 176 published articles, 70 of which fitted the criteria described in Data compilation and were included in this study. Assembling all data compilation strategies, we considered a total of 84 different data sources. A total of 220 species (203 teleosts and 17 elasmobranchs) were recorded, distributed in 149 genera (136 teleosts and 13 elasmobranchs) and 72 families (61 teleosts and 11 elasmobranchs) (Tab. 3). Regarding the Teleostei, a very asymmetrical richness distribution was noted among families given that 14 families make up about 50% of the total recorded richness. Among these, the Sciaenidae included the highest number of species (23), followed by Carangidae (14) and Haemulidae (8). Concerning elasmobranchs, the numerical variation of species between families was lower, with the Dasyatidae and Carcharhinidae including three species each, followed by Sphyrnidae and Rhinobatidae with two species. Other families of the Elasmobranchii are represented by just one species each.

The most recorded estuary use guild was marine estuarine-opportunist, consisting of approximately 48% of the species (106). Forty-seven species (21%) are dependent on the estuarine environment, being classified as marine estuarine-dependents (37), estuarine residents (5), semi-anadromous (3) or amphidromous (2). The 18 species identified as

TABLE 3 | Species reported at Guanabara Bay and the sources, record dates and quadrants (column Q) in which these records occurred. Taxonomic classification (at species level and above) followed the Eschmeyer's Catalog of Fishes (Fricke *et al.*, 2023). New records made after 2020 (*), first published in our study, are not included in the data analysis. Column "FD" corresponds to feeding guilds, where DV = detritivore, HV = herbivore, OV = omnivore, OP = opportunist, PV = piscivore, ZB = zoobenthivore, ZP = zooplanktivore. Column "H" corresponds to habitat, where P = pelagic, SB = non-consolidated substrate (soft bottom) and HB = consolidated substrate (hard bottom). The column "EG" corresponds to the estuarine guild, where AM = amphidromous, ER = estuarine resident, MED = marine estuarine-dependent, MEO = marine estuarine-opportunistic, MM = marine migrant, MS = marine straggler and AS = semi-anadromous. IUCN = IUCN Red List of Threatened Species, and ICMBio = Livro vermelho da fauna brasileira ameaçada de extinção (Subirá *et al.*, 2018). Source numbering available at Tab. **S2**.

Taxon	Sources	Dates	Q	FG	H	EG	IUCN	ICMBio
Chondrichthyes								
Elasmobranchii								
Selachii								
Carcharhiniformes								
Carcharhinidae								
Carcharhinus brachyurus (Günther, 1870)	68	ND	ND	PV	P	MS	VU	DD
Rhizoprionodon lalandii (Valenciennes, 1839)	68, this study*	1997/2022*	ND	PV	SB	MS	VU	NT
Rhizoprionodon porosus (Poey, 1861)	68	1997	D6	PV	SB	MS	VU	DD
Galeocerdonidae								
Galeocerdo cuvier (Perón & Lesueur, 1822)	this study *	2022*	C4	OP	P	MEO	NT	NT
Sphyrnidae								
Sphyrna tiburo (Linnaeus, 1758)	20	2000	D7	OP	SB+HB	MS	EN	CR
Sphyrna zygaena (Linnaeus, 1758)	20	2000	ND	OP	P	MS	VU	CR
Batoidea								
Torpediniformes								
Narcinidae								
Narcine brasiliensis (Olfers, 1831)	68	1938	D7, E7	ZB	SB	MEO	NT	DD
Rhinopristiformes								
Trygonorrhinidae								
Zapteryx brevirostris (Müller & Henle, 1841)	34, 46, 61	2005–2007/2012	D7, E7	ZB	SB	MS	EN	VU
Rhinobatidae								
Pseudobatos horkelii (Müller & Henle, 1841)	30, 34, 61	2005–2007	D7, E7	ZB	SB	MS	CR	CR
Pseudobatos percellens (Walbaum, 1792)	30, 34, 61, 68	2005–2007	D6, D7, E7	ZB	SB	MS	EN	DD
Pristidae								
Pristis pristis (Linnaeus, 1758)	20	2000	D7	PV	SB	AM	CR	CR
Myliobatiformes								
Dasyatidae								
Dasyatis hypostigma Santos & Carvalho, 2004	30, 34, 61, 65, 81	1993/ 2005–2007/2020	D7, E5, E7	ZB	SB	MM	EN	DD
Hypanus guttatus (Bloch & Schneider, 1801)	30, 34, 61, 68	1944/2005–2007/ 2012–2015	E3, E5	ZB	SB	MM	NT	LC
Hypanus say (Lesueur, 1817)	15	2011/2012	D7	OP	SB	MEO	NT	DD
Gymnuridae								
Gymnura altavela (Linnaeus, 1758)	7, 15, 30, 34, 46, 61, 62, 63, 68, 81, 83	1955/1989/ 2005–2007/ 2011–2015/ 2020	C3, C5, D4, D5, D7, E3, E5, E7	ZB	SB	MM	EN	CR
Aetobatidae								
Aetobatus narinari (Euphrasen, 1790)	68	1957	D4	ZB	SB	AM	EN	DD

TABLE 3 | (Continued)

Taxon	Sources	Dates	Q	FG	H	EG	IUCN	ICMBio
Rhinopteridae								
Rhinoptera bonasus (Mitchill, 1815)	68	1997	ND	ZB	P	MS	VU	DD
Actinopterygii								
Teleostei								
Elopiformes								
Elopidae								
Elops saurus Linnaeus, 1766	5, 6, 15, 26, 27, 34, 61, 68	1944/2005–2007/ 2010–2013	B5, C3, C5, C6, D5, D6, D7, E4	ZB	SB	MED	LC	NE
Elops smithi McBride, Rocha, Ruiz-Carus & Bowen, 2010	63	2014	D4, F2	ZB	P	MED	DD	LC
Albuliformes								
Albulidae								
Albula vulpes (Linnaeus, 1758)	7, 15, 27, 31	1989/2010–2015	D4, D6, D7	ZB	SB	MEO	NT	DD
Anguilliformes								
Muraenidae								
Gymnothorax ocellatus Agassiz, 1831	34, 61, 68	1889/ 1985/ 2005–2007	C5, D5, D7, E7	ZB	SB	MEO	LC	DD
Ophichthidae								
Myrichthys ocellatus (Lesueur, 1825)	68	1964	E4	ZB	SB+HB	MEO	LC	LC
Ophichthus gomesii (Castelnau, 1855)	7, 34, 61, 62, 66, 67, 68	1956/ 1989/ 1995/ 2002/ 2005–2007/ 2013–2015	C5, D2, D5, D7, E5, E7	ZB	SB	MEO	LC	LC
Clupeiformes								
Engraulidae								
Anchoa filifera (Fowler, 1915)	62, 68	1995/2013	D5	ZP	P	MEO	LC	LC
Anchoa januaria (Steindachner, 1879)	5, 6, 7, 34, 61, 62, 68	1983/1989/ 2005–2007/2013	C3, C5, D5, D7, E3, E5	ZP	P	MM	LC	LC
Anchoa lyolepis (Evermann & Marsh, 1900)	5, 6, 7, 31, 34, 61, 62, 68	1978/1989/1995/ 2005–2007/ 2012–2015	C3, C5, D5, D6, D7, E3, E5, E7	ZP	P	MM	LC	LC
Anchoa marinii Hildebrand, 1943	34, 61	2005–2007	C3	ZP	P	MM	LC	LC
Anchoa tricolor (Spix & Agassiz, 1829)	5, 6, 7, 34, 61, 62, 64, 66, 68	1944/1977/1978/ 1983/1989/1995/ 2005–2007/ 2009/2010/ 2013/2014	C3, C5, D4, D5, D6, D7, E3, E5, E7	ZP	P	MM	LC	LC
Cetengraulis edentulus (Cuvier, 1829)	5, 6, 7, 9, 27, 34, 36, 37, 45, 54, 61, 62, 63, 64, 65, 68, 70	1944/1977/1983/ 1989/2001/2002/ 2005–2011/ 2013–2015	B5, C3, C5, D4, D5, D6, D7, E3, E4, E5, E7	ZP	P	MM	LC	LC
Engraulis anchoita Hubbs & Marini, 1935	34, 61, 68	1977/2005–2007	C3, D6, D7	OV	P	MM	LC	LC
Pristigasteridae								
Chirocentrodon bleekerianus (Poey, 1867)	7, 34, 61, 62	1989/2005–2007/ 2013–2015	C5, D5, E5	OP	P	MM	LC	LC
Odontognathus mucronatus Lacepède, 1800	34, 61	2005–2007	D5	ZP	P	MM	LC	LC
Pellona harroweri (Fowler, 1917)	34, 61, 62	2005–2007/ 2013/2015	C3, D5, E5	ZP	P	MM	LC	LC
Alosidae								
Brevoortia aurea (Spix & Agassiz, 1829)	7, 27, 31, 34, 54, 61, 62, 63, 64, 65	1989/2001/2002/ 2005–2007/ 2009–2015	C3, C5, D4, D5, D6, D7, E3, E5, E6, E7	ZP	P	MED	LC	LC
Dorosimatidae								
Harengula clupeola (Cuvier, 1829)	5, 6, 7, 15, 26, 27, 31, 34, 61, 62, 63, 64, 66, 68	1989/2005–2007/ 2009–2015	C3, C5, D4, D5, D6, D7, E3, E4, E5, E6, E7	ZP	P	MM	LC	LC

TABLE 3 | (Continued)

Taxon	Sources	Dates	Q	FG	H	EG	IUCN	ICMBio
Opisthonema oglinum (Lesueur, 1818)	7, 15, 34, 61, 62, 63, 64, 65	1989/2005–2007/2009–2015	C3, C5, D3, D4, D5, D6, D7, E3, E4, E5, E7, F3, F4	ZP	P	MM	LC	LC
Sardinella aurita Valenciennes, 1847	68	ND	E7	ZP	P	MS	LC	DD
Sardinella brasiliensis (Steindachner, 1879)	5, 6, 7, 15, 20, 21, 25, 26, 27, 34, 45, 47, 54, 56, 61, 62, 63, 64, 67, 68	1989/1999–2002/2005–2016	B4, B5, C3, C4, C5, C6, D2, D3, D4, D5, D6, D7, E2, E3, E4, E5, E6, E7, F2, F3, F4	ZP	P	MM	DD	DD
Siluriformes								
Ariidae								
Aspistor luniscutis (Valenciennes, 1840)	34, 38, 61, 68	1944/1962/2005–2007	E3	ZB	SB	MEO	NE	LC
Bagre bagre (Linnaeus, 1766)	47, 68, this study*	2005/2022*	D2	OP	SB	MED	LC	NT
Cathorops spixii (Agassiz, 1829)	34, 38, 61, 66, 68	1944/2005–2007	C3, C5, D5, E3, E5	ZB	SB	MED	NE	LC
Genidens barbus (Lacepède, 1803)	7, 9, 27, 32, 34, 38, 61, 62, 63, 64, 66, 68	1986/1989/2003/2005–2007/2009–2015	B3, B4, C3, C4, C5, D2, D4, D5, D6, E2, E3, E4, E5, E7, F2, F3, F4	OP	SB	MED	NE	EN
Genidens genidens (Cuvier, 1829)	7, 8, 9, 18, 24, 27, 29, 34, 35, 38, 39, 61, 62, 64, 67, 68	1944/1955/1962/1982/1989/2002/2005–2007/2009–2011/2013–2015/2018	B5, C3, C4, C5, D2, D5, D6, D7, E3, E4, E5, E6, E7, F2	OP	SB	MED	LC	LC
Notarius grandicassis (Valenciennes, 1840)	34, 38, 61	2005–2007	C3	OP	SB	MED	LC	LC
Aulopiformes								
Synodontidae								
Synodus foetens (Linnaeus, 1766)	5, 6, 7, 15, 34, 61, 66, 68	1898/1944/1989/2005–2007/2011/2012	C3, C5, C6, D4, D5, D7, E3, E5, E7	ZB	SB	MEO	LC	LC
Trachinocephalus myops (Forster, 1801)	34, 61	2005–2007	E7	ZB	SB	MS	LC	LC
Gadiformes								
Phycidae								
Urophycis brasiliensis (Kaup, 1858)	62, 67	2013/2014	D5	OP	SB	MEO	NE	NT
Holocentriformes								
Holocentridae								
Holocentrus adscensionis (Osbeck, 1765)	66	2007	ND	ZB	SB+HB	MS	LC	LC
Batrachoidiformes								
Batrachoididae								
Opsanus beta (Goode & Bean, 1880)	2	2017	C5	OP	HB	MEO	LC	NE
Porichthys porosissimus (Cuvier, 1829)	7, 27, 34, 45, 61, 62, 66, 68	1944/1978/1989/2005–2011/2013–2015	C5, C6, D5, D6, E3, E7	ZB	SB	MEO	NE	LC
Thalassophryne montevidensis (Berg, 1893)	62	2014	D5	OP	SB	MEO	NE	LC
Thalassophryne nattereri Steindachner, 1876	62	2015	D5	OP	SB	MED	LC	LC
Scombriformes								
Pomatomidae								
Pomatomus saltatrix (Linnaeus, 1766)	5, 6, 15, 26, 54, 56, 62, 63, 64, 65, 67, 68, 75, 79	1972/1978/1988/1999/2001/2002/2005/2006/2009–2014	B3, B4, C3, C4, C5, D3, D4, D5, D7, E2, E3, E4, E5, E6, E7, F2, F3, F4	OP	P	MEO	VU	NT
Scombridae								
Sarda sarda (Bloch, 1793)	63	2013	D4	OP	P	MS	LC	LC
Scomber colias Gmelin, 1789	26, 75	1972/2012/2013	D7	OP	P	MS	LC	LC

TABLE 3 | (Continued)

Taxon	Sources	Dates	Q	FG	H	EG	IUCN	ICMBio
Scomber japonicus Houttuyn, 1782	63, 64	2009/2010/ 2013/2014	D6, D7, E7	PV	P	MM	LC	NE
Scomberomorus brasiliensis Collette, Russo & Zavala-Camin, 1978	63	2013/2014	B3, D4	OP	SB	MS	LC	LC
Stromateidae								
Peprilus xanthurus (Quoy & Gaimard, 1825)	34, 61, 62, 67, 68	1944/ 2005–2007/2014	C5, C6, D5, D7, E3, E5, E7	ZP	P	MEO	LC	LC
Trichiuridae								
Lepidopus caudatus (Euphrasen, 1788)	80	2008	ND	OP	SB	MS	DD	NE
Trichiurus lepturus Linnaeus, 1758	5, 6, 34, 41, 43, 44, 47, 48, 49, 54, 56, 61, 62, 63, 64, 65, 66, 68, 77	1993/ 1999/2001/2002/ 2005–2007/2009/ 2010/2013–2015	B3, C3, C4, C5, D4, D5, D7, E3, E4, E5, E6, E7, F2, F3, F4	PV	P	MEO	LC	LC
Syngnathiformes								
Dactylopteridae								
Dactylopterus volitans (Linnaeus, 1758)	5, 6, 7, 15, 26, 27, 34, 61, 62, 64, 65, 66, 68	1944/ 1945/1989/ 1993/1994/ 2005–2007/ 2009–2015	C3, C5, D5, D6, D7, E3, E4, E5, E7	ZB	SB	MEO	LC	LC
Mullidae								
Mullus argentinae Hubbs & Marini, 1933	34, 61, 66, 68	1913/2005–2007	D5, D7, E3, E7	ZB	SB	MEO	NE	LC
Upeneus parvus Poey, 1852	34, 61, 62, 66, 68	1985/ 2005–2007/2013	C5, D5, E3, E7	ZB	SB	MEO	LC	LC
Fistulariidae								
Fistularia petimba Lacepède, 1803	5, 6, 34, 61	2005–2007	D7, E7	PV	HB	MEO	LC	LC
Fistularia tabacaria Linnaeus, 1758	5, 6, 7, 34, 61, 68	1989/2005–2007	D4, D7, E3, E7	PV	HB	MEO	LC	LC
Syngnathidae								
Bryx dunckeri (Metzelaar, 1919)	5, 6	2005/2006	D7	ZP	P	MEO	LC	LC
Cosmocampus elucens (Poey, 1868)	5, 6	2005/2006	D7	ZB	HB	MS	LC	LC
Hippocampus erectus Perry, 1810	20, 68	1953/2000	ND	OP	HB	MEO	VU	VU
Hippocampus reidi Ginsburg, 1933	7, 20, 34, 61, 68	1989/2000/ 2005–2007	D4, D7, E6, E7	ZP	HB	MEO	NT	VU
Syngnathus folletti Herald, 1942	1, 26, 34, 61, 68	1987/1995/ 2005–2007/ 2012/2013	D4, D5, D7, E7	ZP	SB	MED	LC	LC
Syngnathus pelagicus Linnaeus, 1758	5, 6, 7, 68	1960/1989/ 2005/2006	D4, D7	ZB	P	MED	LC	LC
Gobiiformes								
Gobiidae								
Bathygobius soporator (Valenciennes, 1837)	34, 61, 68	1944/1961/ 2005–2007	C3, E3, E4	OV	SB	ER	LC	LC
Gobionellus oceanicus (Pallas, 1770)	7, 34, 61, 62, 68	1989/1995/ 2005–2007/2014	C3, D5, E3, E5, E7	ZB	SB	ER	LC	LC
Gobiosoma hemigymnum (Eigenmann & Eigenmann, 1888)	62	2013	D5	ZB	SB+HB	MEO	NE	LC
Microgobius carri Fowler, 1945	68	1955	D5	ZB	SB	MEO	LC	LC
Carangiformes								
Centropomidae								
Centropomus parallelus Poey, 1860	27, 34, 56, 61, 68	1999/2005–2007/ 2010/2011	B5, C3, E5	ZB	SB	SA	LC	LC
Centropomus undecimalis (Bloch, 1792)	15, 27, 34, 47, 51, 54, 56, 61, 68	1999/2001/2002/ 2005–2007/ 2009–2012	B5, C3, D7	PV	SB	SA	LC	LC
Sphyraenidae								
Sphyraena guachancho Cuvier, 1829	34, 61, 62, 63, 66	1998/2005–2007/ 2013/2015	B4, C3, C5, D5, E3, E5, E7	PV	P	MS	LC	LC
Sphyraena tome Fowler, 1903	5, 6, 26, 34, 61, 63	2005–2007/ 2012/2013	C3, D4, D7	PV	P	MS	NE	DD

TABLE 3 | (Continued)

Taxon	Sources	Dates	Q	FG	H	EG	IUCN	ICMBio
Polynemidae								
Polydactylus oligodon (Günther, 1860)	5, 6	2005/ 2006	D7	ZB	SB	MEO	LC	LC
Polydactylus virginicus (Linnaeus, 1758)	5, 6, 27, 31, 34, 61	2005–2007/ 2010–2015	B5, C3, D6, D7, E4	ZB	SB	MED	LC	LC
Cyclopsettidae								
Citharichthys arenaceus Evermann & Marsh, 1900	27, 66	2005/2010/2011	D6, E4	ZB	SB	MEO	LC	LC
Citharichthys macrops Dresel, 1885	5, 6, 23, 34, 61, 62, 67	2005–2007/ 2010/2014	D5, D7, E7	ZB	SB	MEO	LC	LC
Citharichthys spilopterus Günther, 1862	23, 34, 61, 62, 66, 68	1944/2005–2007/ 2013/2014	C3, C5, C6, D5, D7, E3, E5, E7	ZB	SB	MEO	LC	LC
Cyclopsetta chittendeni Bean, 1895	23, 34, 61, 62	2005–2007/ 2015	D5, D7, E7	ZB	SB	MS	LC	LC
Etropus crossotus Jordan & Gilbert, 1882	23, 27, 34, 61, 62, 68	1994/ 2005–2007/2010/ 2011/2013–2015	C3, C5, D5, D6, D7, E3, E4, E5, E7	ZB	SB	MED	LC	LC
Etropus longimanus Norman, 1933	23, 34, 61, 62	2005–2007/2015	D5, D7, E7	ZB	SB	MED	LC	LC
Syacium micrurum Ranzani, 1842	23, 34, 61	2005–2007	D7, E7	ZB	SB	MS	LC	LC
Syacium papillosum (Linnaeus, 1758)	23, 34, 61, 66	2005–2007	D7, E7	ZB	SB	MEO	LC	LC
Bothidae								
Bothus ocellatus (Agassiz, 1831)	23, 26, 34, 61, 66	2005–2007/ 2012/2013	D7, E7	ZB	SB	MED	LC	LC
Bothus robinsi Topp & Hoff, 1972	23, 34, 61, 66	2005–2007	D7, E7	ZB	SB	MS	LC	LC
Paralichthyidae								
Paralichthys orbignyanus (Valenciennes, 1839)	23, 34, 61	2005–2007	C3, D5, E3	ZB	SB	MS	DD	DD
Paralichthys patagonicus Jordan, 1889	23, 34, 61	2005–2007	D7, E7	ZB	SB	MS	VU	NT
Achiridae								
Achirus declivis Chabanaud, 1940	23, 34, 61, 62	2005–2007/ 2013/2014	C3, D5, D7, E7	ZB	SB	MEO	LC	LC
Achirus lineatus (Linnaeus, 1758)	23, 27, 34, 61, 62, 68	1944/1954/1955/ 2005–2007/ 2010/2011/2015	B5, C3, D5, D7, E3, E4, E7	ZB	SB	MEO	LC	LC
Trinectes microphthalmus (Chabanaud, 1928)	62	2014/2015	D5	ZB	SB	MED	LC	LC
Trinectes paulistanus (Miranda Ribeiro, 1915)	23, 34, 61, 62, 66, 68	1934/2005–2007/ 2014/2015	C3, C5, D5, D7, E5, E7	ZB	SB	MED	LC	LC
Cynoglossidae								
Symphurus diomedeanus (Goode & Bean, 1885)	23, 34, 61, 62	2005–2007/2013	D5, D7, E7	ZB	SB	MEO	LC	LC
Symphurus jenynsi Evermann & Kendall, 1906	27	2010/ 2011	D6, E4	ZB	SB	MEO	NE	LC
Symphurus plagusia (Bloch & Schneider, 1801)	68	1968	E7	ZB	SB	MED	LC	LC
Symphurus tessellatus (Quoy & Gaimard, 1824)	23, 27, 34, 61, 62, 68	1998/ 2005–2007/2010/ 2011/2013–2015	B5, C3, C4, C5, D5, D6, D7, E3, E5, E7	ZB	SB	MED	LC	LC
Symphurus trewavasae Chabanaud, 1948	27	2010/2011	E4	ZB	SB	MED	NE	LC
Carangidae								
Caranx bartholomaei Cuvier, 1833	5, 6	2005/2006	D7	PV	SB+HB	MEO	LC	LC
Caranx crysos (Mitchill, 1815)	26, 54, 63, 64, 68, 74	1974/2001/ 2002/2009/ 2010/2012–2014	B3, B4, C6, D4, D6, D7, E3, E4, E6, E7, F2, F3	OP	SB	MEO	LC	LC
Caranx latus Agassiz, 1831	5, 6, 15, 27, 34, 61, 62, 68	1994/2005–2007/ 2010–2012/2015	B5, C5, D7, E3	PV	SB	MS	LC	LC
Chloroscombrus chrysurus (Linnaeus, 1766)	27, 34, 45, 61, 62, 64, 66	1998/ 2005–2011/ 2013/2015	B5, C3, C5, D5, D6, D7, E3, E5, E7	ZP	P	MS	LC	LC
Hemicaranx amblyrhynchus (Cuvier, 1833)	5, 6	2005/2006	D7	ZB	P	SA	LC	LC
Oligoplites palometa (Cuvier, 1832)	62	2015	C5	OP	SB	MM	LC	LC

TABLE 3 | (Continued)

Taxon	Sources	Dates	Q	FG	H	EG	IUCN	ICMBio
Oligoplites saliens (Bloch, 1793)	63, 64	2009/2010/ 2013/2014	D4, E3, E4, E7	OP	SB	MEO	LC	LC
Oligoplites saurus (Bloch & Schneider, 1801)	34, 61, 62, 66, 68	1955/ 2005–2007/ 2015	C5, D5, E5	PV	P	MS	LC	LC
Selene setapinnis (Mitchill, 1815)	5, 6, 34, 61, 62, 63, 64, 68	1944/ 2005–2007/ 2009/2010/ 2014/2015	C3, C5, C6, D4, D5, D7, E3, E5, E7	ZB	SB	MS	LC	LC
Selene vomer (Linnaeus, 1758)	5, 6, 34, 61, 62, 66, 68	1944/ 2005–2007/ 2013/2014	C3, C5, D5, D7, E3, E5, E7	ZB	SB	MED	LC	LC
Trachinotus carolinus (Linnaeus, 1766)	5, 6, 15, 26, 31, 34, 61, 63, 69	2005–2007/ 2011–2015	B3, B4, C3, D4, D7, E3, E4	ZB	SB	MS	LC	LC
Trachinotus falcatus (Linnaeus, 1758)	5, 6, 26, 31, 34, 61, 66	2005–2007/ 2012–2015	C3, D7	ZB	SB	MEO	LC	LC
Trachinotus goodei Jordan & Evermann, 1896	5, 6, 15, 26, 69	2005/2006/ 2011–2013	D7	OP	SB	MS	LC	LC
Trachurus lathami Nichols, 1920	5, 6, 34, 61	2005–2007	D5, D7, E7	ZB	SB	MS	LC	LC
Echeneidae								
Echeneis naucrates Linnaeus, 1758	34, 61, 66	2005–2007/2011	C5, E5	PV	P	MS	LC	LC
Remora remora (Linnaeus, 1758)	68	1961	ND	OP	P	MS	LC	LC
Rachycentridae								
Rachycentron canadum (Linnaeus, 1766)	5, 6	2005/2006	D7	OP	SB+HB	MS	LC	LC
Cichliformes								
Pomacentridae								
Abudefduf saxatilis (Linnaeus, 1758)	4	2001	D7	OV	HB	MEO	LC	LC
Atheriniformes								
Atherinopsidae								
Atherinella brasiliensis (Quoy & Gaimard, 1825)	5, 6, 7, 15, 26, 34, 61, 62, 68	1944/1989/1995/ 2005–2007/ 2011–2013	C5, D4, D5, D7, E3, E5, E7	ZP	P	ER	LC	LC
Beloniformes								
Belonidae								
Strongylura marina (Walbaum, 1792)	34, 61	2005–2007	C3	ZP	P	MEO	LC	LC
Strongylura timucu (Walbaum, 1792)	7, 26	1989/2012/2013	D4, D7	OP	P	MEO	LC	LC
Hemiramphidae								
Hemiramphus balao Lesueur, 1821	64	2009/2010	E7	OP	P	MS	LC	DD
Hemiramphus brasiliensis (Linnaeus, 1758)	68	ND	ND	OV	P	MEO	LC	LC
Hyporhamphus unifasciatus (Ranzani, 1841)	7, 68	1944/1989	D4, E3	OV	P	MEO	LC	NT
Mugiliformes								
Mugilidae								
Mugil brevirostris (Miranda Ribeiro, 1915)	68	ND	ND	DV	SB	MED	NE	NE
Mugil curema Valenciennes, 1836	5, 6, 15, 26, 31, 34, 54, 56, 61, 64, 66, 68	1913/1999/ 2001/2002/ 2005–2007/ 2009–2015	C3, C4, D7, E3, F2	DV	SB	MED	LC	DD
Mugil curvidens Valenciennes, 1836	68	1944	E3	DV	SB	MED	NE	DD
Mugil liza Valenciennes, 1836	5, 6, 13, 17, 19, 21, 22, 25, 26, 28, 33, 34, 39, 40, 41, 42, 45, 47, 49, 51, 52, 53, 54, 55, 56, 57, 61, 63, 64, 67, 68, 74, 78, 79, 80, 84	1974/1978/ 1990–2003/ 2005–2016/2019	B3, B4, C3, C4, C5, D2, D3, D4, D5, D6, D7, E2, E3, E4, E5, E6, E7, F2, F3, F4	DV	SB	MEO	DD	NT

TABLE 3 | (Continued)

Taxon	Sources	Dates	Q	FG	H	EG	IUCN	ICMBio
Gobiesociformes								
Gobiesocidae								
Gobiesox barbatulus (Starks, 1913)	7, 68	1955/1989	C5, D4, D5, D7, E7	ZB	HB	MED	LC	NE
Tomicodon australis Briggs, 1955	68	1999	E7	ZB	HB	MEO	LC	LC
Blenniiformes								
Labrisomidae								
Gobioclinus kalisherae (Jordan, 1904)	26	2012/ 2013	D7	ZB	HB	MEO	LC	NE
Labrisomus nuchipinnis (Quoy & Gaimard, 1824)	27	2010/ 2011	D6	ZB	HB	MEO	LC	LC
Dactyloscopidae								
Dactyloscopus crossotus Starks, 1913	5, 6	2005/2006	D7	OP	SB	MEO	LC	LC
Blenniidae								
Hypleurochilus fissicornis (Quoy & Gaimard, 1824)	68	1961	E4	ZB	HB	MEO	LC	LC
Parablennius pilicornis (Cuvier, 1829)	68	1915	ND	OV	HB	MEO	LC	LC
Scartella cristata (Linnaeus, 1758)	5, 6, 68, 73	1982/1995/ 2005/2006	D7	HV	HB	MS	LC	LC
Perciformes								
Serranidae								
Diplectrum formosum (Linnaeus, 1766)	27, 34, 61, 66, 68, 72	1944/1955/ 1990–1992/1995/ 1997/2005–2007/ 2010/2011	C5, C6, D5, D6, D7, E5, E7	ZB	SB	MEO	LC	LC
Diplectrum radiale (Quoy & Gaimard, 1824)	27, 34, 61, 62, 65, 66, 68, 72	1944/1990–1993/ 1997/1998/ 2005–2007/2010/ 2011/2013–2015	B5, C4, C5, C6, D5, D6, D7, E3, E4, E5, E7	ZB	SB	MEO	LC	LC
Dules auriga Cuvier, 1829	27, 34, 45, 61, 62, 65, 68, 71	1944/1993/ 2005–2011/ 2013–2015/2019	C5, C6, D5, D6, E3, E5, E7	ZB	SB	MEO	NE	LC
Serranus flaviventris (Cuvier, 1829)	68, 72	1944/1992/1997	D7, E3	ZB	HB	MEO	LC	LC
Epinephelidae								
Epinephelus itajara (Lichtenstein, 1822)	5, 6, 20	2000/2005/2006	D6, D7	OP	SB+HB	MEO	VU	CR
Epinephelus marginatus (Lowe, 1834)	68, 72	1913/1956/ 1991/1997	C5, D7, E6	OP	HB	MEO	VU	VU
Epinephelus morio (Valenciennes, 1828)	5, 6, 68	1944/2005/2006	D7, E7	OP	SB+HB	MEO	VU	VU
Hyporthodus nigritus (Holbrook, 1855)	34, 61	2005–2007	C5	ZB	HB	MEO	NT	EN
Hyporthodus niveatus (Valenciennes, 1828)	34, 61	2005–2007	C5, E7	ZB	HB	MEO	VU	VU
Mycteroperca acutirostris (Valenciennes, 1828)	27, 65, 67, 68	1944/1963/ 1981/1989/1991/ 1993/2010/2011	C5, D4, D6, D7, E7	ZP	HB	MEO	LC	DD
Mycteroperca microlepis (Goode & Bean, 1879)	34, 61	2005–2007	E3	ZB	HB	MEO	VU	DD
Uranoscopidae								
Astroscopus y-graecum (Cuvier, 1829)	5, 6, 68	1998/2005/2006	D7, E7	PV	SB	MS	LC	LC
Triglidae								
Prionotus nudigula Ginsburg, 1950	62	2013/2014	C5	PV	SB	MEO	NE	LC
Prionotus punctatus (Bloch, 1793)	5, 6, 7, 9, 27, 34, 61, 62, 65, 66, 68	1944/1955/1984/ 1989/1993/1994/ 2004–2007/2010/ 2011/2013–2015	C3, C5, C6, D4, D5, D6, D7, E3, E4, E5, E6, E7	ZB	SB	MEO	LC	LC
Scorpaenidae								
Scorpaena brasiliensis Cuvier, 1829	7, 34, 61, 62, 66, 68	1989/1993/1994/ 2005–2007/ 2013/2014	D4, D5, E7	ZB	SB	MEO	LC	LC

TABLE 3 | (Continued)

Taxon	Sources	Dates	Q	FG	H	EG	IUCN	ICMBio
Scorpaena isthmensis Meek & Hildebrand, 1928	7, 34, 61, 62, 65, 66, 68	1989/1993/1994/ 2005–2007/2014	D4, D5, D6, D7, E7	ZB	HB	MEO	LC	LC
Scorpaena plumieri Bloch, 1789	7, 34, 61	1989/2005–2007	D5, D7	ZB	HB	MEO	LC	LC
Acanthuriformes								
Priacanthidae								
Heteropriacanthus cruentatus (Lacepède, 1801)	64	2009/2010	E7	OP	HB	MEO	LC	LC
Priacanthus arenatus Cuvier, 1829	27, 34, 61, 62, 63, 64, 65	1994/2005–2007/ 2009–2011/ 2013–2015	C5, D5, D6, D7, E3, E4, E7	ZB	HB	MEO	LC	LC
Lutjanidae								
Rhomboplites aurorubens (Cuvier, 1829)	68	ND	ND	OP	HB	MS	VU	NT
Gerreidae								
Diapterus auratus Ranzani, 1842	65, 68	1944/1989	ND	ZB	HB	MED	LC	LC
Diapterus rhombeus (Cuvier, 1829)	27, 34, 61, 62, 66, 68, 79	1975/1978/ 1983/1984/ 2005–2007/ 2010/2011/ 2013–2015	B5, C3, C5, D5, D7, E3, E5, E7	OV	SB	MED	LC	LC
Eucinostomus argenteus Baird & Girard, 1855	5, 6, 9, 15, 26, 27, 34, 61, 62, 65, 68	1956/1982/ 1983/1994/ 2005–2007/ 2010–2015	B5, C3, C5, D5, D7, E3, E4, E5, E7	ZB	SB	MED	LC	LC
Eucinostomus gula (Quoy & Gaimard, 1824)	5, 6, 26, 27, 34, 61, 62, 65, 66	1994/2005–2007/ 2010–2015	B5, C3, C5, D5, D6, D7, E3, E4, E5, E7	ZB	SB	MEO	LC	LC
Eucinostomus lefroyi (Goode, 1874)	5, 6, 68	1998/2005/2006	C4, D7	ZB	SB	MEO	LC	LC
Eugerres brasilianus (Cuvier, 1830)	63, 79	1978/2014	D4	ZB	SB	MEO	LC	LC
Haemulidae								
Anisotremus virginicus (Linnaeus, 1758)	34, 61	2005–2007	E7	ZB	HB	MS	LC	LC
Boridia grossidens Cuvier, 1830	5, 6, 34, 61, 66	2005–2007	C3, C5, D5, D7, E7	ZB	SB	MEO	NE	LC
Conodon nobilis (Linnaeus, 1758)	34, 61	2005–2007	C5, E5	ZB	SB	MEO	LC	LC
Genyatremus cavifrions (Cuvier 1830)	5, 6	2005/2006	D7	OV	SB	ER	DD	LC
Haemulon aurolineatum Cuvier, 1830	27, 31	2010–2015	D6	OV	SB+HB	MEO	LC	LC
Haemulon atlanticus Carvalho, Marceniuk, Oliveira & Wosiacki, 2020	27, 31, 34, 61, 68	1944/2005–2007/ 2010–2015	D6, E4, E7	ZB	HB	MEO	LC	LC
Haemulopsis corvinaeformis (Steindachner, 1868)	5, 6, 34, 61, 65	1993/2005–2007	D7, E7	ZB	SB	MEO	LC	LC
Orthopristis rubra (Cuvier, 1830)	5, 6, 9, 11, 27, 34, 47, 58, 61, 62, 63, 64, 65, 67, 68, 73, 79, 82	1944/1955/1978/ 1989/1990/1991/ 1994/1995/2002/ 2005–2007/ 2009–2011/ 2013–2015	B5, C3, C4, C5, C6, D4, D5, D6, D7, E3, E4, E5, E7, F2, F3	ZB	SB	MEO	LC	LC
Sparidae								
Archosargus rhomboidalis (Linnaeus, 1758)	26, 34, 61, 63, 65, 68, 79	1944/1955/ 1978/1993/ 2005–2007/ 2012–2014	C5, D4, D5, D7, E3, E4	OV	SB	MEO	LC	LC
Calamus penna (Valenciennes, 1830)	27, 34, 61, 66, 68	1944/2005–2007/ 2010/2011	D6, E3, E5, E7	ZB	SB+HB	MS	LC	LC
Diplodus argenteus (Valenciennes, 1830)	5, 6, 15, 26, 27, 31, 34, 61, 68	1995/2005–2007/ 2010–2015	D5, D6, D7, E7	HV	HB	MEO	LC	LC
Pagrus pagrus (Linnaeus, 1758)	45	2008/2009	ND	OP	SB+HB	MS	LC	DD
Sciaenidae								
Bairdiella goeldi Marceniuk, Molina, Caires, Rotundo, Wosiacki & Oliveira, 2019	34, 61, 66, 68	1994/2005–2007	C5, E3, E7	ZB	SB	MED	LC	LC
Ctenosciaena gracilicirrhus (Metzelaar, 1919)	9, 27, 34, 61, 62, 65, 66, 67	1983/2005–2007/ 2010/2011/ 2013–2015	C3, C5, D5, D6, D7, E3, E4, E5, E7	ZB	SB	MEO	LC	LC

TABLE 3 | (Continued)

Taxon	Sources	Dates	Q	FG	H	EG	IUCN	ICMBio
Cynoscion acoupa (Lacepède, 1801)	34, 61, 62, 63, 64, 66	2005–2007/ 2009/2010/ 2013–2015	B4, C3, C5, D4, D5, D7, E2, E3, E4, E5, E6, E7, F2, F3	ZB	SB	MEO	VU	NT
Cynoscion guatucupa (Cuvier, 1830)	27, 34, 45, 61, 62, 63, 66	2005–2011/ 2013/2014	D5, D7, E4, E5	OP	SB	MS	LC	LC
Cynoscion jamaicensis (Vaillant & Bocourt, 1883)	9, 34, 45, 61, 62, 63, 64, 67, 79	1978/2005–2010/ 2013–2015	C3, C5, C6, D5, D7, E3, E4, E5, E7	ZB	SB	MEO	LC	LC
Cynoscion leiarchus (Cuvier, 1830)	34, 45, 61, 62, 63, 64, 66, 67	2005–2010/ 2013–2015	B3, B4, C3, C4, C5, D3, D4, D5, D6, E3, E4, E5, E6, E7	ZB	SB	MEO	LC	LC
Cynoscion microlepidotus (Cuvier, 1830)	34, 61, 62, 64	2005–2007/ 2009/2010/ 2013–2015	C5, D5, E5	ZB	SB	MEO	LC	LC
Isopisthus parvipinnis (Cuvier, 1830)	27, 34, 61, 62	2005–2007/ 2010/2011/ 2013–2015	C3, C5, D5, E4, E7	ZB	SB	MED	LC	LC
Larimus breviceps Cuvier, 1830	34, 45, 61, 62, 66, 67	2005–2009/ 2014	D5, D7, E5, E7	ZB	SB	MED	LC	LC
Macrodon atricauda (Günther, 1880)	54	2001/ 2002	ND	OP	SB	MEO	LC	LC
Menticirrhus gracilis (Cuvier, 1830)	5, 6, 27, 31, 34, 61, 66	2005–2007/ 2010–2015	C3, D5, D6, D7, E3, E7	ZB	SB	MEO	LC	DD
Menticirrhus martinicensis (Cuvier, 1830)	5, 6, 27, 31, 34, 61, 62, 65, 66, 68	1944/1982/ 2005–2007/ 2010–2015	C3, C5, D5, D6, D7, E3, E4, E5, E7	ZB	SB	MEO	LC	DD
Micropogonias furnieri (Desmarest, 1823)	4, 5, 6, 9, 10, 16, 18, 21, 25, 27, 33, 34, 39, 40, 45, 47, 49, 50, 51, 52, 53, 54, 55, 56, 57, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68, 76, 78, 79, 80	1944/ 1978/ 1982/ 1983/ 1990–2011/ 2013–2016	B3, B4, B5, C3, C4, C5, C6, D2, D3, D4, D5, D6, D7, E2, E3, E4, E5, E6, E7, F2, F3, F4	ZB	SB	MED	LC	LC
Nebris microps Cuvier, 1830	34, 61, 66	2005–2007	D5, E5	ZB	SB	MED	LC	LC
Odontoscion dentex (Cuvier, 1830)	27	2010/ 2011	D6	OP	HB	MED	LC	LC
Paralonchurus brasiliensis (Steindachner, 1875)	34, 45, 61, 62, 66	2005–2009/ 2013–2015	C5, D5, E7	ZB	SB	MEO	LC	LC
Pogonias courbina (Lacépède, 1803)	34, 61, 62, 63, 64, 66, 67, 79	1978/2005–2007/ 2009/2010/ 2013/2014	B3, B5, C3, C4, C5, D3, D4, D5, D6, D7, E3, E4, E5, E7, F2, F3, F4, F5	ZB	SB	MEO	LC	EN
Stellifer brasiliensis (Schultz, 1945)	34, 61	2005–2007	D5	ZB	SB	MED	LC	LC
Stellifer punctatissimus (Meek & Hildebrand, 1925)	67	ND	D4	ZB	SB	MEO	LC	DD
Stellifer rastrifer (Jordan, 1889)	5, 6, 34, 61, 62, 66	2005–2007/ 2013–2015	C5, D5, D7, E3, E5, E7	ZB	SB	MED	LC	LC
Stellifer stellifer (Bloch, 1790)	34, 61, 62	2005–2007/ 2013–2015	D5	ZB	SB	MED	DD	LC
Umbrina canosai Berg, 1895	27, 34, 45, 61	2005–2011	D5, D6	ZB	SB	MEO	LC	LC
Umbrina coroides Cuvier, 1830	5, 6, 27, 31, 34, 61, 66	2005–2007/ 2010–2015	D5, D6, D7, E3, E7	ZB	SB	MEO	LC	LC
Ephippidae								
Chaetodipterus faber (Broussonet, 1782)	5, 6, 15, 26, 34, 61, 62, 63, 64, 66, 79	1978/2005–2007/ 2009–2015	B4, C3, C4, C5, C6, D4, D5, D7, E3, E4, E5, E7, F3	ZB	SB	MEO	LC	LC
Lophiiformes								
Ogcocephalidae								
Ogcocephalus vespertilio (Linnaeus, 1758)	7, 27, 62, 68	1987/1989/ 2010/2011/ 2014/2015	D5, D6, D7	ZB	HB	MEO	LC	LC
Antennariidae								
Antennarius striatus (Shaw, 1794)	34, 61	2005–2007	E7	PV	SB	MS	LC	DD

TABLE 3 | (Continued)

Taxon	Sources	Dates	Q	FG	H	EG	IUCN	ICMBio
Tetraodontiformes								
Diodontidae								
Chilomycterus reticulatus (Linnaeus, 1758)	12, 27, 34, 61, 62, 67	2005–2007/ 2010/2011/2015	C5, D5, D6, E5	ZB	P	MS	LC	LC
Chilomycterus spinosus (Linnaeus, 1758)	3, 5, 6, 9, 12, 14, 15, 27, 34, 61, 62, 67, 68	1944/1945/ 1995/2000/ 2005–2007/ 2010–2015	C3, C5, D5, D6, D7, E3, E4, E5, E7	ZB	SB	MEO	LC	LC
Diodon hystrix Linnaeus, 1758	68	1954/1956	D5	ZB	HB	MEO	LC	LC
Tetraodontidae								
Canthigaster figueiredoi Moura & Castro, 2002	5, 6	2005/2006	D7	OV	HB	MEO	LC	NE
Lagocephalus laevigatus (Linnaeus, 1766)	5, 6, 12, 34, 61, 62, 67, 68	1944/2005–2007/ 2013/2014	C3, C5, D5, D7, E3, E5, E7	ZB	SB	MM	LC	LC
Lagocephalus lagocephalus (Linnaeus, 1758)	5, 6	2005/2006	D7	OP	P	MS	LC	LC
Sphoeroides greeleyi Gilbert, 1900	5, 6, 12, 15, 26, 27, 34, 61, 62, 66, 67, 68	1993/2003/ 2005–2008/ 2010–2015	C5, D5, D6, D7, E3, E4, E5, E7	ZB	SB	ER	LC	LC
Sphoeroides spengleri (Bloch, 1785)	62, 68	1993/2014	D5, D7	ZB	HB	MEO	LC	LC
Sphoeroides testudineus (Linnaeus, 1758)	5, 6, 12, 15, 27, 31, 34, 61, 62, 66, 68	1944/2005–2007/ 2010–2015	C5, D5, D7, E3, E4, E5, E7	ZB	SB	MEO	LC	DD
Sphoeroides tyleri Shipp, 1972	3, 5, 6, 12, 34, 61, 62, 67	2000/2005–2007/ 2013–2015	C5, D5, D7, E3, E5, E7	ZB	SB	MEO	LC	LC
Ostraciidae								
Acanthostracion quadricornis (Linnaeus, 1758)	34	2005–2007	ND	ZB	P	MS	LC	LC
Monacanthidae								
Aluterus heudelotii Hollard, 1855	12, 34, 61, 67	2005–2007	D7, E7	HV	SB	MS	LC	LC
Aluterus monoceros (Linnaeus, 1758)	27	2010/2011	D6	ZB	HB	MEO	LC	NT
Aluterus schoepfii (Walbaum, 1792)	12, 34, 61, 67	2005–2007	D7, E7	HV	SB	MS	LC	LC
Cantherhines pullus (Ranzani, 1842)	5, 6	2005/2006	D7	OV	HB	MEO	LC	LC
Monacanthus ciliatus (Mitchill, 1818)	26	2012/ 2013	D7	OV	SB+HB	MS	LC	LC
Stephanolepis hispida (Linnaeus, 1766)	12, 27, 34, 61, 62, 63, 67, 68	1916/ 2005–2007/ 2010/ 2011/ 2013/ 2014	C3, C5, D5, D6, D7, E3, E4, E5, E7, F5	OV	SB	MEO	LC	LC
Balistidae								
Canthidermis sufflamen (Mitchill, 1815)	5, 6	2005/ 2006	D7	OP	HB	MEO	LC	LC

marine migrants may also be either opportunistic or dependent, therefore the number of species that depend on the estuary to complete their life cycle can be even higher. Demersal species represented about 80% of the richness, distributed throughout species that inhabit soft substrates (58%), hard substrates (17%) or both (5%), while 44 species are classified as pelagic. These results are reflected in the feeding guilds identified, with 55% (120) of the species being considered zoobenthivores. The other categories have much lower values, with 39 opportunistic species, 21 zooplanktiovorous, 18 piscivorous, 14 omnivorous, four herbivorous and four detritivorous.

Elasmobranchs are vertebrates with a conservative life history (*e.g.*, low fecundity, late sexual maturation, slow growth, high longevity, long gestational periods) and, therefore, have low replacement potential in the event of mortality from unnatural causes (*e.g.*, Hoenig, Gruber, 1990). Thus, it is not surprising that this group has a higher number of threatened species when compared to teleosts, a group with species generally presenting shorter life cycles and high population densities (*e.g.*, Pratt Jr. *et al.*, 1990). Among the ray and shark species recorded in this study, 77% are threatened globally (Vulnerable, Endangered or Critically Endangered), in addition to 23% considered as Near Threatened. Among teleosts, only 7% are threatened or Near Threatened globally, with 82% considered as Least Concern, 3% as Data Deficient, and 8% as Not Evaluated. A similar scenario was found at the Brazilian level, with 79% of the teleosts classified as Least Concern, 4% as Threatened, 5% as Near Threatened, 8% as Data Deficient, and 4% as Not Evaluated. As for the elasmobranchs recorded in Guanabara Bay at the Brazilian level, 47% of the species are assessed as Data Deficient, 35% are Threatened, 12% are Near Threatened, and only 6% are classified as Least Concern.

The rarefaction curve calculated for the estuary as a whole did not reach an asymptote, indicating that Guanabara Bay has an even richer baseline concerning fish species (Fig. 2A). In fact, the analysis by the Chao2 method estimated a richness of 249 species, 29 more than that recorded herein. However, about 88% of the ichthyofauna was successfully inventoried (Fig. 3A). The probability of obtaining a new species record if one more source was consulted would be only 0.046, while a significant effort would be required (319 new sources) for 100% of the fish species in the bay to be fully inventoried (Tab. 4). Regarding only the lower estuary compartment, the results obtained were similar, with no stabilization of the rarefaction curve (Fig. 2B). However, in this case, the number of recorded species (188) was closer to the estimated (approximately 203 species), at 92% of the total ichthyofauna (Fig. 3B). In addition, the "q0" value was even lower (0.03) and the effort to obtain the totality of the lower estuary ichthyofauna would, again, be excessively high (m = 223.5).

Contrary to the lower estuary compartment and the Guanabara Bay as a whole, stabilization of the rarefaction curves was obtained for the middle and upper estuary compartments (Figs. 2C, D), indicating that the records are sufficient to represent the species richness of these two portions of the bay. The observed and estimated richness values were very close in both cases and q0 values were less than 0.01 (Tab. 4). Even though the "m" values were not null, they indicated a sampling of over 99% for these two compartments (Figs. 3C, D). However, a new species was recorded in the upper estuary after 2020. On June 22, 2022, gillnet artisanal fisherman captured one specimen of the tiger-shark *Galeocerdo cuvier* on quadrant C4. This is the first record of the species in Guanabara Bay. The specimen was a juvenile female with total length of 1,80 m and its jaw is deposited in the MNRJ (MNRJ 53604).

TABLE 4 | Chao2 parametric estimator values for Guanabara Bay, Rio de Janeiro, Brazil, as a whole, and for the lower, middle and upper estuaries separately (t = 84).

	t	T	S obs	S est	Q1	Q2	q0	m	mg (g = 0.95)	mg (g = 0.90)	mg (g = 0.85)	mg (g = 0.80)
Guanabara Bay	84	1054	218	247.66	49	40	0.046	318.96	44.83	9.25	-	-
Lower estuary	84	1005	188	202.87	31	32	0.031	223.52	15.49	-	-	-
Middle estuary	84	720	90	90.89	3	5	0.004	60.45	-	-	-	-
Upper estuary	84	735	92	92.64	3	7	0.004	41.15	-	-	-	-

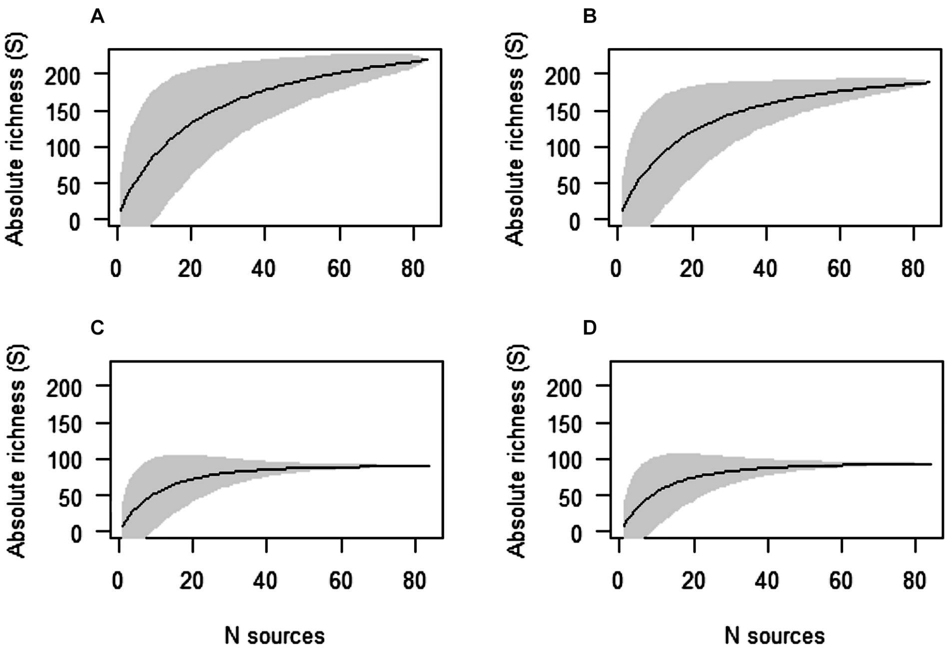

FIGURE 2 | Rarefaction curves for Guanabara Bay's ichthyofauna richness, Rio de Janeiro, Brazil. **A.** For the bay as a whole, and for the estuary compartments separately: **B.** Lower estuary, **C.** Middle estuary and **D.** Upper estuary.

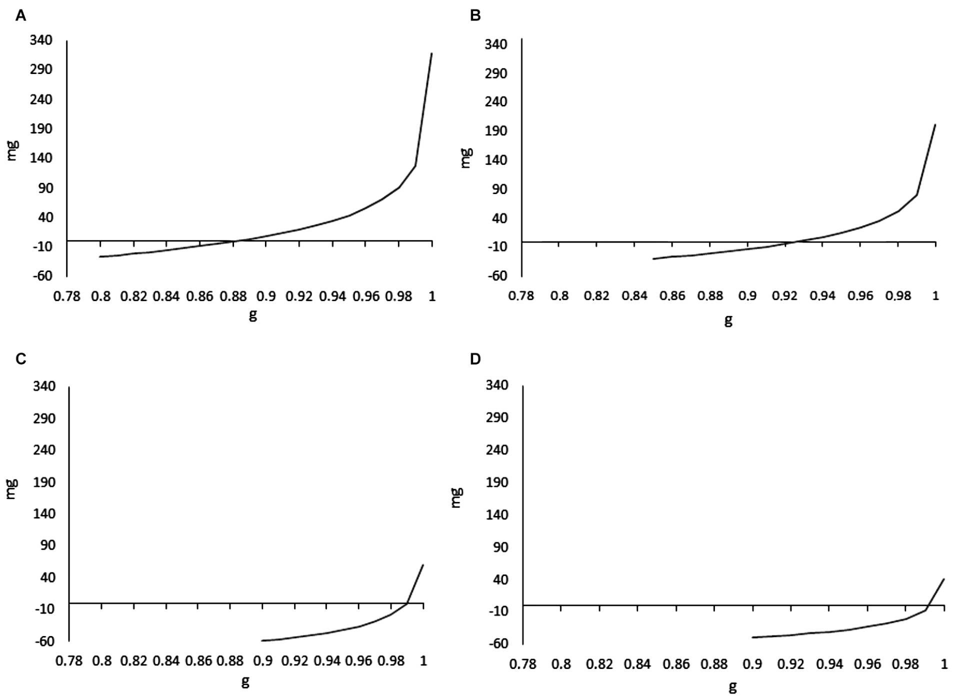

FIGURE 3 | Ichthyofauna rates found for Guanabara Bay, Rio de Janeiro, Brazil. **A.** As a whole and for the **B.** Lower, **C.** Middle, and **D.** Upper estuaries separately, where "mg" corresponds to the number of extra samples needed to reach a "g" for estimated richness. When the line touches the x axis (mg = 0), the "g" values are reached by our study, that is, the value in which extra collections are not necessary.

Spatial distribution. In general, the region of the bay closer to the mouth of the estuary presented the highest values of both absolute richness (S) and species density (SD). Quadrants D7 and E7 at the entrance of the estuary were the richest and densest (Figs. 1, 4). Although D7 presented the highest number of species (127), E7 has the highest density due to its smaller water surface area. High S and SD values were also noted in the other lower estuary quadrants, with D4 having the lowest richness (43 species). However, D6 results were lower than expected (S = 55, SD = 2.34 sp./km^2) considering it is a transition region between D7 and D5, both of which are richer.

A high variation in S was observed in the middle estuary compartment. For instance, quadrants F4 and F5 presented less than 10 species, while quadrants C5 and E5 had over 60 species (Figs. 1, 4A). However, the quadrants of this compartment have very different water surface areas, making SD a more reliable measure for comparison. Even though quadrants B5, F5 and E6 have relatively small S values (18, 2 and 14, respectively), their small water surface area result in SD values above three (Figs. 1, 4B). Therefore, only quadrants C6 and F4 stand out with relativity lower densities when compared to the other quadrants of the middle estuary.

The upper estuary presented most quadrants with relatively lower values of S, with three quadrants with less than 10 species (D2, D3 and E2) and five with less than 20 species (B3, B4, C4, F2 and F3). A similar pattern was recovered for species density, with the upper estuary comprising the only portion of the bay with quadrants with SD values lower than one species per km^2 (B4, D3, E2, F2 and F3). All quadrants in the upper estuary compartment, except for C3 and E3, presented SD values lower than two species per km^2. Indeed, quadrants C3 (S = 62, SD = 2.98 sp./km^2) and E3 (S = 73, SD = 3.07 sp./km^2) stood out in terms of richness, with S and SD values more similar to the ones recovered for the lower and middle estuary compartments (Figs. 1, 4).

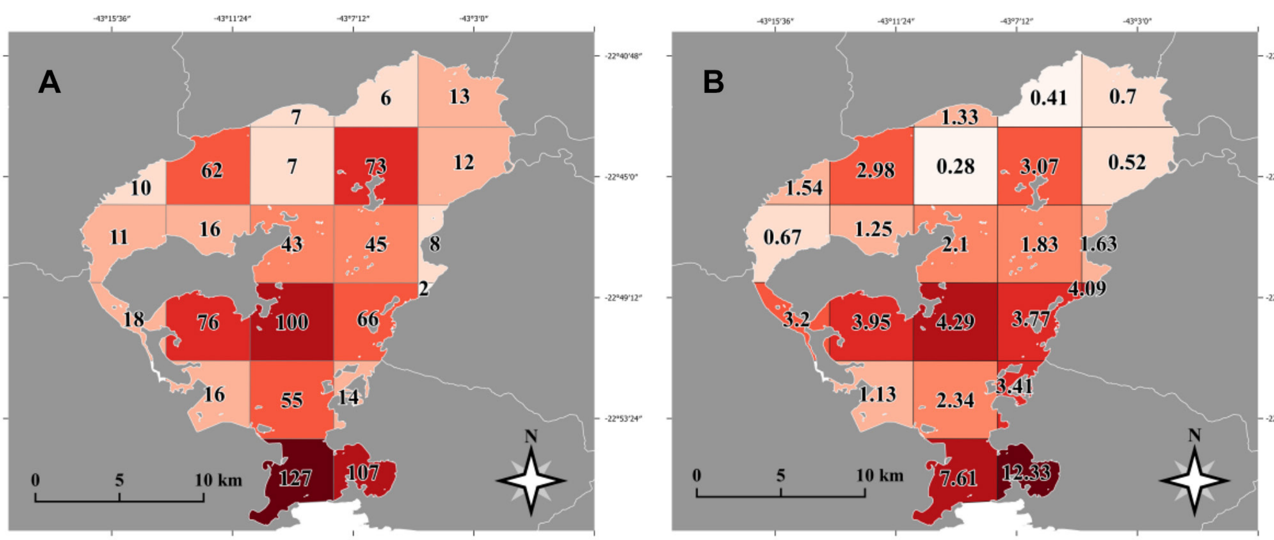

FIGURE 4 | Distribution of absolute richness (**A**) and species density (**B**) per km^2 at Guanabara Bay, Rio de Janeiro, Brazil.

Temporal changes. From the 220 species considered, 84 were not recorded in the last decade (between 2010 and 2020) (Tab. 5). Among these, 65 species were last recorded between 2000 and 2009, comprising 60 teleosts and five elasmobranchs. However, three of these elasmobranchs (*Sphyrna tiburo* (Linnaeus, 1758), *S. zygaena* (Linnaeus, 1758), and *Pristis pristis* (Linnaeus, 1758)) may have been recorded a long time before this timeframe. That is because their records come from past literature and ichthyological collections data presented at Buckup *et al*. (2000) who did not present the years that the records were made. Therefore, we considered the year of publication (2000) as the record data of those species.

Six species, three teleosts and three elasmobranchs (Tab. 5), were last recorded in Guanabara Bay between 1990 and 1999. The teleost *Tomicodon australis* Briggs, 1955, the sharks *Rhizoprionodon lalandii* and *R. porosus* (Poey, 1861) and the ray *Rhinoptera bonasus* (Mitchill, 1815) are represented by only one record each in the MNRJ Fish Collection, while the teleosts *Epinephelus marginatus* (Lowe, 1834) and *Serranus flaviventris* (Cuvier, 1829) were recorded at different dates until 1997, when both species ceased to appear in the records. The most recent records for the teleosts *Hyporhamphus unifasciatus* (Ranzani, 1841), *Diapterus auratus* Ranzani, 1842, and *Gobiesox barbatulus* (Starks, 1913) were all made in 1989.

Four species were recorded between 1960 and 1969 and three others were mentioned only between 1960 and 1969 (Tab. 5). Last records of some species are considerably older, for instance *Mugil curvidens* Valenciennes, 1836, recorded in 1944, *Narcine brasiliensis* (Olfers, 1831), in 1938, and *Parablennius pilicornis* (Cuvier, 1829), in 1915. Data of those records are again based on voucher specimens at MNRJ.

TABLE 5 | Species not recorded after 2010 at Guanabara Bay, Rio de Janeiro, Brazil, until 2020.

Species last recorded	Dates
Species last recorded from 2000 to 2009	
Abudefduf saxatilis (Linnaeus, 1758)	2001
Acanthostracion quadricornis (Linnaeus, 1758)	2005–2007
Aluterus heudelotii Hollard, 1855	2005–2007
Aluterus schoepfii (Walbaum, 1792)	2005–2007
Anchoa marinii Hildebrand, 1943	2005–2007
Anisotremus virginicus (Linnaeus, 1758)	2005–2007
Antennarius striatus (Shaw, 1794)	2005–2007
Astroscopus y-graecum (Cuvier, 1829)	1998/2005/2006
Bagre bagre (Linnaeus, 1766)	2005
Bairdiella goeldi Marceniuk, Molina, Caires, Rotundo, Wosiacki & Oliveira, 2019	1994/2005–2007
Bathygobius soporator (Valenciennes, 1837)	1944/1961/2005–2007
Boridia grossidens Cuvier, 1830	2005–2007
Bothus robinsi Topp & Hoff, 1972	2005–2007
Bryx dunckeri (Metzelaar, 1919)	2005/2006
Cantherhines pullus (Ranzani, 1842)	2005/2006

TABLE 5 | (Continued)

Species last recorded from 2000 to 2009	
Canthidermis sufflamen (Mitchill, 1815)	2005/2006
Canthigaster figueiredoi Moura & Castro, 2002	2005/2006
Caranx bartholomaei Cuvier, 1833	2005/2006
Cathorops spixii (Agassiz, 1829)	1944/2005–2007
Conodon nobilis (Linnaeus, 1758)	2005–2007
Cosmocampus elucens (Poey, 1868)	2005/2006
Dactyloscopus crossotus Starks, 1913	2005/2006
Engraulis anchoita Hubbs & Marini, 1935	1977/2005–2007
Epinephelus itajara (Lichtenstein, 1822)	2000/2005/2006
Epinephelus morio (Valenciennes, 1828)	1944/2005/2006
Eucinostomus lefroyi (Goode, 1874)	1998/2005/2006
Fistularia tabacaria Linnaeus, 1758	1989/2005–2007
Fistularia petimba Lacepède, 1803	2005–2007
Genyatremus cavifrions (Cuvier, 1830)	2005/2006
Gymnothorax ocellatus Agassiz, 1831	1889/1985/2005–2007
Haemulopsis corvinaeformis (Steindachner, 1868)	1993/2005–2007
Hemicaranx amblyrhynchus (Cuvier, 1833)	2005/2006
Hippocampus erectus Perry, 1810	1953/2000
Hippocampus reidi Ginsburg, 1933	1989/2000/2005–2007
Holocentrus adscensionis (Osbeck, 1765)	2007
Hyporthodus nigritus (Holbrook, 1855)	2005–2007
Hyporthodus niveatus (Valenciennes, 1828)	2005–2007
Lagocephalus lagocephalus (Linnaeus, 1758)	2005/2006
Lepidopus caudatus (Euphrasen, 1788)	2008
Macrodon atricauda (Günther, 1880)	2001/2002
Mullus argentinae Hubbs & Marini, 1933	1913/2005–2007
Mycteroperca microlepis (Goode & Bean, 1879)	2005–2007
Nebris microps Cuvier, 1830	2005–2007
Notarius grandicassis (Valenciennes, 1840)	2005–2007
Odontognathus mucronatus Lacepède, 1800	2005–2007
Pagrus pagrus (Linnaeus, 1758)	2008/2009
Paralichthys orbignyanus (Valenciennes, 1839)	2005–2007
Paralichthys patagonicus Jordan, 1889	2005–2007
Polydactylus oligodon (Günther, 1860)	2005/2006
Pristis pristis (Linnaeus, 1758)	2000
Pseudobatos horkelii (Müller & Henle, 1841)	2005–2007

TABLE 5 | (Continued)

Species last recorded from 2000 to 2009	
Pseudobatos percellens (Walbaum, 1792)	2005–2007
Rachycentron canadum (Linnaeus, 1766)	2005/2006
Scartella cristata (Linnaeus, 1758)	1982/1995/2005/2006
Scorpaena plumieri Bloch, 1789	1989/2005–2007
Sphyrna zygaena (Linnaeus, 1758)	2000
Sphyrna tiburo (Linnaeus, 1758)	2000
Stellifer brasiliensis (Schultz, 1945)	2005–2007
Strongylura marina (Walbaum, 1792)	2005–2007
Syacium micrurum Ranzani, 1842	2005–2007
Syacium papillosum (Linnaeus, 1758)	2005–2007
Syngnathus pelagicus Linnaeus, 1758	1960/1989/2005/2006
Trachinocephalus myops (Forster, 1801)	2005–2007
Trachurus lathami Nichols, 1920	2005–2007
Species last recorded from 1990 to 1999	
Tomicodon australis Briggs, 1955	1999
Epinephelus marginatus (Lowe, 1834)	1913/1956/1991/1997
Rhinoptera bonasus (Mitchill, 1815)	1997
Rhizoprionodon lalandii (Valenciennes, 1839)	1997
Rhizoprionodon porosus (Poey, 1861)	1997
Serranus flaviventris (Cuvier, 1829)	1944/1992/1997
Species last recorded from 1980 to 1989	
Diapterus auratus Ranzani, 1842	1944/1989
Gobiesox barbatulus (Starks, 1913)	1955/1989
Hyporhamphus unifasciatus (Ranzani, 1841)	1944/1989
Species last recorded from 1960 to 1969	
Hypleurochilus fissicornis (Quoy & Gaimard, 1824)	1961
Myrichthys ocellatus (Lesueur, 1825)	1964
Remora remora (Linnaeus, 1758)	1961
Symphurus plagusia (Bloch & Schneider, 1801)	1968
Species last recorded from 1950 to 1959	
Microgobius carri Fowler, 1945	1955
Aetobatus narinari (Euphrasen, 1790)	1957
Diodon hystrix Linnaeus, 1758	1954/1956
Species last recorded from 1940 to 1949	
Mugil curvidens Valenciennes, 1836	1944
Species last recorded from 1930 to 1939	
Narcine brasiliensis (Olfers, 1831)	1938
Species last recorded from 1910 to 1919	
Parablennius pilicornis (Cuvier, 1829)	1915

Nevertheless, fishing landing monitoring is still being carried out at Guanabara Bay, resulting in new records. After 2020, two new records of species shown on Tab. 5 were registered. On August 9, 2022, a 30 cm (total length) female *Rhizoprionodon lalandii* was captured by fishing at quadrant D2 and was deposited at MNRJ (MNRJ 53605). The species was recorded at the bay only once before in 1997. The other species is the teleost *Bagre bagre* previously recorded in 2005. The new record occurred on November 3, 2022, at quadrant F2.

DISCUSSION

The use of different sources for the compilation of past data was an efficient way to build a baseline of fish species from Guanabara Bay, as the different sources filled different gaps regarding the ichthyofauna survey. While the published literature provided more recent records, specimens deposited in ichthyological collections revealed more ancient occurrences, some dating back to the 19th century. Scientific sampling and taxonomic monitoring of fish landings, in turn, revealed 13 species not reported by any other type of source. Since this survey is based on past records, it is important to consider the possibility of misidentification of specimens in the sources consulted. For the scientific sampling and fish landings monitoring this problem was likely minimized, since they were carried out by BioTecPesca/UFRJ and all specimens were identified by a specialist. The use of only published data also increases the reliability of the baseline, since all the articles used were peer reviewed by specialists. Other important measure was the exclusion of doubtful records of species that are not confirmed to occur in the state of Rio de Janeiro. Finally, our survey recovered a considerable level of internal data consistency, with the same species recorded in the same areas by different sources, increasing the reliability of the occurrence of these species.

The total richness of 220 species (203 teleosts and 17 elasmobranchs) recorded was higher than previously reported for the Guanabara Bay. Vianna *et al*. (2012), for instance, reported 174 species (169 teleosts and five elasmobranchs). Even though this increase in richness was influenced by the new studies published and the new scientific samplings and fishery landing monitoring since 2012, the inclusion of historical records from scientific collections also contributed substantially. Regarding elasmobranchs, for example, *Dasyatis hypostigma* Santos & Carvalho, 2004, *Gymnura altavela* (Linnaeus, 1758), *Hypanus guttatus* (Bloch & Schneider, 1801), *Pseudobatos horkelii* (Müller & Henle, 1841), *Pseudobatos percellens* (Walbaum, 1792), and *Zapteryx brevirostris* (Müller & Henle, 1841) were recorded between 2012 and 2015 (Gonçalves-Silva, Vianna, 2018a), while *Carcharhinus brachyurus* (Günther, 1870), *Rhizoprionodon lalandii*, *R. porosus*, *Aetobatus narinari* (Euphrasen, 1790), *Rhinoptera bonasus*, and *Narcine brasiliensis* were only found as vouchers deposited in collections.

Despite advances, some taxonomic questions still hinder the establishment of a more comprehensive list of fish species in the Guanabara Bay. For instance, *Elops saurus* Linnaeus, 1766 was considered the only species of the genus *Elops* in the western Atlantic before the description of *Elops smithi* McBride, Rocha, Ruiz-Carus & Bowen, 2010. However, the two species are anatomically similar, such that sympatry of the two species in the region cannot be ruled out at the moment. A similar situation refers to the distribution of *Scomber japonicus* Houttuyn, 1782. Fricke *et al*. (2023) indicates that its distribution is restricted to the Pacific Ocean. However, other studies have recognized *S. japonicus* as occurring in the southwestern Atlantic (Roldán *et al*., 2000; Perrotta *et al*., 2005) and specifically of Rio de Janeiro State (Alves *et al*., 2003; Menezes *et al*., 2003). Further studies are required to clarify the distribution of those species.

The total species richness recorded in the Guanabara Bay is considerably higher in relation to other tropical estuaries (Tab. 6). The coast of the state of Rio de Janeiro is the richest portion in the Brazilian coast concerning estuarine fish species (Vilar *et al*., 2017), and Guanabara Bay stands out when compared to two other estuaries previously inventoried in the state (Sepetiba Bay and Mambucaba Estuary), having practically twice the number of species. Even though the large size of the Guanabara Bay contributes to a naturally greater richness, this factor alone is not able to explain the observed discrepancies. Sepetiba Bay, for instance, is similar in size to Guanabara Bay, but has practically half the number of species. Other example is the Bay of Malaga, in Colombia, that despite being much smaller (126 km^2) still presents three families, 36 genera and 17 species more than what we recorded at Guanabara Bay.

TABLE 6 | Absolute ichthyofauna richness in tropical estuaries in Brazil and worldwide according to the available literature.

Estuary	Locality	Families	Genera	Species	Area (km^2)	References
Guanabara Bay	Brazil, southeast	72	149	220	384	This study
Sepetiba Bay	Brazil, southeast	44	80	107	305	Araújo *et al.* (2002)
Mambucaba estuary	Brazil, southeast	40	81	111	3.82	Neves *et al.* (2011)
Pinheiros Bay	Brazil, south	29	49	61	200	Pichler *et al.* (2015)
Saco da Fazenda	Brazil, south	21	35	42	0.7	Barreiros *et al.* (2009)
São Caetano de Odivelas e Vigia	Brazil, north	23	46	58	13.4	Barros *et al.* (2011)
Caeté River estuary	Brazil, north	82	67	29	93.2	Barletta *et al.* (2005)
Paraguaçu River estuary	Brazil, northeast	49	83	124	128	Reis-Filho *et al.* (2010)
Formoso River estuary	Brazil, northeast	39	59	78	27	Paiva *et al.* (2009)
Mataripe River estuary	Brazil, northeast	15	29	35	18.5	Dias *et al.* (2011)
Mamanguape	Brazil, northeast	23	31	37	6.9	Xavier *et al.* (2012)
Buenaventura Bay	Colombia, west	29	-	69	70	Molina *et al.* (2020)
Málaga Bay	Colombia, west	75	185	237	126	Castellanos-Galindo *et al.* (2006)
Sabancuy estuary	Mexico, Yucatán Peninsula	21	27	33	8.71	González-Solis, Torruco (2013)
Embley estuary	Australia, north	-	-	197	75	Blaber *et al.* (1989)
Vellar estuary	India, southeast	42	61	95	2.62	Murugan *et al.* (2014)
Zuari	India, west	-	-	176	39.9	Sreekanth *et al.* (2020)
Mandovi	India, west	-	-	154	35.5	Sreekanth *et al.* (2020)
Terekhol	India, west	-	-	131	12.7	Sreekanth *et al.* (2020)
Kali	India, west	-	-	133	20.8	Sreekanth *et al.* (2020)
Gâmbia estuary	Gâmbia	32	54	70	624	Albaret *et al.* (2004)
Morrumbene	Mozambique, east	-	84	114	193	Day (1974)

The relatively high value of species richness in the Guanabara Bay is likely promoted by the diversity of environments and microhabitats, as the bay encompasses islands, mangroves, rocky shores, sandy beaches, artificial substates and muddy bottoms. In addition, the bay presents a wide variation of environmental conditions and gradients of salinity and nutrient distribution that are characteristic of estuaries (Vianna *et al*., 2012; Silva-Junior *et al*., 2016; Wolanski, Elliott, 2016). These conditions promote a wide variety of ecological opportunities, reducing competition and favoring the coexistence of a high number of species (Bello *et al*., 2012; Dolbeth *et al*., 2016). Furthermore, the bay conditions are seasonally influenced by a low intensity upwelling event. During spring and summer (November to March) changes in winds promote the outcrop of cold waters from the SACW mass, causing parts of the estuary to present subtropical temperatures (between 10 and 20 ºC) (Silva-Junior *et al*., 2016). This phenomenon allows species that only occur in deeper areas of the continental shelf to enter the estuary.

Concerning the absolute richness accumulation curves calculated, the upper and middle estuary curves stabilized, indicating that richness values recorded are close to the estimated value of those compartments. However, the record of *Galeocerdo cuvier* made in the upper estuary compartment in 2022 indicates that occasional species may occur even in the inner parts of the bay, especially when it comes to opportunistic highly mobile taxa.

Stabilization of the accumulation curves were not observed for the Guanabara Bay as a whole and for the lower estuary, both of which are likely to have larger values of richness than the ones recorded here. The lower estuary seems to have strongly influenced this result. Sampling effort required to reach an asymptote can be prohibitively large for environments with a high number of rare species (Chao *et al*., 2009). As the region closest to the adjacent coastal zone, the lower estuary is affected by the continuous inflow of oceanic water and is visited by many occasional opportunistic marine species, which functionally act as rare species. For instance, species associated with rocky shores from some beaches around the Guanabara Bay (*e.g*., Rodrigues-Barreto *et al*., 2017) probably enter the estuary during tide variations. However, their record can be hampered by the high turbidity that hinders visual census attempts. Indeed, the Chao2 index calculated unusually high "m" values for the lower estuary, indicating that approximately 223 new sources would be needed for the entire ichthyofauna to be inventoried in that compartment. Therefore, the non-stabilization of the lower estuary compartment may be preventing the stabilization of the Guanabara Bay's richness accumulation curve. This is a common situation in tropical environments, where different ecosystems have been sampled for decades without reaching an asymptote in the species richness (*e.g*., Gotelli, Colwell, 2011).

The distribution of the estuarine ichthyofauna is influenced by the interaction between coastal currents and the water from the local drainage basin, as well as by the degree of tolerance of each species to the salinity gradient (Camargo, Issac, 2003; Silva-Junior *et al*., 2016). Other important factors are the colonization capacity of different fish populations and the variety of habitats and biotic interactions that maximize interspecific coexistence (Bello *et al*., 2012; Dolbeth *et al*., 2016). The lower estuary is the compartment of the bay most influenced by coastal oceanic waters, allowing marine species to enter the compartment to feed (Nybakken, Bertness, 2005). These occasional marine species are likely to promote the high S and SD values in the lower estuary. The proximity to the coastal environments seems to produce a gradient in this compartment, with the innermost quadrants (D4 and E4) presenting lower values of S and SD than the outmost quadrants (D5, D7 and E7) (Fig. 1). The only quadrant that deviates from this pattern is D6. However, this is probably due to the difficulty of performing biological samplings, since this quadrant presents depths up to 50 m (Meniconi *et al*., 2012) and undergoes intense boat traffic.

The middle estuary is a transition area, presenting distinct spatial and temporal features. This compartment can be split into two portions that respond differently to the dry and rainy seasons, namely (A) the quadrants to the left of the central channel (B5, C5 and C6) and (B) the quadrants to the right of the central channel (E5, E6, F4 and F5) (Fig. 1). In general, the water column conditions during the rainy season are more variable than in the dry season, but in A the greatest amplitudes are related to temperature (minimum of 17 °C and maximum of 28 °C), while in B salinity is more variable (minimum of 18.8 S and maximum of 33.6) (Silva-Junior *et al*., 2016). The SD value of quadrant C6 differs from the rest of the quadrants of A, being the only one with SD lower than 3.0. As salinity does not vary considerably within this group, this low value is probably related to the fact that this location has been the subject of few studies and is not a BioTecPesca collection point, resulting in a lower sampling of this quadrant. In B, the F4 quadrant presented SD values lower than the rest (1.63 sp/km^2). In this case, lower SD values are probably caused by both a methodological factor (all records come from source 63) and to the innermost position of this quadrant, which makes it difficult for species that do not support lower salinities to inhabit.

Lower salinities may also play a role on the low S and SD values recorded in the upper estuary compartment, preventing marine coastal species from accessing the innermost part of the bay (Nybakken, Bertness, 2005; Silva-Junior *et al*., 2016; Souza, Vianna, 2022). Another important factor is that the upper estuary is the most environmentally impacted portion of the bay. In addition to receiving pollutants from rivers (*e.g*., untreated sewage and inorganic pollutants), natural water renewal is slow, resulting in low environmental quality anoxic zones. (Fistarol *et al*., 2015). However, two quadrants (E3 and C3) stood out with much higher S and SD values than the rest of the upper estuary. The absolute richness of 73 species found in E3 may be a result of the influence of the central channel during drought periods, when more saline waters advance to more inland estuarine regions, and the wide variety of habitats associated with the Paquetá island located in that region. Quadrant C3, on the other hand, is relatively far from the central channel and has no islands. The high S and SD values of C3 are thereby more likely to be related to collection efforts, as C3 was a BioTecPesca collection point. It also might be noteworthy that, both quadrants with higher S and SD values are within the influence of Protected Areas (Fig. 1). Quadrant E3 is very close to the APA Guapimirim, while the Barão de Mauá Municipal Natural Park is located on C3's coast. These Protected Areas may be relieving local anthropic impacts such as over-fishing, allowing for a higher number of species to be recorded in its vicinities.

Our results also suggest that temporal changes in the composition of Guanabara Bay's ichthyofauna occurred over the decades. As much as the absence of records between 2010 and 2020 is indicative of local extinction or at least of abundance reduction of species, more studies are still required to confirm this situation as shown by the recent records of *Rhizoprionodon lalandii* and *Bagre bagre* in 2022. Among the 84 species unrecorded from

2010 to 2020 (Tab. 5), 81% are not estuarine-dependent. Thus, the lack of more recent records for this non-dependent species may be due to their non-obligatory relation with the estuary coupled with declining environmental conditions. Another factor to be considered is the habitat of those species since there is a lack of recent studies in more consolidated substrate regions in the interior of the bay.

The decreased sampling efforts by BioTecPesca is especially important when it comes to the species last recorded between 1990 and 2010. The main sampling method used by BioTecPesca was bottom trawling, which results mostly in the capture of demersal species of unconsolidated substrate. Therefore, pelagic species like *Hemicaranx amblyrhynchus* (Cuvier, 1833), *Rhinoptera bonasus*, *Rhizoprionodon lalandii*, *R. porosus*, and *Syngnathus pelagicus* Linnaeus, 1758 would not be easily captured, so that their local extinction cannot be attested. This hypothesis is again supported by the new record of *R. lalandii* since this species was previously only recorded in 1997 but was captured by fisherman in 2022. Furthermore, collections made by BioTecPesca in 2013 and 2014 were less numerous and covered fewer locations when compared to the period between 2005 to 2007, thus hampering more recent records of species that do not commonly appear in scientific papers and are not recorded in fishing landings.

However, of the 70 species last recorded between 1990 and 2010, six are at risk of extinction at the global level (*Mycteroperca microlepis* (Goode & Bean, 1879), *Paralichthys patagonicus* Jordan, 1889, *Pseudobatos percellens*, *Rhinoptera bonasus, Rhizoprionodon lalandii*, and *R. porosus*), two are threatened at the national level (*Hippocampus reidi* Ginsburg, 1933 and *Hyporthodus nigritus* (Holbrook, 1855)) and nine are threatened at both levels (*Epinephelus itajara* (Lichtenstein, 1822), *E. marginatus*, *E. morio* (Valenciennes, 1828), *Hippocampus erectus* Perry, 1810, *Hyporthodus niveatus* (Valenciennes, 1828), *Pristis pristis*, *Pseudobatos horkelii*, *Sphyrna zygaena*, and *S. tiburo*). For those species, abundance reduction at some level is likely to have occurred at Guanabara Bay. Considering the large number of studies and collections carried out after 1990, local extinction or great abundance reduction are also very likely to have occurred for the 13 species last recorded before 1990. These species span a wide functional range including pelagic and demersal species which are dependent or not dependent on the estuary.

Another worrying result recovered in this survey is that of the 17 elasmobranchs species, 10 (58.8%) were not recorded between 2010 and 2020. A well-documented case of elasmobranch regional extinction is the sawfish *Pristis pristis*, formerly occurring from northern Brazil to São Paulo and now restricted to the northern regions of Brazil (Fernandez-Carvalho *et al*., 2013). The disappearance of high trophic level predators is of concern for biodiversity conservation, as these animals play an important role in the ecosystem regulating prey populations. Besides, estuaries are extremely important for sharks and rays, serving both as a feeding area and as nursery grounds (Gonçalves-Silva, Vianna, 2018a; Plumlee *et al*., 2018). Signs of population reduction for these species in a large estuary such as Guanabara Bay may indicate the decline of elasmobranch populations throughout southeastern Brazil.

Even though Guanabara Bay still has a relatively rich ichthyofauna, with wide taxonomic and functional fish diversity, the implementation of management and conservation actions are paramount to reduce the loss of the biological richness recorded in our study in the more recent decades. There is a need for improvement of the environmental quality of the bay and adjacent regions. Many urban centers around the bay still dump untreated sewage in the estuary (Elk *et al*., 2022), and therefore it is necessary to expand the sewage collection network that leads the waste to sewage treatment centers. Other important action is the promotion of fisheries management measures focused on sustainable practices. We recommend the prohibition of bottom trawling at Guanabara Bay, since it is an extremely impactful fishing technique that is already forbidden in many Brazilian estuaries. Lastly, our results highlighted the potential of Protected Areas to promote fish species conservation. Our results indicate that Guanabara Bay would benefit largely from the establishment of new protected areas aimed to preserve mangrove ecosystems in its area. Mangroves serve as nursery grounds for many fish species, including highly threatened elasmobranchs, hence reforestation efforts would improve species recovery and promote the conservation of the bay's ichthyofauna.

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AUTHORS' CONTRIBUTION

Clara V. Teixeira-Leite: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Writing-original draft, Writing-review and editing.

Marcelo Vianna: Conceptualization, Methodology, Project administration, Resources, Supervision, Validation, Writing-review and editing.

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