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ORIGINAL ARTICLE

The bycatch of piramutaba, *Brachyplatystoma vaillantii* industrial fishing in a salinity and depth gradient in the Amazon estuary, Brazil

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ABSTRACT

The piramutaba, *Brachyplatystoma vaillantii* is a freshwater catfish that is the most abundant fishery resource in the Amazon estuary. Piramutaba trawling is done on industrial fishing scale and is characterized by the presence of many freshwater and marine bycatch species, with and without commercial value. Here we describe the bycatch of the industrial fishery of piramutaba in the Amazon estuary and evaluate the relationship of two important environmental factors, depth and salinity, with the accidental capture of freshwater and marine fishes in the Amazon estuary in the rainy and dry seasons. We identified 21 cartilaginous fish species (19.1% freshwater and 80.9% marine) and 125 bony fish species (25.6% freshwater and 74.4% marine). The bycatch included 64 species without commercial value (43% of all bycatch species), which are always discarded. Freshwater and estuarine fishes exhibited significantly higher abundances in shallower environments, while marine fishes were similarly abundant along the entire depth gradient. On the contrary, the abundance of freshwater fishes significantly decreased, and that of estuarine and marine fishes significantly increased with increasing salinity. Regarding the conservation status of the bycatch species, one is classified as vulnerable (VU), and seven as critically endangered (CR). The information on the bycatch of piramutaba fishery in the Amazon estuary is important to subsidize regional fisheries policies and the management of protected areas.

KEYWORDS: freshwater, marine, environmental factors

A captura incidental na pesca industrial da piramutaba, *Brachyplatystoma vaillantii* em um gradiente de salinidade e profundidade no estuário do Amazonas, Brasil

RESUMO

A piramutaba, *Brachyplatystoma vaillantii* é um bagre de água doce que representa o recurso pesqueiro mais abundante no estuário amazônico. O arrasto da piramutaba é feito em escala industrial, caracterizado pela presença de muitas espécies de água doce e marinha capturadas de forma incidental, com e sem valor comercial. Aqui descrevemos a captura incidental da pesca industrial de piramutaba no estuário amazônico e avaliamos a relação de dois fatores ambientais, profundidade e salinidade, com a captura incidental de espécies de água doce e marinhas nas estações chuvosa e seca. Identificamos 21 espécies de peixes cartilaginosos (19,1% de água doce e 80,9% marinhos) e 125 espécies de peixes ósseos (25,6% de água doce e 74,4% marinhos). A captura incidental incluiu 64 espécies sem valor comercial (43% de todas as espécies capturadas) que sempre são descartadas. Os peixes de água doce e estuarinos exibiram abundâncias significativamente maiores em ambientes mais rasos, enquanto os peixes marinhos foram igualmente abundantes ao longo de todo o gradiente de profundidade. Inversamente, a abundância de peixes de água doce diminuiu significativamente, e a de peixes estuarinos e marinhos aumentou significativamente em salinidades maiores. Em relação ao estado de conservação das espécies capturadas, uma é reconhecida como vulnerável (VU) e sete como criticamente ameaçadas (CR). As informações sobre a captura incidental da pesca da piramutaba no estuário amazônico são fundaentais para subsidiar políticas pesqueiras regionais e gestão de áreas protegidas.

PALAVRA-CHAVE: água doce, marinho, fatores ambientais

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INTRODUCTION

The piramutaba, *Brachyplatystoma vaillantii* (Siluriformes: Pimelodidae) is a freshwater catfish that is the most abundant fishery resource of the Amazon estuary, formed by a panmitic population along the Solimões-Amazonas River (Barthem and Goulding 1997; Formiga *et al.* 2021). This catfish is explored by artisanal fisheries using gillnets and long lines and industrial fisheries using pair or triple trawling (Barthem, and Goulding 1997; Ruffino 2003). The industrial fishery of the piramutaba began in 1971 with the use of adapted shrimp boats (Silva *et al.* 2016), reached the largest landing (22,486 tonnes) in 1977, and occupied the ninth place on the list of exportation goods from Pará state, Brazil by 1980 (Dias-Neto *et al.* 1985; Barthem 1990; Dias-Neto 1991; Prestes *et al.* 2022). The piramutaba trawl fishery is limited to the Amazon estuary facing the Marajó Island and the coast of state of Amapá coast, Brazil (Prestes *et al.* 2022), a region characterized by the extensive input of sediments by the Amazon River (Geyer *et al.* 1996), with enormous oscillation in the discharge of the Amazon River, which, at its peak in May-June, more than doubles the minimum discharge, which occurs in November (Guimberteau *et al.* 2012). The region is located between the North Cape (01º42'S and 49º55'W) and the Maguari Cape (00º15'S and 48º25'W) (Figure 1), encompassing a 80-mile coastline stretch with a depth range between 3 and 20 m (Santos *et al.* 1984; Dias-Neto *et al.* 1985).

The great economic importance of the piramutaba fishery led to many scientific studies on the species, including topics such as migration (Godoy 1979; Barthem and Goulding 1997; Duponchelle *et al.* 2021), age and growth determination (Barthem and Petrere 1995; Alonso and Pirker 2005), genetic variability (Rodrigues 2009; Batista *et al.* 2005), fishing stock (Barthem 1990; Barthem and Petrere 1995; Chaves *et al.* 2003; Alonso and Pirker 2005; Barthem *et al.* 2015), gear selectivity (Barthem 1998; Furtado Junior *et al.* 2013), and fisheries management (Klautau *et al.* 2016a; Prestes *et al.* 2022). The knowledge on the biodiversity of the bycatch produced during the paired trawling, however, is still poor and marred by dubious species identifications (Barthem 1985; Jimenez *et al.* 2013; Silva *et al.* 2016; Klautau *et al.* 2016b) which is further complicated by the absence of voucher material from bycatch surveys (AP Marceniuk, personal observation).

Trawling has low selectivity, therefore producing a high proportion of accidental captures (Perez and Pezzuto 1998; Diamond *et al.* 2000) of species with and without commercial value, the latter being discarded (Alverson *et al.* 1994; Clucas 1998). Accidental captures may have a significant impact on local biodiversity (Clucas 1997) by altering the community structure and food webs (Anderson *et al.* 2013), which makes trawling management challenging (Davies *et al.* 2009). The correct identification of the bycatch is fundamental for establishing the guidelines for fisheries zonation, which should be based on all the populations affected by the activity (sensu Manthey and Fridley 2009). Therefore, the incomplete knowledge of the fish diversity of the bycatch of the piramutaba industrial fishery hampers the development of effective protection measures for the local fauna and the management of the ecosystems affected by the activity (Thrush *et al.* 1998; Greenstreet and Rogers 2004; Juan and Demestres 2012).

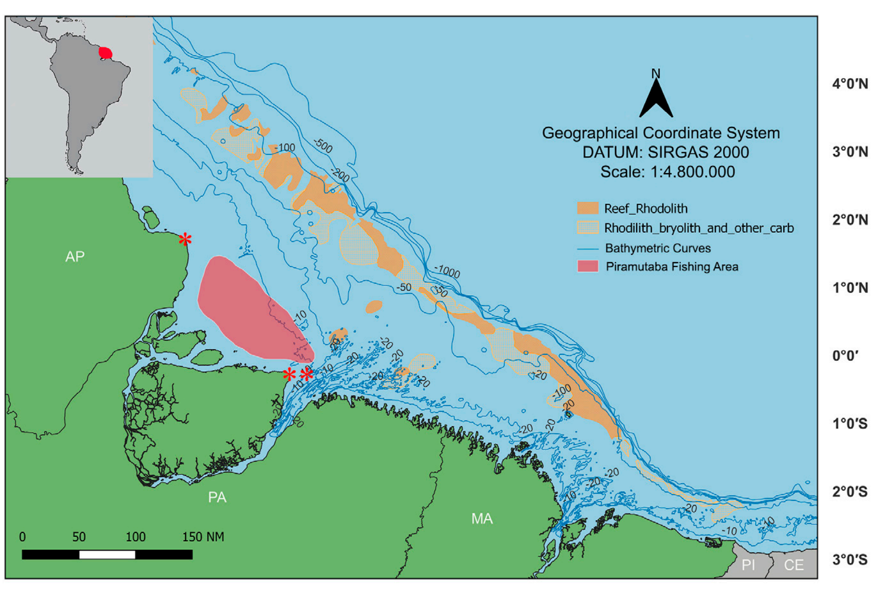

Figure 1. Location of the Amazon estuary (small map, in red) and detailment of the study area between North Cape (one asterisk) and Maguari Cape (two asterisks) by the mouth of the Amazon River. This figure is in color in the electronic version.

In this study, we describe the bycatch of the industrial fishery of the piramutaba in the Amazon estuary by integrating secondary data from the literature with primary data from the Japan International Cooperation Agency (JICA), the Centro Nacional de Pesquisa e Conservação da Biodiversidade Marinha do Norte (CEPNOR-ICMBIO), and personal databases from collaborators. Considering that salinity and depth were the main forces that structured the distribution patterns of species in the Ariidae family in the Amazon estuary (Soares *et al.* 2021), we analyzed the influence of these two factors considering the abundance of all fish captured by trawls in the same area. For this, we grouped the fish into three groups, marine, estuarine and freshwater, and tested the abundance of these groups in response to salinity and depth in the periods of the year when the discharge of the Amazon River is maximum and minimum.

MATERIAL AND METHODS

Study area

The study area was undertaken in the inner estuary of the Amazon River mouth, in the fishing area of the Brazilian bottom pair trawler fleet (Figure 1). The area is characterized by the shallow muddy bottom and the dynamism of the mixture of the freshwater of the Amazon River and the marine water (Curtin and Legeckis 1986; Eisma and Marel 1971). The annual discharge cycle of the Amazon River ranges from 230×103 m^3 s^{-1} in the first half of the year to 103×103 m^3 s^{-1} in the second half (Guimberteau *et al.* 2012) and causes the displacement of wedge salt along the shelf of the Amazon mouth, being the most critical force acting on the salinity structure of the plume (Geyer *et al.* 1996). The dry season is marked by the arrival of brackish waters to the coast in May, and by the predominance of fresh waters from December (Barthem and Schwassmann 1994).

Database

We compiled a species list of bycatch from available data of published studies on the bycatch of the industrial outrigger trawling fleet of the North coast do Brazil (Barthem 1985; Jimenez *et al.* 2013; Silva *et al.* 2016; Klautau *et al.* 2016), primary data from the Japan International Cooperation Agency (JICA) from 1996 to 1997, and Research and Conservation National Center of Northern Marine Biodiversity (CEPNOR, Brazil) from 2016 to 2020.

The collections by JICA, Museu Paraense Emilio Goeldi (MPEG), and Instituto Brasileiro do Meio Ambiente e dos Recursos Naturais Renováveis (IBAMA) were performed between 1996 and 1997, sampling in an area divided into 1330 blocks of 3′ latitude by 3′ longitude each and nearly nine square nautical miles in total. Samplings were carried out during three trawling expeditions in the dry period of 1996 (August to September), the rainy period of 1997 (March to April), and the dry period of 1997 (August to September). Each seasonal survey comprised 120 trawling stations distributed randomly and proportionally to the area of three strata of isobaths: 5–10 m, 10–20 m, and 20–50 m. In each station, fishes were sampled by bottom trawling conducted by a pair of vessels operating for 30 min along the current direction at a constant 2–3 knots speed. Standardized trawls were carried out at daytime by trawlers equipped with bottom trawl nets of 58.2 m length and 14 cm between opposite knots, with all collected specimens identified and counted.

The collections by CEPNOR were carried out under SISBIO license # 44915-7 and all species collected by CEPNOR are represented by voucher specimens in the ichthyological collection of Museu Paraense Emílio Goeldi (MPEG) in Belém (Pará, Brazil), the zoological collection of Universidade Santa Cecília at Santos (AZUSC) in Santos (São Paulo, Brazil), and the Laboratory of Fish Biology and Genetics (LBP) at Universidade Estadual Paulista Júlio de Mesquita in Botucatu (São Paulo, Brazil). Images and voucher numbers of all marine species captured by CEPNOR are available in Marceniuk *et al.* (2020; 2021a).

Species were identified using the descriptions and collection keys provided by Van Der Sleen and Albert (2017) and Marceniuk *et al.* (2021a). Species were further classified as primary marine, estuarine, or freshwater following Nelson (2016) and as pelagic, demersal, or benthonic following Marceniuk *et al.* (2021b). The market value for the piramutaba and all other bycatch was obtained at Ver-o-Peso Market (Belém, Pará state, Brazil) by WSRS, APM and JPRJ. The conservation status of the species followed the Red Book of the Brazilian Fauna Threatened with Extinction (ICMBio, 2018), and its updates (MMA 2022).

Depth and salinity information were obtained during the sea-borne survey in the Amazon River Mouth by JICA, concomitantly with the collection of the primary data on fish composition. Salinity was measured from the surface to the bottom with an STD (Alec Denshi AST200PK STD, salinity measuring capability 0–40 ‰, depth range 0–200 m, measurement distance 0.2 m).

Statistical analysis

We evaluated the importance of seasonality and two environmental variables (depth and salinity) to the abundance of freshwater, estuarine, and marine fish using the data sampled by JICA between 1996 and 1997. As the data distribution was heteroscedastic (according to Levene's test), we used the Kruskal-Wallis H test to evaluate differences in the abundance of freshwater, estuarine, and marine fish between the rainy and dry seasons. We then evaluated the importance of depth (average depth at hauling) and salinity (average salinity at hauling) to the average abundance of freshwater, estuarine, and marine fishes by fitting generalized additive models (GAMs) integrating a smoothing parameter to consider the nonlinear relationship of the variables. GAMs were performed using the default *gam* function from the *mgcv* package (Wood 2011) in the R environment (R Core Team 2021). All analyses considered a 5% level of significance.

RESULTS

Bycatch species composition

We identified 21 sharks and batoids from 10 taxonomic families and five orders (Table 1; Figure 2a), with four freshwater species (19.1%), and 17 marine species (80.9%). The richest order among the elasmobranchs was Myliobatiformes, with 11 species, four associated with freshwater, and seven with marine environments (Table 1). The richest family among cartilaginous fishes was Potamotrygonidae, including five species, four associated with freshwater (Table 1). Regarding habitat use, 12 cartilaginous species were benthonic (i.e., associated with the substrate), and nine were pelagic or demersal (i.e., actively swimming in the water column) (Table 1). *Isogomphodon oxyrhynchus, Fontitrygon geijskesi*, *Plesiotrygon iwamae* (Figure 3a), *Potamotrygon humerosa* (Figure 3b), *Potamotrygon scobina* (Figure 3d) and *Styracura schmardae* are endemic to the area of influence of the Amazon-Orinoco plume and its drainages (Table 1).

Regarding bony fishes, we identified 125 species (Table 1; Figure 2b) of 40 families and 18 orders. Thirty-two species were from freshwater (25.6%), and 93 were marine (74.4%) (Table 1). The richest order of Teleostei was Siluriformes, with 34 species, 23 of them associated with freshwater, belonging to the families Aspredinidae (Figure 3h,i), Auchenipteridae (Figure 3l-n), Doradidae (Figure 3j,k), Heptapteridae and Pimelodidae (Figure 3o-t), and 11 associated with marine environments belonging to the family Ariidae. The second richest taxonomic order of bony fishes was Acanthuriformes, including 20 species of Sciaenidae, mainly associated with marine environments (18 vs. two freshwater species, Table 1). Most of the captured teleosteans were pelagic or demersal (112 species), and only 19 were benthonic, primarily Gobiiformes and Pleuronectiformes (Table 1). Thirty-three (26.4%) of the captured bony fish species were endemic (Table 1).

The bycatch included 64 species (43% of all bycatch species) with no commercial value (Figure 2c), which are always discarded, and 81 species (57%) with some commercial value (Table 1). Among the latter, nine were more valuable than piramutaba, 11 had similar value to piramutaba, and 61 had lower value than piramutaba and were only occasionally traded (Table 1). Regarding the conservation status of the bycatch species (Figure 2d), 109 (74.7%) were classified as safe or least concern (LC), six as near threatened (NT), one as vulnerable (VU), and seven as critically endangered (CR) (Table 1). Among the critically endangered species, six were cartilaginous fishes, including the endemic *Isogomphodon oxyrhynchus,* the sawfish *Pristis pristis* and three species of hammerhead sharks (*Sphyrna*), and only one was a bony fish, the Atlantic goliath grouper, *Epinephelus itajara*. We highlight that 23 of the identified species were not evaluated (NE) or data deficient (DD), eight of them endemic to the area (Table 1).

Effect of depth and salinity

The standardized samples obtained by JICA occurred in sites with depth ranging from 6 to 50 m, and salinity near the substrate ranging from 0.05 to 36 ppm. The occurrence and abundance of freshwater, estuarine, and marine fishes between the seasons and along the depth and salinity gradients was not random. While estuarine fishes did not differ in abundance

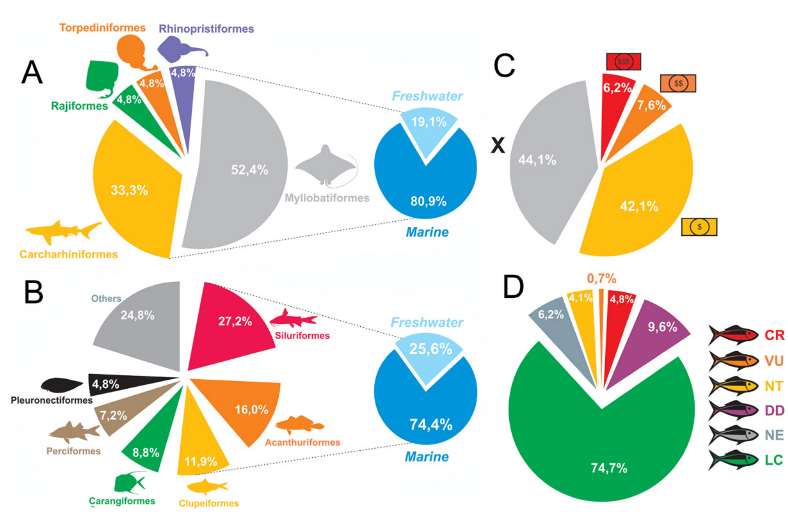

Figure 2. Composition of the bycatch of piramutaba fisheries in the Amazon estuary, northern coast of Brazil. A – Taxonomic and marine-estuarine/freshwater composition (%) of Elasmobranchii; B – Taxonomic and marine-estuarine/freshwater composition (%) of Teleostei; C – Economic value of the by-catch species: higher than *Brachyplatystoma vaillantii* (red), equal to *B. vaillantii* (orange), lower than *B. vaillantii* (yellow), no commercial value (grey); D – Conservation status: critically endangered (CR), vulnerable (VU), near threatened (NT), data deficient (DD), not evaluated (NE), least concern (LC). This figure is in color in the electronic version.

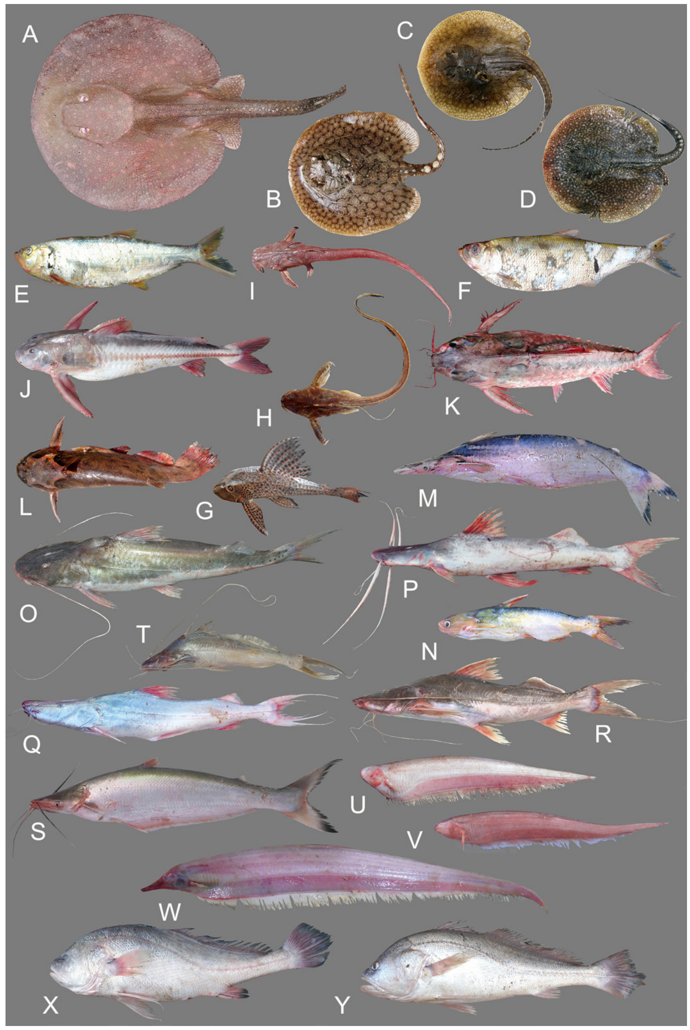

Figure 3. Freshwater batoids and bony fishes captured as bycatch of piramutaba fisheries in the Amazon estuary, northern coast of Brazil. Order Myliobatiformes, family Potamotrygonidae: A – *Plesiotrygon iwamae* (broken caudal fin); B – *Potamotrygon humerosa*; C – *Potamotrygon orbignyi*; D – *Potamotrygon scobina*. Order Clupeiformes, family Pristigasteridae: E – *Pellona castelnaeana*; F – *Pellona flavipinnis*. Order Siluriformes, family Loricariidae: G – *Aphanotorulus emarginatus*; family Aspredinidae: H – *Aspredinichthys filamentosus*; I – *Aspredo aspredo*; family Doradidae: J – *Centrodoras brachiatus*; K – *Lithodoras dorsalis*; family Auchenipteridae: L – *Trachelyopterus galeatus*; M – *Ageneiosus ucayalensis*; N – *Pseudauchenipterus nodosus*; family Pimelodidae: O – *Brachyplatystoma filamentosum*; P – *Brachyplatystoma platynemum*; Q – *Brachyplatystoma rousseauxii*; R – *Brachyplatystoma vaillantii*; S – *Hypophthalmus edentatus;* T – *Propimelodus eigenmanni*. Order Gymnotiformes, family Apteronotidae: U – *Sternarchella schotti*; V – *Sternarchella sima*; W – *Sternarchorhamphus muelleri*. Order Acanthuriformes, family Sciaenidae: X – *Plagioscion auratus*; Y – *Plagioscion squamosissimus*. This figure is in color in the electronic version.

Table 1. Sharks, batoids and bone fishes caught as bycatch of piramutaba fishery in the Amazon estuary, on the northern coast of Brazil. Orders and families are ordered alphabetically. Figure = in Marceniuk *et al*. (2019) (*), in Marceniuk *et al*. (2021a) (**), or in present study (without asterisk). Species list = published and unpublished species surveys where the soecies is listed: Barthem (1985) (A), Jimenez *et al*. (2013) (B), Silva *et al*. (2016) (C), Klautau *et al*. (2016) (D), JICA (E), CEPNOR onboard observers (F). Comm value = commercial value: target species (A), commercial value higher than target species (>), commercial value lower than target species (<), equal commercial value equal to target species (=), no commercial value (*). Habitat: freshwater (FW), brackish water (BW), marine and estuarine (M). Habit: pelagic (I), demersal (J), benthic (K). End = endemic to the influence area of the Amazonian-Orinoco plume and its drainages. Status = conservation status in the Brazilian List of Endangered Fauna (ICMBio 2018): CR = critically endangered (CR), vulnerable (V), near threatened (NT), least concern (LC), data deficient (DD), not evaluated (X).

Order	Family	Species	Figure	Species list						Comm value	Habitat	Habit			End	Status
				A	B	C	D	E	F			I	J	K		
Carcharhiniformes	Carcharhinidae	*Carcharhinus leucas* (Valenciennes, 1839)		X				X		<	M	X	X			NT
Carcharhiniformes	Carcharhinidae	*Carcharhinus limbatus* (Valenciennes, 1839)	*Fig. 3e	X				X	X	<	M	X	X			NT
Carcharhiniformes	Carcharhinidae	*Carcharhinus porosus* (Ranzani, 1839)		X				X	X	<	M	X	X			CR

Table 1. Continued.

Order	Family	Species	Figure	Species list						Comm value	Habitat	Habit			End	Status
				A	B	C	D	E	F			I	J	K		
Carcharhiniformes	Carcharhinidae	*Isogomphodon oxyrhynchus* (Müller & Henle, 1839)	*Fig. 4a	X				X	X	*	M		X		X	CR
Carcharhiniformes	Sphyrnidae	*Sphyrna lewini* (Griffith & Smith, 1834)	*Fig. 4d						X	<	M	X	X			CR
Carcharhiniformes	Sphyrnidae	*Sphyrna tiburo* (Linnaeus, 1758)	*Fig. 4f					X	X	<	M	X	X			CR
Carcharhiniformes	Sphyrnidae	*Sphyrna tudes* (Valenciennes, 1822)		X				X	X	<	M	X	X			CR
Torpediniformes	Narcinidae	*Narcine brasiliensis* (Olfers, 1831)	*Fig. 5c					X	X	*	M			X		DD
Rhinopristiformes	Pristidae	*Pristis pristis* (Linnaeus, 1758)	*Fig. 2a	X					X	<	M			X		CR
Myliobatiformes	Dasyatidae	*Fontitrygon geijskesi* (Boeseman, 1948)	*Fig. 2f		X			X	X	<	M/BW			X	X	DD
Myliobatiformes	Dasyatidae	*Hypanus berthalutzae* Petean, Naylor & Lima, 2020	*Fig. 5j							<	M			X		DD
Myliobatiformes	Dasyatidae	*Hypanus guttatus* (Bloch & Schneider, 1801)	*Fig. 5k	X		X	X	X	X	<	M			X		LC
Myliobatiformes	Gymnuridae	*Gymnura micrura* (Bloch & Schneider, 1801)	*Fig. 6e-f					X	X	*	M			X		NT
Myliobatiformes	Myliobatidae	*Aetobatus narinari* (Euphrasen, 1790)	*Fig. 6g					X	X	<	M	X	X			DD
Myliobatiformes	Potamotrygonidae	*Plesiotrygon iwamae* Rosa, Castello & Thorson, 1987	Fig. 3a						X	<	FW			X	X	NT
Myliobatiformes	Potamotrygonidae	*Potamotrygon humerosa* Garman, 1913	Fig. 3b						X	<	FW			X	X	DD
Myliobatiformes	Potamotrygonidae	*Potamotrygon orbignyi* (Castelnau, 1855)	Fig. 3c						X	<	FW			X		LC
Myliobatiformes	Potamotrygonidae	*Potamotrygon scobina* Garman, 1913	Fig. 3d			X	X		X	<	FW			X	X	LC
Myliobatiformes	Potamotrygonidae	*Styracura schmardae* (Werner, 1904)	*Fig. 6d						X	<	M/BW			X	X	DD
Myliobatiformes	Urotrygonidae	*Urotrygon microphthalmum* Delsman, 1941	*Fig. 5i						X	<	M			X		DD
Rajiformes	Rhinopteridae	*Rhinoptera bonasus* (Mitchill, 1815)	*Fig. 6i					X	X	<	M	X				DD
Elopiformes	Elopidae	*Elops smithi* McBride *et al.* 2010	** pg. 81	X				X	X	<	M	X	X			LC
Elopiformes	Megalopidae	*Megalops atlanticus* Valenciennes, 1847	** pg. 83	X			X	X		<	M/BW	X				VU
Anguilliformes	Ophichthidae	*Ahlia egmontis* (Jordan, 1884)						X	X	*	M			X		LC
Anguilliformes	Muraenesocidae	*Cynoponticus savanna* (Bancroft, 1831)	**pg. 117						X	*	M		X			LC
Anguilliformes	Moringuide	*Neoconger sp.*	**pg. 127						X	*	M		X		X	X
Clupeiformes	Pristigasteridae	*Chirocentrodon bleekerianus* (Poey, 1867)	**pg. 131						X	*	M	X				LC
Clupeiformes	Pristigasteridae	*Odontognathus mucronatus* Lacepède, 1800	**pg. 132					X	X	*	M	X				LC
Clupeiformes	Pristigasteridae	*Pellona castelnaeana* Valenciennes, 1847	Fig. 3e						X	<	FW	X			X	LC
Clupeiformes	Pristigasteridae	*Pellona flavipinnis* (Valenciennes, 1837)	Fig. 3f	X	X	X	X	X	X	<	FW	X				LC
Clupeiformes	Pristigasteridae	*Pellona harroweri* (Fowler, 1917)	**pg. 133					X	X	<	M	X				LC

Table 1. Continued.

Order	Family	Species	Figure	Species list						Comm value	Habitat	Habit			End	Status
				A	B	C	D	E	F			I	J	K		
Clupeiformes	Engraulidae	*Anchoa januaria* (Steindachner, 1879)	**pg. 137						X	*	M/BW	X				LC
Clupeiformes	Engraulidae	*Anchoa spinifer* (Valenciennes, 1848)	**pg. 140	X				X	X	*	M/BW	X				LC
Clupeiformes	Engraulidae	*Anchovia clupeoides* (Swainson, 1839)	**pg. 141				X			*	M/BW	X				LC
Clupeiformes	Engraulidae	*Anchoviella cayennensis* (Puyo, 1945)	**pg. 144	X						*	M/BW	X				LC
Clupeiformes	Engraulidae	*Anchoviella lepidentostole* (Fowler, 1911)	**pg. 147					X		*	M/BW	X				LC
Clupeiformes	Engraulidae	*Lycengraulis batesii* (Günther, 1868)	**pg. 149	X				X		*	FW/BW	X			X	LC
Clupeiformes	Engraulidae	*Lycengraulis grossidens* (Spix & Agassiz, 1829)	**pg. 150							*	M/BW	X				LC
Clupeiformes	Clupeidae	*Opisthonema oglinum* (Lesueur, 1818)	**pg. 156					X	X	*	M	X				LC
Clupeiformes	Clupeidae	*Sardinella aurita* Valenciennes, 1847							X	*	M	X				DD
Siluriformes	Loricariidae	*Aphanotorulus emarginatus* (Valenciennes, 1840)	Fig. 3g	X					X	*	FW			X		X
Siluriformes	Loricariidae	*Hypostomus punctatus* Valenciennes, 1840			X					*	FW			X		LC
Siluriformes	Ariidae	*Amphiarius rugispinis* (Valenciennes, 1840)	**pg. 162	X		X	X	X		<	M				X	LC
Siluriformes	Ariidae	*Amphiarius phrygiatus* (Valenciennes, 1840)	**pg. 163	X	X			X	X	<	M/BW		X		X	LC
Siluriformes	Ariidae	*Aspistor quadriscutis* (Valenciennes, 1840)	**pg. 164		X	X	X	X	X	<	M/BW		X		X	LC
Siluriformes	Ariidae	*Bagre bagre* (Linnaeus, 1766)	**pg. 165	X	X	X		X	X	<	M		X			NT
Siluriformes	Ariidae	*Cathorops arenatus* (Valenciennes, 1840)	**pg. 167					X	X	<	M		X		X	LC
Siluriformes	Ariidae	*Cathorops spixii* (Agassiz, 1829)	**pg. 168	X	X		X		X	<	M/BW		X			LC
Siluriformes	Ariidae	*Notarius grandicassis* (Valenciennes, 1840)	**pg. 169	X	X		X	X	X	<	M		X		X	LC
Siluriformes	Ariidae	*Sciades couma* (Valenciennes, 1840)	**pg. 170	X				X	X	<	M/BW		X		X	DD
Siluriformes	Ariidae	*Sciades herzbergii* (Bloch, 1794)	**pg. 171		X					<	M		X		X	LC
Siluriformes	Ariidae	*Sciades parkeri* (Trail, 1832)	**pg. 172	X	X	X	X	X	X	>	M		X		X	LC
Siluriformes	Ariidae	*Sciades proops* (Valenciennes, 1840)	**pg. 174	X	X	X	X	X	X	<	M		X		X	DD
Siluriformes	Aspredinidae	*Aspredinichthys filamentosus* (Valenciennes, 1840)	Fig. 3h	X				X	X	*	FW			X	X	LC
Siluriformes	Aspredinidae	*Aspredo aspredo* (Linnaeus, 1758)	Fig. 3i	X	X	X	X		X	*	FW			X	X	LC
Siluriformes	Doradidae	*Centrodoras brachiatus* (Cope, 1872)	Fig. 3j	X				X	X	<	FW		X		X	LC
Siluriformes	Doradidae	*Lithodoras dorsalis* (Valenciennes, 1840)	Fig. 3k	X	X	X	X		X	<	FW		X		X	LC
Siluriformes	Doradidae	*Pterodoras granulosus* (Valenciennes, 1821)			X		X			<	FW		X			LC

Table 1. Continued.

Order	Family	Species	Figure	Species list						Comm value	Habitat	Habit			End	Status
				A	B	C	D	E	F			I	J	K		
Siluriformes	Auchenipteridae	*Trachelyopterus galeatus* (Linnaeus, 1766)	Fig. 3l						X	<	FW	X				LC
Siluriformes	Auchenipteridae	*Ageneiosus inermis* (Linnaeus, 1766)			X					<	FW	X				LC
Siluriformes	Auchenipteridae	*Ageneiosus ucayalensis* Castelnau, 1855	Fig. 3m	X		X	X	X	X	*	FW	X			X	LC
Siluriformes	Auchenipteridae	*Pseudauchenipterus nodosus* (Bloch, 1794)	Fig. 3n					X	X	*	FW		X		X	LC
Siluriformes	Heptapteridae	*Pimelodella altipinnis* (Steindachner, 1864)				X	X			*	FW		X		X	X
Siluriformes	Heptapteridae	*Pimelodella cristata* (Müller & Troschel, 1849)			X					*	FW		X			LC
Siluriformes	Pimelodidae	*Brachyplatystoma filamentosum* (Lichtenstein, 1819)	Fig. 3o	X	X	X	X	X	X	>	FW		X		X	LC
Siluriformes	Pimelodidae	*Brachyplatystoma platynemum* Boulenger, 1898	Fig. 3p	X	X	X	X		X	<	FW		X		X	LC
Siluriformes	Pimelodidae	*Brachyplatystoma rousseauxii* (Castelnau, 1855)	Fig. 3q		X	X	X		X	>	FW		X		X	LC
Siluriformes	Pimelodidae	*Brachyplatystoma vaillantii* (Valenciennes, 1840)	Fig. 3r	X				X	X	A	FW		X		X	LC
Siluriformes	Pimelodidae	*Hypophthalmus edentatus* Spix & Agassiz, 1829	Fig. 3s			X	X		X	*	FW		X		X	LC
Siluriformes	Pimelodidae	*Hypophthalmus marginatus* Valenciennes, 1840			X					*	FW		X		X	LC
Siluriformes	Pimelodidae	*Pimelodus blochii* Valenciennes, 1840		X			X			*	FW		X		X	LC
Siluriformes	Pimelodidae	*Pinirampus pirinampu* (Spix & Agassiz, 1829			X					*	FW		X			LC
Siluriformes	Pimelodidae	*Propimelodus eigenmanni* (van der Stigchel, 1946)	Fig. 3t				X		X	*	FW		X		X	LC
Siluriformes	Pimelodidae	*Zungaro zungaro* (Humboldt, 1821)		X				X		=	FW		X		X	LC
Gymnotiformes	Apteronotidae	*Sternarchella schotti* (Steindachner, 1868)	Fig. 3u						X	*	FW		X			LC
Gymnotiformes	Apteronotidae	*Sternarchella sima* Starks, 1913	Fig. 3v						X	*	FW		X			LC
Gymnotiformes	Apteronotidae	*Sternarchorhamphus muelleri* (Steindachner, 1881)	Fig. 3w						X	*	FW		X		X	LC
Gymnotiformes	Sternopygidae	*Eigenmannia virescens* (Valenciennes, 1836)			X					*	FW		X			LC
Batrachoidiformes	Batrachoididae	*Batrachoides surinamensis* (Bloch & Schneider, 1801)	**pg. 203	X	X	X	X	X	X	<	M/BW			X		LC
Batrachoidiformes	Batrachoididae	*Porichthys plectrodon* Jordan & Gilbert, 1882	**pg. 208						X	*	M			X		LC
Gobiiformes	Gobiidae	*Awaous flavus* (Valenciennes, 1837)	**pg. 231	X						*	M			X		DD
Gobiiformes	Gobiidae	*Bathygobius soporator* (Valenciennes, 1837)	**pg. 233	X						*	M			X		LC
Gobiiformes	Gobiidae	*Gobioides broussonnetii* Lacepède, 1800	**pg. 243						X	*	M			X		LC
Gobiiformes	Gobiidae	*Gobioides grahamae* Palmer & Wheeler, 1955	**pg.244	X				X	X	*	M/BW			X	X	LC
Mugiliformes	Mugilidae	*Mugil brevirostris* Miranda Ribeiro, 1915	**pg. 269						X	=	M	X				X

Table 1. Continued.

Order	Family	Species	Figure	Species list						Comm value	Habitat	Habit			End	Status
				A	B	C	D	E	F			I	J	K		
Mugiliformes	Mugilidae	*Mugil curema* Valenciennes, 1836	**pg. 270	X		X	X		X	=	M	X				DD
Mugiliformes	Mugilidae	*Mugil incilis* Hancock, 1830	**pg. 272		X					=	M	X				LC
Cyprinodontiformes	Anablepidae	*Anableps microlepis* Müller & Troschel, 1844	**pg. 324	X						*	M	X				LC
Carangiformes	Echeneidae	*Echeneis naucrates* Linnaeus, 1758	**pg. 330					X	X	*	M	X				LC
Carangiformes	Carangidae	*Caranx hippos* (Linnaeus, 1766)	**pg. 341	X						<	M	X	X			LC
Carangiformes	Carangidae	*Chloroscombrus chrysurus* (Linnaeus, 1766)	**pg. 344						X	*	M	X				LC
Carangiformes	Carangidae	*Hemicaranx amblyrhynchus* (Cuvier, 1833)	**pg. 349					X	X	<	M	X				LC
Carangiformes	Carangidae	*Oligoplites palometa* (Cuvier, 1832)	**pg. 350	X	X			X	X	<	M	X				LC
Carangiformes	Carangidae	*Oligoplites saliens* (Bloch, 1793)	**pg. 351		X			X		<	M	X				LC
Carangiformes	Carangidae	*Oligoplites saurus* (Bloch & Schneider, 1801)	**pg. 352		X			X		<	M	X				LC
Carangiformes	Carangidae	*Selene setapinnis* (Mitchill, 1815)	**pg. 354					X	X	<	M	X				LC
Carangiformes	Carangidae	*Selene vomer* (Linnaeus, 1758)	**pg. 356					X	X	<	M	X				LC
Carangiformes	Carangidae	*Trachinotus carolinus* (Linnaeus, 1766)	**pg. 359					X	X	=	M	X				LC
Carangiformes	Carangidae	*Trachinotus cayennensis* Cuvier, 1832	**pg. 360					X	X	=	M	X			X	DD
Istiophoriformes	Sphyraenidae	*Sphyraena guachancho* Cuvier, 1829	**pg. 365					X	X	*	M	X				LC
Pleuronectiformes	Paralichthyidae	*Citharichthys macrops* Dresel, 1885	**pg. 381	X					X	*	M			X		LC
Pleuronectiformes	Bothidae	*Bothus robinsi* Topp & Hoff, 1972	**pg. 394					X	X	*	M/BW			X		LC
Pleuronectiformes	Achiridae	*Achirus achirus* (Linnaeus, 1758)	**pg. 397	X	X			X	X	*	M/BW			X		LC
Pleuronectiformes	Achiridae	*Achirus lineatus* (Linnaeus, 1758)	**pg. 399	X	X	X	X			*	M			X		LC
Pleuronectiformes	Achiridae	*Apionichthys dumerili* Kaup, 1858.	**pg. 400		X			X	X	*	M/BW			X	X	LC
Pleuronectiformes	Achiridae	*Trinectes paulistanus* (Miranda Ribeiro, 1915)	**pg. 403		X				X	*	M			X		LC
Scombriformes	Trichiuridae	*Trichiurus lepturus* Linnaeus, 1758	**pg. 431		X			X	X	<	M	X	X	X		LC
Scombriformes	Scombridae	*Acanthocybium solandri* (Cuvier, 1832)	**pg. 434		X					<	M	X				LC
Scombriformes	Scombridae	*Scomberomorus brasiliensis* Collette *et al.* 1978	**pg. 439	X	X			X		=	M	X				LC
Scombriformes	Scombridae	*Scomberomorus cavalla* (Cuvier, 1829)	**pg. 440						X	>	M	X				LC
Scombriformes	Stromateidae	*Peprilus crenulatus* Cuvier, 1829	**pg. 447	X				X	X	<	M	X				X
Perciformes	Centropomidae	*Centropomus irae* Carvalho-Filho *et al.* 2019	**pg. 482		X				X	>	M		X		X	X

Table 1. Continued.

Order	Family	Species	Figure	Species list						Comm value	Habitat	Habit			End	Status
				A	B	C	D	E	F			I	J	K		
Perciformes	Centropomidae	*Centropomus parallelus* Poey, 1860	**pg. 483	X	X				X	>	M		X			LC
Perciformes	Centropomidae	*Centropomus pectinatus* Poey, 1860	**pg. 484		X			X	X	>	M		X			LC
Perciformes	Centropomidae	*Centropomus undecimalis* (Bloch, 1792)	**pg. 485		X		X		X	>	M		X			LC
Perciformes	Serranidae	*Epinephelus itajara* (Lichtenstein, 1822)	**pg. 548				X		X	*	M		X			CR
Perciformes	Serranidae	*Serranus atrobranchus* (Cuvier, 1829)	**pg. 535					X	X	*	M		X			LC
Perciformes	Haemulidae	*Genyatremus luteus* (Bloch, 1790)	**pg. 565	X	X			X	X	=	M		X			LC
Perciformes	Haemulidae	*Orthopristis scapularis* Fowler, 1915	**pg. 574					X		*	M		X			X
Perciformes	Polynemidae	*Polydactylus virginicus* (Linnaeus, 1758)	**pg. 596		X				X	*	M		X			LC
Ephippiformes	Ephippidae	*Chaetodipterus faber* (Broussonet, 1782)	**pg. 619	X	X			X	X	*	M	X	X			LC
Acanthuriformes	Sciaenidae	*Bairdiella goeldi* Marceniuk et al, 2019	**pg. 625				X			*	M		X			X
Acanthuriformes	Sciaenidae	*Ctenosciaena gracilicirrhus* (Metzelaar, 1919)	**pg. 626		X			X		*	M		X			LC
Acanthuriformes	Sciaenidae	*Cynoscion acoupa* (Lacepède, 1801)	**pg. 627	X	X	X	X		X	>	M		X			NT
Acanthuriformes	Sciaenidae	*Cynoscion jamaicensis* (Vaillant & Bocourt, 1883)	**pg. 628						X	<	M		X			LC
Acanthuriformes	Sciaenidae	*Cynoscion leiarchus* (Cuvier, 1830)	**pg. 629					X		<	M		X			LC
Acanthuriformes	Sciaenidae	*Cynoscion microlepidotus* (Cuvier, 1830)	**pg. 630	X						<	M		X			LC
Acanthuriformes	Sciaenidae	*Cynoscion similis* Randall & Cervigón, 1968	**pg. 631						X	<	M		X			X
Acanthuriformes	Sciaenidae	*Cynoscion steindachneri* (Jordan, 1889)	**pg. 632						X	<	M		X			LC
Acanthuriformes	Sciaenidae	*Cynoscion virescens* (Cuvier, 1830)	**pg. 633				X		X	<	M		X			LC
Acanthuriformes	Sciaenidae	*Isopisthus parvipinnis* (Cuvier, 1830)	**pg. 635					X	X	<	M		X			LC
Acanthuriformes	Sciaenidae	*Larimus breviceps* Cuvier, 1830	**pg. 636						X	*	M		X			LC
Acanthuriformes	Sciaenidae	*Lonchurus lanceolatus* (Bloch, 1788)	**pg. 638					X	X	*	M		X		X	LC
Acanthuriformes	Sciaenidae	*Macrodon ancylodon* (Bloch & Schneider, 1801)	**pg. 639	X	X	X	X	X	X	=	M		X			LC
Acanthuriformes	Sciaenidae	*Micropogonias furnieri* (Desmarest, 1823)	**pg. 642		X		X	X	X	<	M		X			LC
Acanthuriformes	Sciaenidae	*Nebris microps* Cuvier, 1830	**pg. 643		X			X	X	<	M		X			LC
Acanthuriformes	Sciaenidae	*Paralonchurus brasiliensis* (Steindachner, 1875)	**pg. 645					X	X	<	M		X			LC
Acanthuriformes	Sciaenidae	*Plagioscion auratus* (Castelnau, 1855)	Fig. 3x	X	X			X	X	=	FW		X		X	LC
Acanthuriformes	Sciaenidae	*Plagioscion squamosissimus* (Heckel, 1840)	Fig. 3y	X	X	X	X		X	=	FW		X			LC

Table 1. Continued.

Order	Family	Species	Figure	Species list						Comm value	Habitat	Habit			End	Status
				A	B	C	D	E	F			I	J	K		
Acanthuriformes	Sciaenidae	*Stellifer microps* (Steindachner, 1864)	**pg. 652	X	X			X	X	*	M		X			LC
Acanthuriformes	Sciaenidae	*Stellifer rastrifer* (Jordan, 1889)	**pg. 656	X	X			X	X	*	M		X			LC
Lobotiformes	Lobotidae	*Lobotes surinamensis* (Bloch, 1790)	**pg. 665	X				X	X	<	M	X	X			LC
Lophiiformes	Ogcocephalidae	*Ogcocephalus nasutus* (Cuvier, 1829)	**pg. 681						X	*	M			X		LC
Tetraodontiformes	Tetraodontidae	*Colomesus psittacus* (Bloch & Schneider, 1801)	**pg. 710	X	X			X	X	*	M/BW		X		X	LC
Tetraodontiformes	Tetraodontidae	*Lagocephalus laevigatus* (Linnaeus, 1766)	**pg. 711					X		*	M	X	X			LC
Tetraodontiformes	Diodontidae	*Chilomycterus antillarum* Jordan & Rutter, 1897	**pg. 720					X	X	*	M		X			LC

between the dry and rainy season ($H_{(1)} = 0.851$; $p = 0.356$), the abundance of both freshwater ($H_{(1)} = 20.712$; $p < 0.001$) and marine fishes ($H_{(1)} = 6.462$; $p = 0.011$) was significantly higher during the rainy season. Depth and salinity affected the abundance of freshwater, estuarine, and marine fishes differently (Figure 4). Freshwater (GAM; $R^2 = 0.132$; $p < 0.001$) and estuarine fishes ($R^2 = 0.024$; $p = 0.002$) exhibited significantly higher abundance in shallower environments, while marine fishes had similar abundance along the entire depth gradient ($R^2 = 0.001$; $p = 0.221$). On the contrary, the abundance of freshwater fishes significantly decreased ($R^2 = 0.444$; $p < 0.001$), and that of estuarine ($R^2 = 0.067$; $p < 0.001$) and marine fishes ($R^2 = 0.211$; $p < 0.001$) significantly increased with increasing salinity.

DISCUSSION

The bycatch of piramutaba fishery is composed of species with and without commercial value, being that 20 to 30% of the total capture is discarded (Dias-Neto *et al*. 1985; Ruffino 2003; Jimenez *et al*. 2013). We showed that almost 45% of all captured species in the bycatch have no commercial value, while the remaining species range from lower to higher market value than that of the piramutaba. This information is crucial for optimizing management criteria for the use of the bycatch of piramutaba. Some bycatch species are already overexploited fishery resources, such as *Brachyplatystoma rousseauxii* (Garcia-Vasquez *et al*. 2009; Agudelo-Córdoba *et al.* 2013).

The bycatch of the industrial fishery that targets piramutaba, a primary freshwater species, is mainly composed of marine fishes, while about 25% of the species are freshwater fishes (see Table 1). This association between freshwater and marine species in the Amazonian estuary is unique compared to other oceanic basins worldwide, due to the enormous oscillation in the discharge of the Amazon River (Guimberteau *et al*. 2012).

The abundance of estuarine fishes did not vary significantly between the dry and the rainy seasons (minimum and maximum discharge of the Amazon River), while freshwater species were more abundant during the rainy season and marine species were more abundant during the dry seasons. Seasonal variation in rainfall is a major environmental factor determining the taxonomic and functional composition of fish communities in estuaries (Barletta *et al*. 2005; Castillo-Rivera 2013; Molina *et al*. 2020). The composition turnover is usually associated to: (i) life-history traits by species using different habitats for reproduction (Dantas *et al*. 2010; Fontoura *et al*. 2019) and (ii) physiological constraints due to changes in salinity level (Lisboa *et al*. 2015; Smyth and Elliott 2016).

The seasonal variation in salinity is more important for primary marine or primary freshwater species than for estuarine species, because the latter display higher osmoregulatory efficiency and can better cope with this environmental variation (Becker *et al*. 2011; Marshall 2012; Park *et al*. 2020). Consequently, the abundance of estuarine fishes tends to be stable between seasons, while abundance of marine and freshwater fishes is higher in the season when salinity levels are lower (rainy season) or higher (dry season), respectively, as corroborated by our GAM results.

The association of fish species with depth is more complex than with salinity, depending on habitat use and osmoregulation. Freshwater fishes have lower osmoregulatory efficiency and might occupy the shallower waters along the coastline both because of lower salinity levels and of adequate habitat structure. Estuarine fishes can better cope with salinity variation, but are usually inhabit or migrate seasonally to shallower areas and more structured environments (Akin *et al*. 2003; Barletta *et al*. 2005; Dantas *et al*. 2010). Marine species might use shallower areas with lower salinity levels in specific periods of their life cycle (Smyth and Elliott 2016). Therefore, the spatial pattern of variation in salinity levels in the Amazon estuary, where lower salinity is frequently

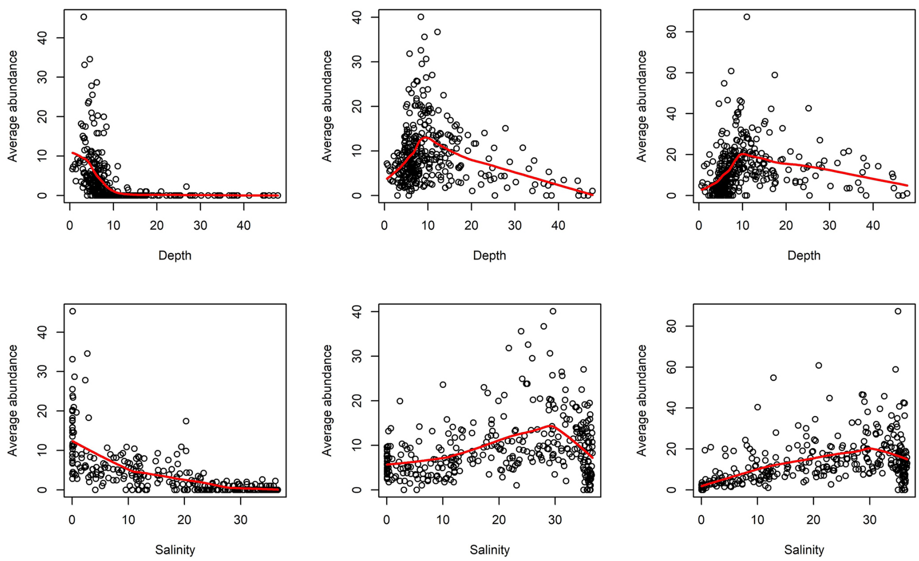

Figure 4. Generalized additive models (GAM) with smoothing parameters describing the relationship of depth (upper) and salinity (bottom) with the average abundance of freshwater (left), estuarine (middle), and marine fishes (right) of the bycatch of the piramutaba fisheries in the Amazon estuary. This figure is in color in the electronic version.

associated with shallower areas, is important in shaping the distribution of fishes and the turnover of species with different affinity levels (Soares *et al.* 2021).

The majority (90%) of threatened species in the bycatch are elasmobranchs, six of them critically endangered and three vulnerable. Other threatened elasmobranch species that occur in the area, but were not reported in the piramutaba bycatch, include the stingrays *Fontitrygon colarensis* (VU), *Paratrygon aiereba* (CR) and *Pseudobatos percellens* (VU) (ICMBio 2018; MMA 2022). The potential negative impact of the fishery on the populations of these endangered species has not yet been assessed.

CONCLUSIONS

The present study poses an important advance on the knowledge of the fauna captured during piramutaba trawling in the mouth of the Amazon River and the influence of the hydrological cycle of the river on the structure of this community. This information will support the establishment of criteria for management for the use of the bycatch of the piramutaba fishery in order to improve the definition of areas and periods allowed for the operation of this fishing fleet. Given the observed gaps in the knowledge of the ichthyofauna in the region, we highlight the importance to increase the knowledge on the biology and fishery stocks of the endemic fauna, especially sharks and batoids.

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