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Composition of functional ecological guilds of the fish fauna of the internal sector of the Amazon Estuary, Pará, Brazil

KEILA R.M. MOURÃO[1], VALDIMERE FERREIRA[2] and FLÁVIA LUCENA-FRÉDOU[2]

[1]Universidade Federal do Pará/UFPA, Laboratório de Biologia Pesqueira e Manejo de Recursos Aquáticos, Av. Perimetral, 2651, Terra Firme, 66077-530 Belém, PA, Brasil
[2]Universidade Federal Rural de Pernambuco/UFRPE, Departamento de Pesca e Aquicultura/DEPAQ, Rua Dom Manoel de Medeiros, s/n, Dois Irmãos, 52171-900 Recife, PE, Brasil

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ABSTRACT

The present study describes the spatial and temporal structure of the estuarine fish community in the internal sector of the Amazon Estuary. Samples were obtained in the main channels and tidal creeks of Guajará and Marajó Bays and Guamá River. A total of 41,516 fish specimens were collected, representing 136 taxa, 38 families and 12 orders. In the dry season, the mean salinity of the main channel increased along a limnic-marine gradient, between the Guamá River and the Marajó Bay. Species richness was lowest in the mouth of the Guamá River and in the right margin of the Guajará Bay. Fish species composition and environmental guilds differed markedly among areas: Migrants and Freshwater Stragglers were dominant in the Guamá River and the Guajará Bay, while Estuarine, Marine Stragglers and Migrants predominated in the Marajó Bay. However, the trophic guilds were still relatively well balanced, in functional terms. Piscivores and Zoobenthivores were the dominant feeding functional groups in all the studied areas. In this study, the assessment of the community and the use of the guild approach were efficient to describe the structure and functioning of the assemblages of estuarine fish also helping to assess the anthropogenic pressures in the area.

Key words: estuaries, fish diversity, functional ecology, habitat, salinity gradients.

INTRODUCTION

In recent studies, the concept of ecological "guilds" has been used to organize information on the function, hierarchical structure, and connectivity of ecological systems, primarily by simplifying relatively complex ecological interactions (Elliott et al. 2007, Noble et al. 2007, Franco et al. 2008a). Guilds or biecological categories (Albaret 1999), became important tools in providing a better understanding of the structure and functioning of the assemblages of fish (Mathieson et al. 2000), contributing to the knowledge of the system and the implementation of strategic planning, which is especially important in estuaries, where human activities have been causing ever greater impacts on the environment and its natural resources (Whitfield and Elliott 2002, McLusky and Elliott 2004).

Estuaries require additional attention because of the increasing population density and intensive anthropogenic activity which often affect the water

Correspondence to: Keila Renata Moreira Mourão
E-mail: kmourao@yahoo.com.br

quality and aquatic biodiversity (Viana et al. 2010, 2012). In addition, the high socio-economic value of their goods, especially as a source of income and food is well documented (Lambert and Turpie 2003, Glaser and Diele 2004, Ortiz and Wolff 2004, Isaac et al. 2009). Ecologically, this environment plays an essential as a feeding and breeding ground, providing appropriate habitats for different stages of the fish life cycle, in addition to functioning as a migratory routes for both anadromous and catadromous species (Yañez-Arancibia 1986, Elliott et al. 2007, Martinho et al. 2007).

The Amazon Estuary is considered to be a single system, however it is highly heterogeneous in terms of the dynamics of sedimentary deposition and freshwater discharge. This determines the characteristics of its fauna (Coelho 1980, Camargo and Isaac 2001) and flora (Prost and Rabelo 1996), including species richness and distribution patterns (Giarrizo and Krumme 2008). Additionally, in the Amazon Estuary, there is a river-ocean gradient in the distribution of different species, reflecting their capacity to tolerate varying levels of salinity, and the presence of an essentially euryhaline community. However, seasonal changes in the composition of the community indicate an influx of freshwater species during the rainy season, while marine species predominate during the dry season, reflecting changes in salinity levels (Camargo and Isaac 2001).

The internal sector of the Amazon Estuary, including the Bays of Marajó and Guajará and the mouth of the Guamá River, our study area, suffers a wide range of anthropogenic impacts. Among some of the impacts, we can cite a petrochemical complex and wood industries, numerous ports and shipping lanes, and the widespread discharge of domestic and industrial effluents, especially in the Guajará Bay and the mouth of the Guamá River, where the metropolitan area of Belém is located (IBGE 2010). Marajó Bay is one of the most important fishing grounds in the Amazon Estuary. Artisanal fisheries are especially intense (Oliveira and Lucena Frédou 2011) and human activities have been gradually depleting the area's fish stocks (Barthem and Petrere 1995, Isaac et al. 2008). In this area, marine species such as *Scomberomorus brasiliensis*, *Cynoscion acoupa*, *Mugil* sp. and *Bagre bagre*, are harvested (Mourão et al. 2009).

The use of functional ecological groups or guilds of fish have been recognized in estuaries (Elliott et al. 2007, Noble et al. 2007, Franco et al. 2008a, Elliott and Whitfield 2011) not only as an alternative for the analysis of traditional taxonomic divisions of fish assemblages, providing a better understanding of the structure and functioning of the assemblages of fish occurring in estuaries (Mathieson et al. 2000), but also, as a useful tool to describe ecosystem services, helping to assess the anthropogenic pressures which threat the integrity of estuaries world-wide. For example, the knowledge on the structure and functioning variability of the guilds in transitional water is useful for identifying different water body types for which specific biological reference conditions can be reliably derived (Franco et al. 2008b). In addition, the structure of a community's trophic guilds may be considered as a good indicator of trophic integrity (Deegan et al. 1997, Elliott et al. 2007, Henriques et al. 2008) and is widely adopted in current indices, because it allows a direct functional approach to the estuarine assessment (Pérez-Domínguez et al. 2009).

The present study describes the spatial and temporal structure of the estuarine fish community in the internal sector of the Amazon Estuary, assuming a connectivity of the ichthyofauna between limnic and marine systems, using the fish guild approach. Additionally, this study looks at the species composition and guild approach in order to assess the ecological integrity of the area, also comparing our results with other tropical estuaries in the world.

MATERIALS AND METHODS

Studied Area

The Amazon Estuary, located in Northern Brazil, is formed by the discharge of the Amazon and the Tocantins River, resulting in the annual mixture of approximately 6,300 km^3 of river water carrying 9.3 x 10^8 tons of sediments from the Atlantic Ocean (Meade et al. 1979). This unique environment harbors both marine and freshwater species (Milliman and Meade 1983). This work was conducted at the aquatic environments surrounding the city of Belém (state of Pará), including three zones: mouth of the Guamá River (and Combu Island); Guajará (Onças Island) and Marajó (Mosqueiro Island) Bays, in the southeast of the Amazon Estuary (Fig. 1). The area is located in the internal sector of the Amazon Estuary, with a mean annual temperature of 25°C, air humidity above 80% and a rainfall of 2,889 $mm.y^{-1}$ (Bezerra et al. 2011). The tidal propagation goes on for several kilometers upstream, characterizing a broad zone of fluvial–marine transition under the impact of semidiurnal tides (Gregório and Mendes 2009). This region is classified as a tidally-influenced area of river (tidal fresh: salinity < 0.5–limnetic; Guamá River and Guajará Bay) and mesohaline environment (salinity 5-18; Marajó Bay).

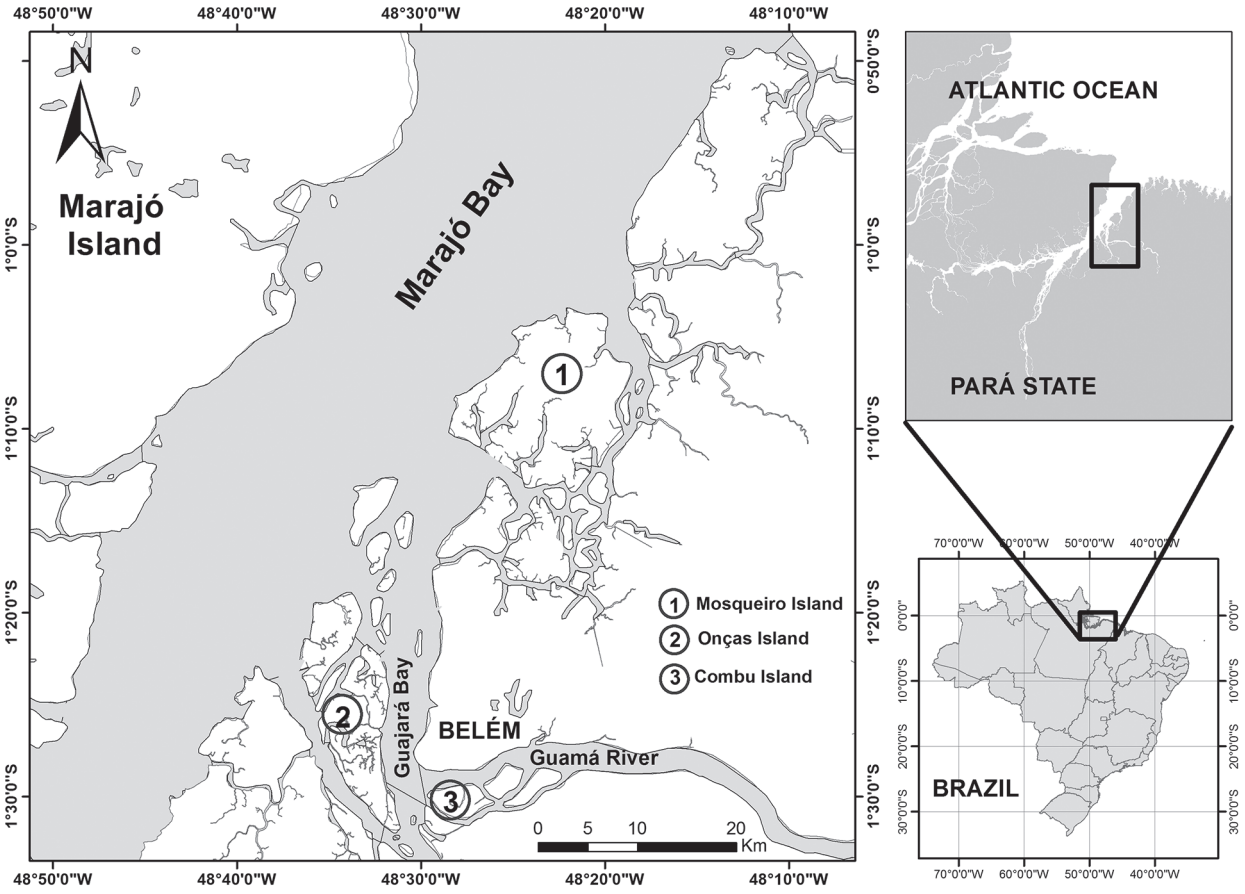

Figure 1 - Location map of study area in the mouth of the Guamá River, and Guajará and Marajó Bays, its adjacent islands: (1) Combu; (2) Onças and (3) Mosqueiro, Amazon Estuary, northern Brazil.

Data Collection

For all zones, two different types of environment – the main river channel and the tidal creek (inside the islands) were sampled in all three zones. Data were collected in the Guamá River and the Combu Island in 2004-2005 and 2008-2009, in the Guajará Bay and the Onças Island in 2004-2005 and 2007-2008, and in the Marajó Bay and the Mosqueiro Island in 2008-2011 (Fig. 2). In all three zones, samples were collected in both dry (July to December) (159 sets) and rainy seasons, between January to June (155 sets).

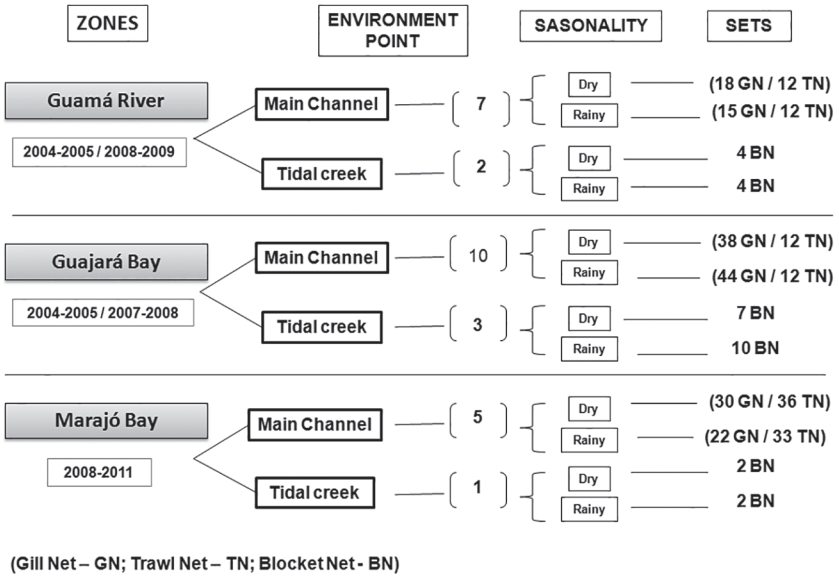

Figure 2 - Ecological descriptor and number of species by environment, season and guilds in the Guamá River, Guajará Bay and Marajó Bay, Amazon Estuary, northern Brazil.

As the main channels and tidal creek show distinct dynamics (Viana et al. 2010), different sampling protocols were used. In the main channels, gillnets (knot-to-knot meshes of 25 mm, 30 mm, 40 mm, and 50 mm; and total area 1.204,70 m^2) were used to capture specimens. In the specific case of the Marajó Bay, nets with larger meshes (60 mm and 70 mm; and total area 1.435,70 m^2) were used, given the more favorable conditions – depth and extension – of this area. During the collection of specimens, nets were set in a random configuration, twice, for two to three hours at a time. The 60 mm and 70 mm nets were tested in the Guamá River and the Guajará Bay, although they proved inoperable, due to the shallow depths and the frequent presence of submerged trunks and branches. Trawl net, with a mesh of 5 mm on all its extension, length of 5.50 m, height of 0.60 m, and opening of 1.10 m, was only used in the main channel (except in the main channel of the islands, due to the presence of submerged trunks and branches). Three trawls of approximately 20 minutes were conducted in each study area at a mean velocity of 1.62 knots.

Multifilament block nets with a 25 mm mesh were used in the tidal creeks. These nets were 50 m long and 5 m high. Blocking was initiated at the end of the high tide and continued throughout the entire ebb tide cycle, of approximately six hours. The tidal creeks drain completely at low tide, and the specimens were either gilled in the net (smaller fishes) or collected manually from remaining pools.

All specimens were stored in ice and transported to the laboratory for processing. The specimens were sized (Total Length – TL, cm), weighed (Total Weight – TW, kg). Salinity was measured in the field using a portable conductivimeter Orion model 115.

Data Analyses

The species richness was estimated using the non-parametric Bootstrap extrapolation procedure, which was found to be the most adequate procedure for the data collected, given that the assumption of the random occurrence of species was satisfied, resulting in more reliable standard deviations (Magurran 1988, Colwell and Codington 1994). The index and standard deviation of the estimates were calculated using Colwell et al. (2004) analytical equation, run in EstimateS v.8 (Colwell 2009). Data entry included individuals caught by all gears.

For each study zone, environment and season, the composition of the fish fauna was reported in terms of absolute species richness (S). For each species, relative abundance (%N), relative weight (%W), and frequency of occurrence (%FO) was also calculated. Species were considered to be common when %N was greater than 100/S, where S = the number of species recorded in the area. A species was classified as frequent when its %FO value for a given area was greater than 50%. The combination of these parameters enabled the classification of the different species into four categories (following Garcia and Vieira 2001): (1) common and frequent (%N > 100/S and %FO ≥ 50%); (2) common, but infrequent (%N > 100/S and %FO < 50%); (3) rare, but frequent (%N < 100/S and % FO ≥ 50%), and (4) rare and infrequent (%N < 100/S and %FO < 50%).

Estuarine Use Functional Group was defined according to the classification of Elliott et al. (2007). This classification is based on the type, frequency, and period of use of the estuarine environment, and the abundance of the species in the estuary, classified under the following categories: Marine Stragglers (MS); Marine Migrants (MM); Estuarine Species (ES); Freshwater Migrants (FM), and Freshwater Stragglers (FS). Feeding mode functional groups, based on feeding preferences and strategies, were also defined. In order to perform this classification, species were allocated to one of the following ecological guilds (based on Elliott et al. 2007): Zooplanktivore (ZP); Detritivore (DV); Piscivore (PV); Zoobenthivore (ZB); Herbivore (HV); Opportunist/Omnivore (OP). Two additional categories were included: Piscivore/Zoobenthivore: PV/ZB (following Krumme et al. 2004) and Insectivore (IS). The trophic categories were identified by combining the regional information available on predominant diet and stomach examination of several species. Where little information was available, trophic and habitat preferences were inferred from the data available in the Fishbase project (Froese and Pauly 2007), and when no information was found, the species was not included in this analysis.

An "importance value", (Iv) (Harrison and Whitfield 2008), was derived from the relative contribution (%) of each functional group in each study area, based on Iv = 0.33 (a + b + c), where a = the percentage of species, b = percentage abundance, and c = percentage biomass. As a combination of these elements, the Iv provides an integrated measure of the global importance of each guild.

Multivariate multidimensional scaling (MDS) was used to compare species composition (%N and %W) and guilds in relation to spatial (zones and environmental) and temporal (seasonality) variables. All groups defined in the MDS were tested through similarity analysis (Two-way nested ANOSIM). This analysis explores the dissimilarities between groups and calculates the contribution of each species to this relationship, based on its relative occurrence in each group (Clarke and Warwick 1994). These analyses were run in Primer 6.1.6.

RESULTS

Species richness was lowest in the mouth of the Guamá River. The cumulative species curves for the three zones indicate that sampling was not exhaustive, given that they did not reach an asymptote. However, the results of the bootstrap analysis suggest that sampling was relatively reliable in all three study areas, with around ninety-percent of the estimated number of species being recorded in all three cases. A total of 55 species were recorded in the Guamá River, representing 90.2% of the richness estimated by the bootstrap procedure. Similar patterns were recorded in the Guajará Bay, where 88.7% (94) of the estimated 106 species were recorded, and in the Marajó Bay, where 7.9% (95) of the estimated 108 species were observed in the study (Table I).

The mean salinity, measured during the dry season, of the main channel increased along a limnic-marine gradient, i.e., between the Guamá River and the Marajó Bay. Marked variation in mean salinity was recorded only in the Marajó Bay (mean = 2; range 0.7 - 2.9), while in the Guajará Bay low salinity (mean = 0.018; range: 0 – 0.15) was recorded in the rainy season. Additionally, salinity was zero in the tidal creeks of all three zones throughout the year (Table I).

TABLE I
Ecological descriptor and number of species by environment, season and guilds in the Guamá River, Guajará Bay and Marajó Bay.

Ecological Descriptor	Guamá River	Guajará Bay	Marajó Bay
Absolute richness	55	94	95
Estimate richness	61	106	108
Number of species			
Environment			
Main channel	44	71	80
Tidal creek	24	65	26
Season			
Rainy season	42	73	62
Dry Season	48	72	78
Estuarine Use Functional Group			
Estuarine Species - ES	8	12	19
Freshwater Migrants - FM	11	12	12
Freshwater Stragglers - FS	33	59	38
Marine Migrants - MM	2	5	11
Marine Stragglers - MS	1	5	7
Feeding Use Functional Group			
Detritivore - DV	3	6	3
Herbivore - HV	3	7	8
Opportunist/Omnivore - OP	-	1	1
Piscivore - PV	10	12	11
Piscivore/Zoobenthivore - PV/ZB	3	8	10
Zoobenthivore - ZB	19	33	29
Zooplanktivore - ZP	2	2	2
Salinity	0-0.2	0-0.75	0-2.9

A total of 41,516 fish specimens were collected, representing 136 taxa, 38 families and 12 orders (Supplement Table I). In general, the families Sciaenidae (10.9% of the species recorded), Loricariidae (10.9%), Engraulididae (8.7%), and Cichlidae (6.5%) were the most diverse. *Plagioscion squamosissimus* was the most common species in the Guamá River (22% of individuals) and in the Guajará Bay (24%), while *Stellifer microps* was the most common (44%) in the Marajó Bay. The siluriforms *Brachyplatystoma filamentosum* (17% of the total) and *Brachyplatystoma rousseauxi* (16%) contributed to the largest proportion of the biomass in the Guamá River, *Lithodora dorsalis* (53%) in the Guajará Bay, and *Brachyplatystoma rousseauxi* (17%) and *Plagioscion squamosissimus* (16%) in the Marajó Bay (Supplement Table I).

A total of 28 species were common to all zones and habitats (Supplement Table I). However, there were considerable differences between habitats. Overall, 66 species were recorded only in the main channels, while 20 were found only in tidal creeks. The proportion of exclusive species also increased along the limnic-marine gradient, from 2% in the Guamá to 21% in the Guajará Bay and 27% in the Marajó Bay.

The multivariate analysis indicated significant differences in the composition of the fish assemblages among zones, considering both types of habitat (main channel and tidal creek), in terms of percentage abundance and biomass (ANOSIM, $p < 0.05$). Three distinct groups were identified (Fig. 3). In relation to seasonal variation, significant differences in the composition of the fish assemblages were found only in percentage abundance and in tidal creeks (ANOSIM, $p < 0.05$).

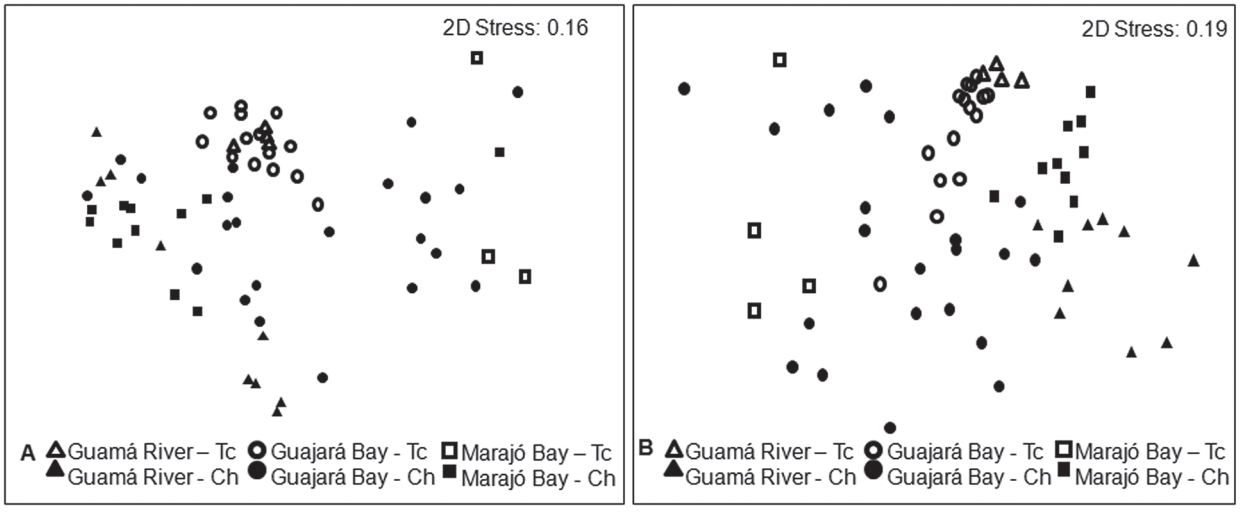

Figure 3 - Multivariate multidimensional scaling analysis by zone (Guamá River, Guajará Bay and Marajó Bay) and environment (Main channel and Tidal creek): A) abundance percentage and B) biomass percentage.

The MDS ordination of the Estuarine Use Functional Group showed two different groups (ANOSIM, $p < 0.05$), mainly composed by guilds of the Marajó Bay and the Guamá River. However, guilds of the Guajará Bay were observed within both groups, (Fig. 4). The same pattern was also observed considering the Feeding Mode Functional Groups (ANOSIM, $p < 0.05$). Significant differences between seasons were not reported (ANOSIM, $p > 0.05$) (Fig. 5).

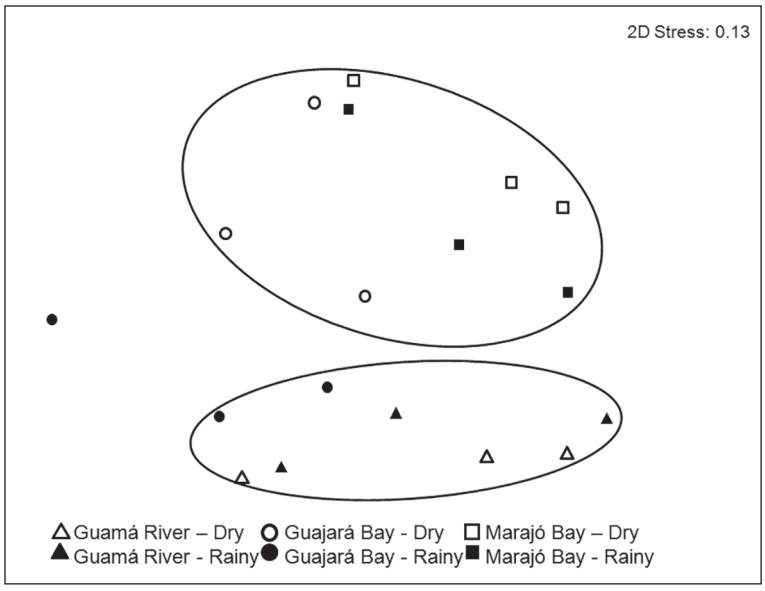

Figure 4 - Multivariate multidimensional scaling analysis by environment guild by zone (Guamá River, Guajará Bay and Marajó Bay) and season (Dry and Rainy season), Amazon Estuary, northern Brazil.

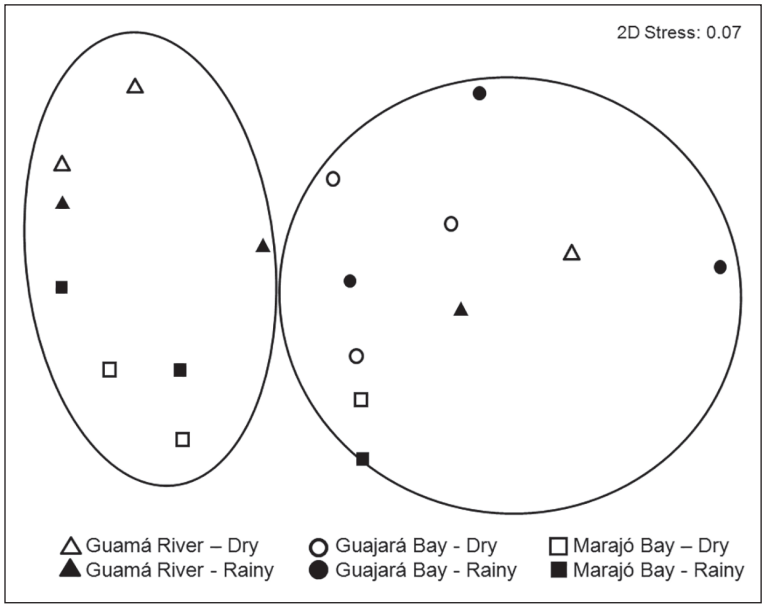

Figure 5 - Multivariate multidimensional scaling analysis by feeding guild by zone (Guamá River, Guajará Bay and Marajó Bay) and season (Dry and Rainy season), Amazon Estuary, northern Brazil.

Estuarine Species (ES) were dominant in the Marajó Bay for both dry and rainy seasons (IV= 9.27 – Dry; IV= 9.63 - Rainy). Together, Marine Migrants (MM) and Marine Stragglers (MS) were the representative in the Marajó Bay (Table II). Freshwater Migrants (FM) predominated for both periods in the Guamá River (IV= 11.65 – Dry; 11.54 – Rainy). Freshwater Stragglers (FS) were most frequent in the Guajará Bay (IV= 10.98 – Dry and 12.73 – Rainy).

TABLE II
Mean ± S.D. Importance Values (IV) of estuary association fish environment guilds by zone and season in the Guamá River, Guajará Bay and Marajó Bay. Estuarine Species (ES); Freshwater Migrants (FM); Freshwater Stragglers (FS) Marine Migrants (MM) and Marine Stragglers (MS).

	DRY			*RAINY*		
	Guamá River	**Guajará Bay**	**Marajó Bay**	**Guamá River**	**Guajará Bay**	**Marajó Bay**
ES	2.87 ± 0.96	4.45 ± 3.48	9.27 ± 4.75	3.68 ± 1.41	3.17 ± 1.21	9.63 ± 5.00
FM	11.65 ± 7.56	7.72 ± 1.94	7.90 ± 5.34	11.54 ± 8.51	8.28 ± 8.22	8.07 ± 6.55
FS	9.76 ± 1.07	10.98 ± 14.41	4.07 ± 1.79	8.67 ± 1.53	12.73 ± 1.21	6.35 ± 3.05
MM	0.75 ± 0.24	1.43 ± 0.79	2.79 ± 2.07	1.15 ± 0.38	0.52 ± 0.20	0.62 ± 0.22
MS	0.37	0.34 ± 0.06	1.42 ± 0.44		0.72	0.32 ± 0.03

Piscivores and zoobenthivores were the dominant feeding functional groups in all the study zones, however the highest percentages of piscivores were recorded in the mouth of the Guamá River and the percentage of zoobenthivores was highest in the Marajó Bay, for both seasons. The contribution of zooplanktivores (IV) decreased progressively between the Guamá River and the Marajó Bay. In the Guajará Bay, a larger proportion of herbivores was recorded during two season periods (Table III).

TABLE III
Mean ± S.D. Importance Values (IV) of estuary association fish feeding guilds by zone and season in the Guamá River, Guajará Bay and Marajó Bay. Detritivore (DV); Herbivore (HV); Omnivore (OP); Piscivore (PV); Piscivore/Zoobenthivore (PV/ZB); Zoobenthivore (ZB) and Zooplanktivore (ZP).

	DRY			*RAINY*		
	Guamá River	**Guajará Bay**	**Marajó Bay**	**Guamá River**	**Guajará Bay**	**Marajó Bay**
DV	0.91 ± 0.17	0.97 ± 0.23	1.09 ± 1.21	0.58 ± 0.03	1.29 ± 0.66	0.47 ± 0.04
HV	2.05 ± 1.11	6.92 ± 10.04	1.72 ± 1.53	3.24 ± 2.60	7.13 ± 7.58	2.09 ± 1.70
ON		0.31	0.29 ± 0.01		0.36 ± 0.04	0.40
PV	12.80 ± 7.69	5.15 ± 0.93	7.22 ± 4.92	10.71 ± 6.93	6.52 ± 6.73	8.81 ± 7.85
PV/ZB	0.98	1.29 ± 0.34	2.37 ± 1.93	1.27	1.12 ± 0.60	0.43 ± 0.02
ZB	7.87 ± 0.15	9.55 ± 2.20	12.04 ± 5.57	9.59 ± 2.05	9.69 ± 4.08	12.75 ± 4.94
ZP	2.13 ± 1.58	1.03 ± 1.03	0.69 ± 0.33	1.89 ± 0.85	1.06 ± 0.98	0.41

DISCUSSION

Comparisons of fish assemblage structure require data that accurately reflect the true composition of species. One means of ensuring accurate representation of the species assemblage is through effective sampling design (Kwak and Peterson 2007). The heterogeneity of the Amazon Estuary makes standardization of sampling equipment and methodology difficult. Even when standardized equipment is used, bias may arise from differential application of sampling effort (Viana et al. 2012). The differences in the ichthyofaunal composition between estuaries in this study may be related to the use of data from distinct years and gears and

also differential effort, although standardized sampling gears was used within each environment (main river channel and tidal creek) and clear trends were noticeable from our analysis. In our study, a multi-gear approach was used in order to provide the most complete estimate of fish assemblage structure (Kwak and Peterson 2007).

The present study recorded significant differences in the composition of the fish assemblages among areas. Species richness was lowest in the mouth of the Guamá River. While the input of freshwater is vital to the productivity and diversity of estuarine systems, Schlacher and Wooldridge (1996) and Livingston (1997) found that it could contribute to a decrease in species richness and diversity, which may not necessarily be related to saline stress, but rather to the composition and instability of the sediments (Elliott and Mclusky 2002). Marajó and Guajará Bays presented the highest species richness, which could have been favored by the hydrodynamic conditions and the enhancement of high-salinity habitats (Nicolas et al. 2010a). The diversity of the Guajará Bay could also be related to the presence of many small islands and tidal creeks, as well as to the availability of feeding resources and habitat diversity in the Onças Island. This swampy island, which is inundated by the tides (Carvalho et al. 1998), presents a wide variety of habitats, which are occupied by a large number of fish species (77).

In the right margin of the Guajará Bay is located the city of Belém, with a metropolitan area occupied by 1.4 million inhabitants (IBGE 2010), and a wide range of anthropogenic impacts. These factors most certainly contribute to the reduced species richness found in this area (40 species). By reducing habitat quality, anthropogenic factors also affect the survival or reproduction of many species, typically leading to reduced species richness and alterations in community structure (Whitfield and Elliott 2002). Viana et al. (2010) stated that, for the main channel of the Guajará Bay, the sewage and industrial discharges have not yet severely affected the area due to the efficiency of self-purifiers, which dilute the pollutant discharge probably due to the highly dynamic mixed-energy environment of the bay (Gregório and Mendes 2009). However, these authors found anthropogenic influence in tidal creeks located at the right margin of the Guajará Bay. This environment is a more closed aquatic system where pollutants remain for longer periods of time without dilution in the water. Most species that inhabit tidal creeks have restricted migratory habits and are considered good indicators of water quality. This reduction on species richness due to anthropic factors was also reported in an industrial district (Vila do Conde, Pará, Brazil) located near our study area (Viana et al. 2012).

Only recently has the functionality of ecological guilds been integrated into studies of fish communities only recently, with applications in Europe (Selleslagh et al. 2009, Nicolas et al. 2010b) and Africa (Harrison and Whitfield 2008, Ecoutin et al. 2010). The reviews of Elliott et al. (2007) and Noble et al. (2007) have been widely used to describe estuarine fish assemblages and offer an opportunity to compare and contrast estuaries from different geographical areas in a systematic fashion.

The internal sector of the Amazon Estuary is known to be a transition zone between limnic and mesohaline environments. Freshwater migrants and freshwater stragglers were dominant in the Guamá River and the Guajará Bay, while Estuarine, Marine Stragglers and Migrants predominated in the Marajó Bay. In the Pará River estuary, which is located at a similar longitude to the Guamá River and the Guajará Bay and presents similar habitats, a community composed basically of Freshwater Stragglers and Migrants was recorded, although a number of coastal species, more tolerant of low salinity, were also found (Paz et al. 2011). In the opposite direction, in the outer portion of the Marajó Bay, Barthem (1985) recorded mainly estuarine and marine species (stragglers and migrants), at a

higher proportion than that recorded in the present study. In this study, seasonal differences in the fish community structure were only observed for the tidal creek (in terms of biomass), probably due to the dominance of the large-sized *Lithodora dorsalis* during the dry season. This was different to what was observed by Camargo and Isaac (2001), in Amazonian estuaries with large variation of salinity, who found seasonal changes in the composition of the community, reflecting changes in salinity levels.

In the Amazon Estuary, the river-ocean gradient in the distribution of different species, reflects their capacity to tolerate varying levels of salinity, and the presence of an essentially euryhaline community. Sciaenids were the most abundant fishes in all study areas, but the catfishes siluriforms predominated in terms of body weight. The species of the families Sciaenidae and Pimelodidae are characterized by their considerable diversity and widespread distribution on the northern coast of Brazil (Barthem 1985, Camargo and Isaac 2001), where they occur typically in environments with salinity of around 8 (Barthem 1985), indicating that, while they have limnic habits, they are tolerant of estuarine conditions. When the present study zones were considered separately, however, different patterns of dominance of both species and families were observed.

In estuaries, the feeding ecology of fishes is highly diversified, with all different trophic levels being represented, and a predominance of sediments rich in nutrients (Paiva et al. 2008). This trophic diversity was recorded in all the zones surveyed in the present study, however zoobenthivores and piscivores were predominant. The substrate within the study area was composed of mud (fluid and compact), fine to medium-grained sand (Gregório and Mendes 2009), and organic material (leaves), favoring the presence of a wide range of animals, which represent a feeding resource for fish (Uieda and Uieda 2001). The composition of this substrate probably accounts for the relatively high percentage of zoobenthivores found in all areas, as predicted by Blaber (2000), who proposed that benthivores should predominate in all types of estuaries. The dominance of piscivores may have been related to the high biomass of pimelodid species in the study area. These species are considered to be second-order carnivores, which feed primarily on fishes and invertebrates (Paiva et al. 2008).

The number of trophic guilds found in this study was similar to that reported for others aquatic ecosystem such as coral reefs and flood plain lakes (Abujanra et al. 2009, Santana-Porto and Andrian 2009) and also to other estuaries world-wide. In south Brazil, the number of guilds was similar to the present study and also zoobenthivores and piscivouros dominated (Passos et al. 2013). In the estuary of the Caeté River (Amazon) and also in other tropical estuaries world-wide, zoobenthivores also dominate (Chua 1973, Day 1964, Blaber et al. 1989, Krumme et al. 2004).

Trophic guilds have been considered to be excellent indicators of the integrity of an environment (Henriques et al. 2008). The insertion of trophic guild as metrics (number and abundance of zoobenthivorous, piscivorous and piscivororous/ zoobenthivorous) for the application of multimetric indices of ecosystem integrity was used in an industrial district in the Amazon Estuary (Vila do Conde, Pará, Brazil), adjacent to our study area and with similar characteristic to the Guajará Bay (Viana et al. 2012). In this study, the number of guilds differed and the absence of piscivores, zoobenthivores, and detritivores, revealed the alterations in the industrial district. Elliott et al. (2007) affirms that, in general, the greater the number of trophic guilds, the greater the integrity of the estuarine environment, given the greater equilibrium of predator–prey relationships, which normally reflects reduced anthropogenic impacts (Elliott et al. 2007). Browne and Lutz (2010) and Ecoutin et al. (2010) found that anthropogenic

disturbances result in the loss of organisms at the top of the trophic web. In our case, the fish species composition and environmental guilds differed markedly among zones, however, the trophic guilds are still relatively well balanced, in functional terms, even considering the antropogenic impacts of the Guajará Bay and the fishery importance of the Marajó Bay. We believe that the level of disturbance of the Guajará Bay has not yet affected the trophic structure, differently than the reported for the industrial district with severe alteration related to the community (eg. diversity and abundance) (Viana et al. 2012, Viana and Lucena Frédou 2014) and individual level (e.g. histological alterations) (Viana et al. 2013). Selleslagh et al (2009) found clear similarities in the fish assemblages among preserved and polluted estuaries, suggesting that anthropogenic impacts (chemical contamination) on estuaries do not affect their ecological functioning as described by the ecological guilds. According to Selleslagh et al (2009), growth may affect the ecological functioning of estuaries. Gilliers et al. (2006) and Amara et al. (2007) have successfully linked aspects of the estuarine functioning (density, growth and condition indices) to nursery quality.

In this study, the assessment of the estuarine fish community and the use of the guild approach were also efficient in identifying different water body types. The application of the Estuarine Use Functional Group demonstrates that the inner portion of the Amazon Estuary consists of different water body types, were the Guamá River and the Guajará Bay are considered as freshwater and the Marajó Bay as a brackish water body. This classification corroborates with the Brazilian National Council of Environmental (CONAMA), responsible for the classification of the water bodies in Brazil. However, this council used only salinity as reference. The guild approach may also be used to validate water body types, since variation in the community could occur depending on season and other environmental features. Furthermore, the guild approach proved effective for the investigation of fish diversity along a salinity gradient. The presence of all the different ecological guilds within the study area emphasizes its role as a contact zone between tidal currents, river discharge, and wave forces, in a highly-dynamic, mixed-energy environment (Corrêa 2005, Gregório and Mendes 2009).

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RESUMO

O presente estudo descreve a estrutura espacial e temporal da comunidade de peixes estuarinos da porção interna do estuário Amazônico. Amostras foram obtidas no canal principal e canais de maré das Baías do Guajará e Marajó e rio Guamá. Foram coletados um total de 41.516 espécimes, correspondendo 136 espécies, 38 famílias e 12 ordens. Na estação seca, a salinidade média no canal principal aumentou ao longo do gradiente limnico–marinho, entre o rio Guamá e a Baía do Marajó. A riqueza de espécies foi mais baixa na foz do rio Guamá e na margem direita da baía do Guajará. A composição das espécies e as guildas ambientais diferiram significativamente entre as áreas: Migrantes e Ocasionais de água doce foram dominantes no rio Guamá e na Baía do Guajará, enquanto Estuarinas, Marinhas Migrantes e Ocasionais dominaram na Baía do Marajó. Contudo, as guildas tróficas foram relativamente bem balanceadas, em termos funcionais. Piscívoros e Zoobentívoros foram os grupos alimentares dominantes em todas as áreas. Neste estudo, a avaliação da comunidade e o uso da abordagem com guildas foram eficientes para descrever a estrutura e o funcionamento das assembleias de peixes estuarinos e também como ferramenta na avaliação das pressões antrópicas na área.

Palavras-chave: estuários, diversidade de peixes, ecologia funcional, habitat, gradiente de salinidade.

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SUPPLEMENT TABLE I

Composition of the ichthyofauna captured in the three sampling zones. Guamá River – GR; Guajará Bay – GB; Marajó Bay - MB. Main Channel - Ch and Tidal creek - Tc; Dry – D and Rainy – R; Estuarine Use Functional Groups (EUFG) - Marine Stragglers (MS); Marine Migrants (MM); Estuarine Species (ES); Freshwater Migrants (FM), and Freshwater Stragglers (FS); Feeding Mode Functional Groups (FMFG) - Zooplanktivore (ZP); Detritivore (DV); Piscivore (PV); Zoobenthivore (ZB); Opportunist/Omnivore (OP); Piscivore/Zoobenthivore: PV/ZB; Insectivore (IS). (*) species present in all the studied area and environments. Abundant and Frequent (AF); Abundant and Infrequent (AI); Less abundant and Frequent (LAF) and Less abundant and Infrequent (LAI).

Family	Species	Environment	Seasonality	EUFG	FMFG	FO	N	W (kg)	Classification		
		Ch / Tc	**D/R**						**GR**	**GB**	**MB**
Acestrorhynchidae	*Acestrorhynchus* sp.	Tc	R			1	1	0.076			LAI
Achiridae	*Achirus achirus*	Ch / Tc	D	ES	ZB	3	8	0.7607		LAI	LAI
	**Apionichthys dumerili*	Ch / Tc	D / R	ES		15	783	0.9441	AI	LAI	AF
	Syacium papillosum	Tc	D	MS	ZB	1	1	0.016			LAI
Anablepidae	*Anableps anableps*	Tc	D / R	ES	HV	11	33	2.543	LAI	LAI	LAI
Anostomidae	*Leporinus fasciatus*	Ch	R	FS	ZB	1	4	0.91		LAI	
	Leporinus friderici	Ch / Tc	D / R	FS	PV/ZB	4	5	0.725	LAI	LAI	
Apteronotidae	*Apteronotus albifrons*	Tc	D / R	FS	ZP	6	12	1.508	LAI	LAI	
	Orthosternarchus tamandua	Ch	D / R	FS		2	2	0.1332	LAI	LAI	
	Sternarchella schotti	Ch	R	FS		1	7	0.0826			LAI
	Sternarchella sima	Ch	D / R	FS		5	8	0.0997	LAI	LAI	LAI
	**Sternarchella terminalis*	Ch / Tc	D / R	FS		11	494	1.7886	AI	LAI	LAI
	**Sternarchogiton* sp.	Ch / Tc	D / R	FS		10	345	1.1921	AI	LAI	LAI
	**Sternarchorhamphus muelleri*	Ch / Tc	D / R	FS		10	41	1.5302	LAI	LAI	LAI
	Sternarchorhynchus cf. *roseni*	Ch	R	FS		1	1	0.0095	LAI		
Ariidae	*Amphiarius phrygiatus*	Ch	D / R	ES		8	156	21.416			LAF
	Aspistor sp.	Ch / Tc	D / R	ES		3	8	1.25	LAI		LAI
	Bagre bagre	Ch	D	MM	PV/ZB	2	127	14.379			LAI
	Cathorops sp.	Ch	D / R	ES		4	67	12.601			LAI
	Cathorops spixii	Ch	D / R	ES	ZB	10	429	11.891			AF
	Sciades couma	Ch / Tc	D / R	ES	ZB	12	36	5.54		LAI	LAF
	**Sciades herzbergii*	Ch / Tc	D / R	ES	ZB	6	20	1.353	LAI	LAI	LAI
Aspredinidae	*Aspredinichthys filamentosus*	Ch / Tc	D / R	ES	ZB	13	125	1.7946		LAI	LAF
	Aspredinichthys tibicen	Ch	D / R	ES	ZB	3	27	0.2363			LAI
	**Aspredo aspredo*	Ch / Tc	D / R	ES	ZB	30	3099	14.904	AF	AF	AF
Auchenipteridae	**Ageneiosus ucayalensis*	Ch / Tc	D / R	FM	ZB	40	507	36.859	AF	AF	LAF
	Ageneiosus inermis	Tc	D	FS	PV/ZB	1	1	0.535		LAI	
	Auchenipterus nuchalis	Tc	D			1	1	0.052			LAI
	**Pseudauchenipterus nodosus*	Ch / Tc	D / R	FS	ZB	15	61	3.3006	LAI	LAI	LAF
	**Trachelyopterus galeatus*	Ch / Tc	D / R	FS	PV/ZB	14	69	4.1159	LAI	LAI	LAI
Belonidae	*Strongylura timucu*	Ch	D / R	MS	PV	2	2	0.0178	LAI	LAI	
Carangidae	*Oligoplites palometa*	Ch	D	MM	PV/ZB	4	36	3.1			LAI
	Trachinotus carolinus	Ch	D	MM	ZB	1	2	0.218			LAI
Cetopcidae	*Cetopsis coecutiens*	Ch	D	FS		2	2	0.1479	LAI		LAI
Characidae	*Acestrocephalus* sp.	Ch / Tc	D / R	FS		5	11	0.1053	LAI	LAI	
	Astyanax fasciatus	Tc	D / R	FS	ZB	11	41	0.827	LAI	LAI	LAI
	Astyanax sp.	Ch / Tc	D / R	FS	ZB	2	8	0.114		LAI	
	Pristobrycon calmoni	Ch / Tc	D	FS	PV/ZB	3	4	0.072		LAI	
	Serrasalmus sp.	Ch / Tc	D	FS	PV/ZB	2	6	0.206	LAI		LAI
	Triportheus elongatus	Ch / Tc	D / R	MS	ZB	8	21	1.6256		LAI	
Cichlidae	*Cichla* sp.	Ch / Tc	D / R	FS	PV	3	8	2.642		LAI	
	Crenicichla cincta	Ch / Tc	D / R	FS		2	5	0.91		LAI	

Family	Species	Environment	Seasonality	EUFG	FMFG	FO	N	W (kg)	Classification		
		Ch / Tc	**D/R**						**GR**	**GB**	**MB**
	Crenicichla johanna	Tc	D / R	FS	PV	4	6	0.835		LAI	LAI
	Crenicichla lugubris	Tc	D	FS		1	3	0.744		LAI	
	Crenicichla semifasciata	Tc	R	FS		2	3	0.446	LAI	LAI	
	Crenicichla sp.	Tc	D / R	FS		3	4	0.317	LAI		
	Geophagus proximus	Ch / Tc	D / R	FS	DV	9	27	2.083		LAI	LAI
	Geophagus sp.	Ch	D	FS		1	1	0.172		LAI	
	Geophagus surinamensis	Ch / Tc	D / R	FS	DV	6	12	0.868	LAI	LAI	
Clupeidae	*Rhinosardinia amazonica*	Ch	D	FS	ZP	1	3	0.0011			LAI
Ctenoluciidae	*Boulengerella cuvieri*	Ch	D / R	FS	PV	2	2	0.496	LAI	LAI	
Curimatidae	**Curimata inornata*	Ch / Tc	D / R	FM	HV	17	110	3.85	LAI	AF	LAI
Cynodontidae	*Raphiodon vulpinus*	Ch	D	FS	PV	1	1	0.192		LAI	
Doradidae	**Lithodoras dorsalis*	Ch / Tc	D / R	FS	HV	34	935	288.44	LAF	AF	LAF
	Lithodoras sp.	Ch / Tc	D / R	FS	HV	2	2	0.152		LAI	LAI
Engraulididae	**Anchoa spinifer*	Ch / Tc	D / R	MM	ZB	25	866	12.605	AF	AI	AF
	**Anchovia surinamensis*	Ch / Tc	D / R	FM		19	757	3.1444	LAF	LAI	AF
	Anchoviella cayennensis	Ch	D / R	MS		4	39	0.0868			LAI
	Anchoviella guianensis	Ch	D / R	FS	HV	3	79	0.05		LAI	LAI
	Cetengraulis edentulus	Ch	D / R	MS	HV	3	42	1.7		LAI	LAI
	Engraulidae sp 1	Ch	D			1	1	0.004			LAI
	Engraulidae sp 2	Ch	D			1	1	0.018		LAI	
	Engraulidae sp 3	Ch	D			1	1	0.004			LAI
	**Lycengraulis batesii*	Ch / Tc	D / R	FM	ZB	26	249	9.8253	LAF	AF	LAF
	Lycengraulis grossidens	Ch	D	ES	ZB	1	8	0.136			AI
	Pterengraulis atherinoides	Ch / Tc	D / R	ES	PV/ZB	3	14	0.6452		LAI	LAI
Erythrinidae	*Hoplias malabaricus*	Tc	D / R	FS	PV	9	20	1.886	LAI	LAI	LAI
Gasteropelecidae	*Gasteropelecus levis*	Ch	D	FS	ZB	1	1	0.002		LAI	
Gobiidae	*Gobioides broussonnetii*	Ch	D / R	ES		4	24	0.1315			LAI
Haemulidae	*Genyatremus luteus*	Ch	D	MM	ZB	15	2	0.126			LAI
Heptapteridae	**Pimelodella* gr. *altipinnis*	Ch / Tc	D / R	FS	ZB	30	1792	11.817	AI	AF	AF
	Pimelodella sp.	Ch	D	FS		1	1	0.078	LAI		
	Rhamdia quelen	Tc	D / R	FS	ZB	5	12	0.955	LAI	LAI	LAI
Hypopomidae	*Steatogenys elegans*	Ch	D / R	FS		8	181	0.7185	AI	LAI	LAI
Loricariidae	*Acanthicus hystrix*	Ch	R	FS		1	1	3.62			LAI
	Ancistrus sp.	Ch	R	FS	ZB	1	1	0.026		LAI	
	Ancistrus sp.1	Tc	R	FS	ZB	1	1	0.034		LAI	
	Ancistrus sp.2	Tc	D / R	FS	ZB	2	2	0.168		LAI	
	Ancistrus sp.3	Tc	R	FS	ZB	3	3	0.236		LAI	
	Farlowella cf. *hasemani*	Ch	D	FS		1	1	0.072			LAI
	Hypostomus plecostomus	Ch	D / R	FS	ZB	4	13	1.3382		LAI	
	Hypostomus punctatus	Ch	D	FS	DV	1	1	0.108		LAI	
	Hypostomus sp.	Tc	R	FS		1	1	0.142		LAI	
	Limatulichthys griseus	Tc	D			1	1	0.02		LAI	
	**Loricaria cataphracta*	Ch / Tc	D / R	FS	DV	16	43	1.1482	LAI	LAI	LAF
	**Peckoltia* sp.	Ch / Tc	D / R	FS	DV	18	44	2.0164	LAI	LAF	LAI
	Peckoltia sp.1	Ch / Tc	D / R	FS	DV	3	3	0.58		LAI	
	Pseudacanthicus histrix	Ch	D	FS		1	1	1.65			LAI
	Pseudacanthicus spinosus	Ch	R	FS		1	1	0.04		LAI	
Mugilidae	*Mugil curema*	Ch	D	MS	HV	1	35	5.666			LAI
	Mugil incilis	Ch	D	MS	HV	2	13	1.846		LAI	LAI
	Mugil sp.	Ch / Tc	D	MS		2	2	0.0645		LAI	LAI
Muraenidae	Not identified	Ch	D			1	1	0.0002			LAI
Paralichthyidae	*Citharichthys spilopterus*	Ch	D	ES	ZB	1	2	0.032		LAI	
Pimelodidae	*Brachyplatystoma filamentosum*	Ch	D / R	FM	PV	16	75	44.28	LAF	LAI	LAF

Family	Species	Environment	Seasonality	EUFG	FMFG	FO	N	W (kg)	Classification		
		Ch / Tc	**D/R**						**GR**	**GB**	**MB**
	Brachyplatystoma platynemum	Ch	D / R	FS	PV	5	7	10.136	LAI		
	Brachyplatystoma rousseauxii	Ch	D / R	FM	PV	25	420	122.2	AF	LAI	LAF
	**Brachyplatystoma vaillantii*	Ch / Tc	D / R	FM	PV	26	260	15.108	LAF	LAI	LAF
	**Hypophthalmus marginatus*	Ch / Tc	D / R	FM	ZP	22	229	32.985	LAF	AF	LAF
	**Pimelodus blochii*	Ch / Tc	D / R	FS	ZB	18	32	2.565	LAI	LAI	LAI
	Platystomatichthys sturio	Ch / Tc	R	FS		2	4	0.38		LAI	
	Propimelodus eigenmanni	Tc	R	FS		1	1	0.106		LAI	
Potamotrygonidae	*Plesiotrygon iwamae*	Ch	D / R	FS	PV/ZB	3	5	0.4912			LAI
	Plesiotrygon sp.	Ch	D / R			3	5	16.28			LAI
	Potamotrygon motoro	Ch	D / R	FS	ZB	4	7	23.062			LAI
	Potamotrygon sp.	Ch	D	FS		1	1	0.382			LAI
	Potamotrygon sp.1	Ch	R	FS		1	1	0.078		LAI	
	Potamotrygon sp.2	Tc	R	FS		1	1	0.082		LAI	
	Potamotrygon orbignyi	Ch	R	FS		1	1	0.832			LAI
	Potamotrygonidae	Ch	R			1	1	6.01			LAI
Pristigasteridae	*Pellona castelanaeana*	Ch	D	FM	PV/ZB	3	5	1.99		LAI	LAI
	**Pellona flavipinnis*	Ch / Tc	D / R	FM	PV	26	133	61.316	LAF	LAI	LAF
Rhamphichthyidae	*Rhamphichthys marmoratus*	Ch / Tc	D / R	FS	ZB	6	15	3.094		LAI	
	**Rhamphichthys rostratus*	Ch / Tc	D / R	FS	ZB	16	71	14.087	LAI	LAI	LAI
Sciaenidae	*Cynoscion acoupa*	Ch	D	MM	PV/ZB	15	128	6.4486		AI	LAI
	Cynoscion leiarchus	Ch	D	MM	PV/ZB	2	20	0.1323			LAI
	Cynoscion sp.	Ch	D	MM		1	1	0.0006			LAI
	Macrodon ancylodon	Ch	D / R	MM	PV/ZB	4	405	11.144			AI
	Menticirrhus americanus	Ch	D	MM	PV/ZB	1	81	0.014		AI	
	Micropogonias furnieri	Ch	D / R	MM	ZB	7	197	1.0987	LAI	LAI	LAF
	Nebris microps	Ch	D	ES	ZB	1	1	0.868			LAI
	Ophioscion sp.	Ch	D			1	1	0.0007		LAI	
	**Pachypops fourcroi*	Ch / Tc	D / R	FS	ZB	18	78	4.0424	LAI	AF	LAI
	**Plagioscion auratus*	Ch / Tc	D / R	FS	ZB	19	74	1.9816	LAI	LAI	LAF
	**Plagioscion squamosissimus*	Ch / Tc	D / R	FM	PV	42	5004	163.95	AF	AF	AF
	**Plagioscion surinamensis*	Ch / Tc	D / R	FM	PV	27	1153	33.994	AI	AF	AF
	Stellifer microps	Ch	D / R	ES	ZB	12	14727	3.8286	AI	AI	AF
	Stellifer naso	Ch	D / R	ES	ZB	14	4045	4.1937	LAI	LAI	AF
	Stellifer rastrifer	Ch	D / R	ES	ZB	10	1558	0.6026	AI	AI	AF
Scombridae	*Scomberomorus brasiliensis*	Ch	D	MM	PV	1	1	1.3			LAI
Sternopygidae	*Rhabdolichops caviceps*	Ch / Tc	D / R	FS	ZB	5	18	0.2589	LAI	LAI	
	**Rhabdolichops eastwardi.*	Ch / Tc	D / R	FS		7	668	1.6837	AI	LAI	LAI
	**Sternopygus macrurus*	Ch / Tc	D / R	FS		9	32	5.107	LAI	LAI	LAI
Tetraodontidae	*Colomesus asellus*	Ch / Tc	D / R	FS	ON	11	49	0.3935		LAI	LAI
Trichiuridae	*Trichiurus lepturus*	Ch	D	MS	PV	1	3	1.066			LAI
Trichomycteridae	*Trichomycterus* sp.	Ch	R			1	2	0.0033			LAI