Comparative Analysis of Distribution of Intertidal Fish Assemblages in Different Estuarine Systems on Northern Coast of Brazil

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Abstract

The northern coast of Brazil has more than 30 estuaries distributed along 650 km of coastline. These conditions favor the presence of relatively large fish communities in estuarine environments, but published information on the fish fauna in tidal creeks in northern Brazil is only available for some mangrove systems, and comparative studies between fish estuarine communities in different tidal creeks are less common. The choice of the study area was based on the fact that it has been poorly investigated with regard to estuarine fish fauna in comparison in mangrove tidal creeks using the same fishing gear. The objective of the present study was to compare the composition of the relative biomass of taxonomic, functional and ecological guilds of fish assemblages occurring in estuarine systems along the northern coast of Brazil. The study area of the present comparative analysis extended from the southeastern edge of the Marajoara Gulf to the western edge of the Maranhense Gulf. A comparative analysis among different estuarine systems was performed using data from other studies. The abundance of juveniles was greater in the Caeté, Curuçá and Cururuca estuaries than other estuaries. Cluster analysis separated the estuaries into two distinct groups and significant differences between these groups only exist in relation to geographical proximity. The present investigation indicates that the coastal region between the states of Pará and Maranhão is characterized by high dynamics and environmental heterogeneity, particularly with regard to changes in river discharge and tidal fluctuations. The present results underscore the importance of ecological information on ichthyofauna in tropical estuaries in order to include appropriate descriptors in conservation or restoration processes of marine communities and habitats.

Keywords: ichthyofauna, functional and ecological guilds, tidal creeks

1. Introduction

The northern coast of Brazil hosts the longest continuous stretch of coastline colonized by estuarine mangrove forests in the world, accounting for 56.6% of all mangroves in South America (Souza Filho, 2005). In this region, more than 30 estuaries are distributed along 650 km of coastline (Barletta et al., 2010), nine of which have been designated marine extractive reserves (Giarrizzo and Krumme, 2009).

Mangroves and their tidal creeks, which cover the estuarine system on the coast of the states of Pará and Maranhão, function as exporters of biomass, a source of nutrients and sediment maintainers and are conditioned by both tidal patterns and freshwater flow from hydrographic basins (MMA, 2002). These conditions favor the presence of relatively large fish communities in estuarine environments (Rozas and Zimmerman, 2000; Vidy, 2000). However, published information on the fish fauna in tidal creeks in northern Brazil is only available for some mangrove systems (Barletta et al., 2010). In general, most studies investigate the ichthyofauna communities of specific tidal creeks or analyze temporal patterns (Rountree and Able, 1997; Barletta-Bergan et al., 2002a; Layman and Silliman, 2002; Barletta et al., 2003; Spach et al., 2004).

Comparative studies between fish estuarine communities in different tidal creeks are less common (Giarrizzo and Krumme, 2007, 2008; Viana et al., 2010). For instance, Barletta et al. (2003) identified seasonal changes in the composition of fish assemblages in a macro-tidal region of the estuary of the Caeté River. Krumme et al. (2004) investigated the intertidal movements of fish (sensu Gibson, 1982) in the sub-tidal estuarine

compartments of the Caeté River and its intertidal tributaries. Giarrizzo and Krumme (2007) described the composition of and seasonal changes in fish assemblages in four intertidal mangrove creeks in a homogeneous salinity zone of the mangrove estuary of the Curuçá River.

The choice of the study area in the present investigation was based on the fact that it has been poorly investigated with regard to estuarine fish fauna in comparison in mangrove tidal creeks using the same fishing gear. To date, records have been published by Giarrizzo and Krumme (2008) and Viana et al. (2010), who carried out comparisons of the fish fauna in tidal creeks, estuaries and non-estuarine bays along the northern coast of Brazil.

The main objective of the present study was to compare the composition of the relative biomass of taxonomic, functional and ecological guilds of the fish assemblages occurring in estuarine systems along the northern coast of Brazil, testing the null hypothesis that there is no spatial or seasonal variation in the composition, structure and diversity of fish assemblages and functional groups between tidal creeks in the estuarine systems investigated.

2. Method

2.1 Study Area

The study area of the present comparative analysis extended from the southeastern edge of the Marajoara Gulf to the western edge of the Maranhense Gulf (Fig. 1). The continental shelf is 562 to 640 km wide, with islands, sand banks and intertidal creeks. The high-intertidal zone is covered by approximately 7000 km2 of mangrove forests (Kjerfve and Lacerda, 1993).

The local estuarine systems are differently influenced by the Amazon estuary, approximately 250 km west of the Marajoara Gulf. Therefore, the Gurupi River, which divides this tract of coastline into two approximately equal parts, was used as a geographic reference to separate the estuaries into two groups: those to the west of this river (Curuçá and Caeté estuaries in the state of Pará) and those to the east of it (Anil, Caranguejos Island, Cururuca, Paciência and Tibiri estuaries in the state of Maranhão) (Fig. 1).

The estuaries west of the Gurupi River are characterized by semi-diurnal, meso-tidal to macro-tidal regimens (range: 2 to 5 m) and relatively little freshwater input. In fact, the estuarization of the continental shelf and the high degree of turbidity of the waters in this area are largely determined by the Amazon River (Krumme and Saint-Paul, 2010).

The estuaries west of the Gurupi River have dynamic aspects similar to the Amazon estuary due to the greater amount of discharge. These rivers have vast floodplains with a strong marine influence and a greater variation in tidal range than the other group (up to 7 m) (Stride, 1992; MMA, 2002) as well as a wider range of salinity in the mangrove systems (Giarrizzo and Krumme, 2007). The vegetation is predominantly mangrove and forms a belt of up to 30 km wide, penetrating as many as 40 km inland as mangrove forests. The mangroves are almost exclusively composed of Rhizophora mangle L., Avicennia germinans (L) Stearn and Laguncularia racemosa (L) Gaertn.
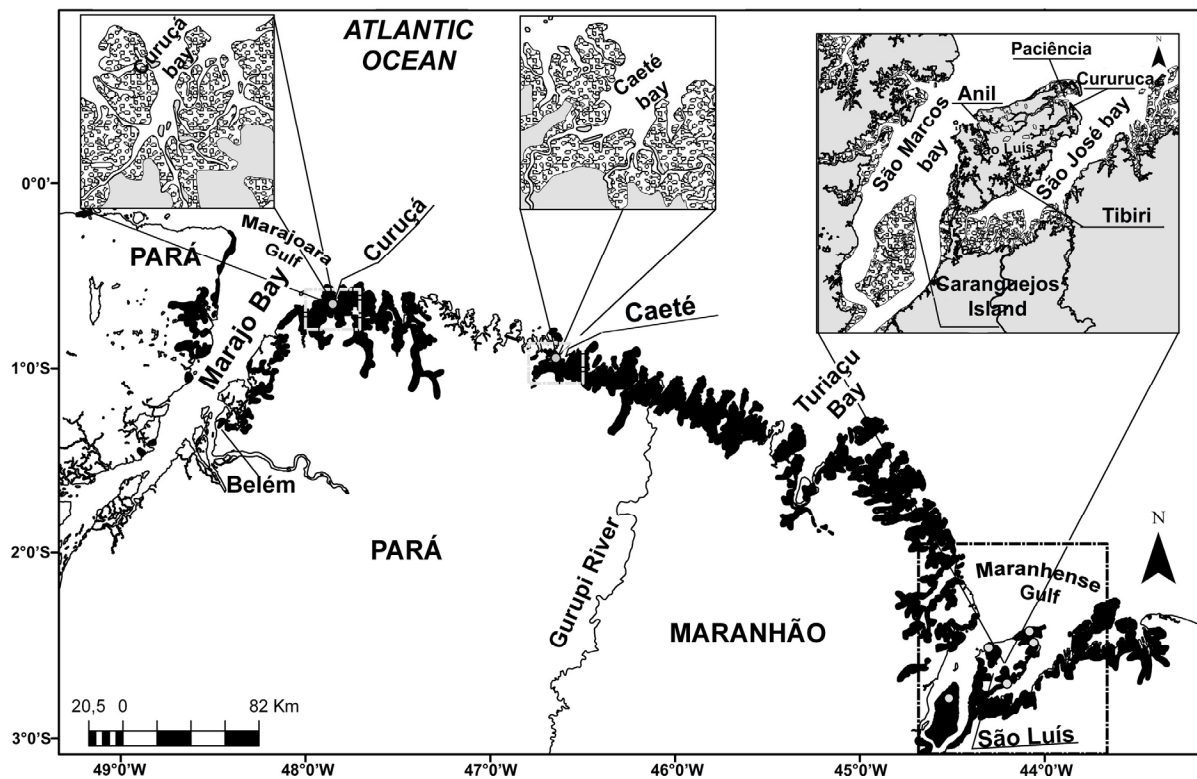
Figure 1. Northern coast of Brazil between states of Pará and Maranhão

2.2 Sampling and Data Analysis

The Paciência estuary (Maranhense Gulf) was sampled bimonthly with block nets between January 2006 and September 2007. Samples were collected in the same tidal creeks as those sampled by Castro (2001).

A comparative analysis among different estuarine systems was performed using data from SUDAM/UFMA (1983), Batista and Rego (1996), Castro (2001), Barletta et al. (2003), Pinheiro-Junior et al. (2005), Giarrizzo and Krumme (2007) and Carvalho-Neta and Castro (2008). In these studies, all sampling surveys were carried out using fixed fishing gear (block nets) set at the mouths of intertidal mangrove creeks.

Species nomenclature was standardized based on information from the FishBase (Froese and Pauly, 2010). The Shannon-Wiener diversity index was used to compare species compositions and explore the geographical variation in the ichthyofauna. Cluster analysis was conducted to explore the similarity among fish assemblages in different estuaries in terms of species composition. The matrix consisted of presence/absence data (Jaccard similarity index; PRIMER 6.0) software ©PRIMER-E Ltd). A similarity profile (SIMPROF) was built to test the statistical significance of the clusters (Clarke and Warwick, 2001). All analyses were performed using the DivEs 2.0, PRIMER 6.0 and STATISTICA 7.0 programs.

2.3 Ecological Classification

Fish species were ecologically classified based on estuary use and functional feeding mode, following Elliott et al. (2007). Five guilds defined different primary estuary use: occasional marine visitors, marine estuarine-opportunists, marine estuarine-dependent species, estuarine residents and freshwater species. Six guilds defined different feeding strategies: herbivores, omnivores, detritivores, piscivores, zoobenthivores and zooplanktivores.

3. Results

The broadest salinity range was recorded in the Curuçá, Caeté, Cururuca and Paciência estuaries (Table I). A total of 139 fish species were recorded in the entire dataset and are given as supplementary material in Appendix. However, only eight species were found in all the estuaries surveyed: *Batrachoides surinamensis* (Bloch and Schneider, 1801) *Cetengraulis edentulus* (Cuvier, 1829), *Chaetodipterus faber* (Broussonet, 1782), *Cynoscion acoupa* (Lacepède, 1801), *Cynoscion leiarchus* (Cuvier, 1830), *Genyatremus luteus* (Bloch, 1790), *Pseudauchenipterus nodosus* (Bloch, 1794) and *Sciades herzbergii* (Bloch, 1794). Thirty-two species were

located only in the estuaries west of the Gurupi River and 55 species were captured exclusively in the Maranhense Gulf (state of Maranhão).

The highest number of families and species was recorded by Castro (2001) in the Paciência estuary. The abundance of juveniles was > 80% in the Caeté, Curuçá and Cururuca estuaries and < 70% in the other estuaries.

Based on the findings of the survey, the Caeté and Curuçá estuarine systems (state of Pará) are apparently more diverse with regard to the number of families and species that the other estuaries (Maranhão). This interpretation is supported by a similar species-to-family ratio (Table I). The Shannon-Wiener diversity index also revealed similar values in the environments studied (Table I).

On a 25-year time scale since the first records on fish fauna in the Paciência estuary, a sharp decline in species and family richness in the fish assemblages has been recorded (Table I). The opposite occurred with the Shannon-Wiener diversity index, which revealed an increase in variation over the same time period (Table I).

Most families identified exhibit a pattern of spatial occurrence. Comparing the percentage of biomass of the catches, several dominant families exhibit a spatial pattern. The highest percentage of Ariidae biomass was obtained in the tidal creeks of Caranguejos Island and the Anil estuary, where *Sciades herzbergii* (Bloch, 1794) contributed most to the catches. In the Tibiri estuary, the largest contribution was provided by *Cathorops spixii* (Agassiz, 1829) and, in the Caeté estuary, *Cathorops agassizii* made the largest contribution to the catch (Eigenmann and Eigenmann, 1888).

The families Engraulidae and Haemulidae were poorly represented in the biomass from the tidal creeks. Only the tidal creeks of the Cururuca estuary exhibited a high abundance of *C. edentulus* and *Genyatremus luteus*. In the Caeté estuary, *Anchovia clupeoides* (Swainson, 1839) accounted for the highest percentage of engraulid biomass in the first group of estuaries. Within Mugilidae, *Mugil curema* Valenciennes, 1836 and *Mugil incilis* Hancock, 1830 contributed most to the values recorded in the Paciência estuary and *Mugil gaimardianus* Desmarest, 1831 contributed most to those recorded in the Anil estuary.

In the Paciência and Tibiri estuaries, the family Sciaenidae was mainly represented by *Cynoscion acoupa*. A sharply larger relative biomass of species of Tetraodontidae was recorded in the Curuçá and Caeté estuaries, with larger catches in comparison to the other estuaries. Among the species that contributed most to the catches, only *Ariopsis bonillai* (Miles, 1945) and *C. spixii* have no commercial value.

The samples contained relatively few marine occasional visitors and freshwater fish. Marine occasional visitors were virtually absent from the estuarine system located in the inner region of the Maranhense Gulf. Freshwater fish were more abundant in the Cururuca and Anil estuaries.

Marine species contributed > 50% to the total biomass collected in the second group of estuaries, but < 6% in the first group. Moreover, estuarine residents contributed > 85% in the first group, and only 65.4% in the second one.

With regard to feeding mode functional groups, detritivores accounted for > 70% of the relative biomass in the systems of the first group, but only 26.0 to 55.1% in those of the second group (Table I). Detritivores and zoobenthivores accounted for > 50% of the fish biomass collected in the second group. Zooplanktivores and herbivores were more represented in the second group, where the estuarine systems are under a greater marine influence, as was the case of engraulids. Omnivores were the least abundant category in all the systems studied, except the Paciência and Anil estuaries, where they were only more abundant than zooplanktivores (Table I).

Table 1. Comparative overview of relative biomass of taxonomic, functional and feeding categories of fish fauna in seven estuarine systems along coast of states of Pará and Maranhão, Brazil; (−) no data

| | **Estuarine systems** | | | | | | | |
| | **Pará** | | **Maranhão** | | | | | |
	Caeté[a]	**Curuçá**[b]	**Cururuca**[c]	**Tibiri**[d]	**Paciência**[e]	**Anil**[f]	**Caranguejos Island**[g]	**Paciência (present study)**
Salinity range	6.0 - 35.0	6.1 - 40.8	1.5 - 38.0	2.3 - 28.1	2.6 - 38.3	−	5.0 - 25.0	11.5 - 35.0
Number of families	26	31	21	22	33	23	19	27
Number of fish species	49	65	49	34	75	43	32	55
Number of species exclusively caught in the study	8	21	7	1	13	3	1	7
Species/family ratio	1.9	2.1	2.3	1.5	2.3	1.9	1.7	2.0
Abundance of juveniles (%)	80.0	90.0	79.6	52.4	−	−	65.5	66.2
Shannon–Wiener diversity index	0.6 - 1.1	−	1.1	1.3 - 1.7	1.2 - 1.4	0.8	1.8 - 2.5	0.3 - 1.2
Dominant families (% total catch mass)								
Ariidae	41.9	4.3	19.0	42.8	13.6	52.1	52.7	35.2
Engraulidae	14.3	3.0	17.6	2.1	1.2	1.3	0.6	5.9
Haemulidae	1.7	0.5	13.9	2.9	8.2	0.4	2.1	3.5
Mugilidae	0.9	1.5	20.2	6.1	26.8	27.9	2.4	7.2
Sciaenidae	3.3	0.8	9.9	29.7	18,0	3.0	6.8	22.4
Tetraodontidae	27.1	88.4	0.4	2.3	4.1	3.7	7.9	7.1
Estuarine Use Functional Group (% total catch mass)[h]								
Marine occasional visitors	0.3	<0.1	0.5	−	2.4	−	−	−
Marine estuarine-opportunist	5.5	2.9	50.4	19.7	21.6	18.5	8.5	22.2
Marine estuarine dependent	4.6	2.0	24.4	27.7	47.7	26.5	23.2	27.7
Estuarine residents	87.7	94.9	20.5	51.5	27.7	46.7	65.4	49.3
Freshwater fishes	1.8	0.2	4.1	1.1	0.6	8.3	3.0	0.8
Feeding Mode Functional Group (% total catch mass)[h]								
Herbivore	16.1	4.4	37.8	9.9	30.3	29.5	19.9	14.6
Omnivore	<0.1	−	1.6	−	2.7	0.2	0.2	<0.1
Detritivore	75.4	94.2	27.4	26.0	36.1	55.1	47.6	37.8
Piscivore	1.6	0.3	8.1	29.1	12.5	3.8	20.1	16.3
Zoobenthivore	5.8	0.8	20.2	34.9	18.0	11.3	11.4	31.1
Zooplanktivore	1.1	0.3	5.0	0.2	0.4	<0.1	0.9	0.2

a (Barletta *et al*., 2003);

b (Giarrizzo & Krumme, 2007);

c (SUDAM & UFMA, 1983);

d (Batista & Rêgo, 1996);

e (Castro, 2001);

f (Pinheiro-Junior *et al*., 2005);

g (Carvalho-Neta & Castro, 2008);

h (Elliott *et al*., 2007).

The cluster analysis based on presence/absence data (Fig. 2) separated the estuaries into two distinct groups (A and B − west and east of the Gurupi river, respectively), with a similarity level of only 30%. The SIMPROF test confirmed that significant differences between these groups only exist in relation to geographical proximity.
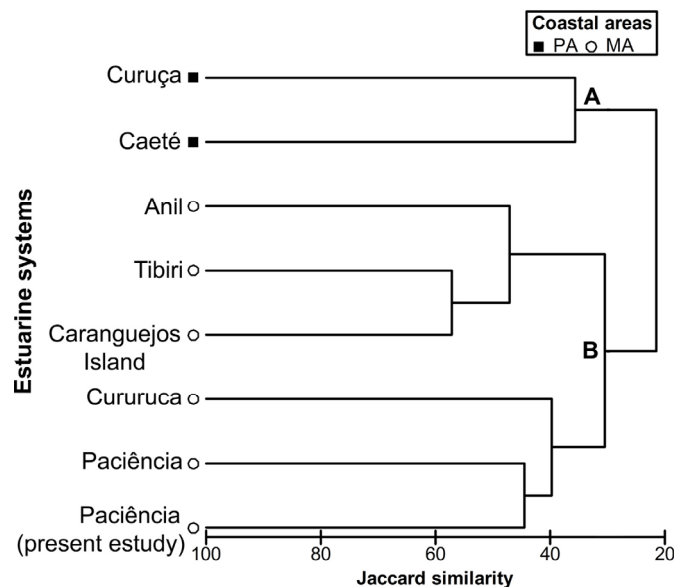
Figure 2. Dendrogram of cluster analysis of matrix presence/absence data, demonstrating similarity of estuarine systems of northern Brazil in terms of fish assemblage composition

4. Discussion

According to Barletta *et al.* (2003, 2005), the variation in the salinity gradient occurred due to salinity, demonstrating a seasonal trend in the estuarine environments. Previous studies indicate that fluctuations in salinity may be considered a primary factor influencing the distribution patterns of juvenile fish along an estuarine ecocline (Barletta *et al*., 2005, 2008). However, Blaber (2007) states that substrate type, depth and turbidity may be more important factors to determining the distribution of juvenile fish in tropical estuaries than salinity.

The data from the present study corroborate Blaber's statements, as the Curuçá and Caeté estuaries in the state of Pará are influenced by the Amazon River, where the high degree of turbidity and sedimentation make the environment propitious to the development of estuarine species. These features can therefore be considered determinants of the occurrence of juveniles in these estuarine systems. In the Cururuca estuary, the broad tidal ranges, together with the availability of detritus from the mainland, contribute toward waters rich in suspended matter, favoring the occurrence of a large number of juveniles in this estuary.

Krumme and Liang (2004) report that the number of species and species-to-family ratio are likely linked to habitat accessibility and food availability. This is observed in the estuaries of the state of Pará (influenced by discharge from the Amazon River) and in the Maranhense Gulf, which is a macro-tidal zone. Thus, it remains unclear whether there are latitudinal trends in the species-to-family ratio and its ecological potential or bio-geographical significance (Moraes *et al*., 2009).

The diversity values found on the coast of Pará and Maranhão were lower than those recorded in similar studies on fish assemblages carried out in northeastern Brazil. In the state of Paraiba, Nunes and Rose (1998) report a maximal diversity of 2.46. Santos (2000) reports diversity exceeding 3.0 on the coast of Pernambuco. Moraes et al. (2009) obtained an accumulated diversity of 2.79 on the coast of Ilhéus in the state of Bahia. The difference in diversity values may have been caused by changes in biotic and/or abiotic variables. However, the discrepancy in values in relation to those from previous studies may have been influenced by the characteristics of each ecosystem.

With regard to the reduction in the occurrence of species and the increase in diversity in the Paciência estuary, Barletta *et al*. (2005) report that seasonal changes in estuarine fish assemblages may be determined by a combination of temporal fluctuations in the abundance of species induced by rainfall as well as the reproduction and recruitment of marine, estuarine and freshwater species.

According to Barletta and Blaber (2007), the considerable tolerance of Ariidae species to areas with turbid waters and low salinity explains why this family is dominant in estuarine-resident fish assemblages throughout its worldwide distribution. Carvalho Neta *et al*. (2006) state that, in addition to these features, C. *spixii*, C.

agassizii and S. *herzbergii* have generalist opportunist feeding habits, which enable juveniles and adults to remain longer in estuaries. These findings were corroborated in the present study, as Ariidae species did not exhibit a defined geographic distribution among the tidal creeks west and east of the Gurupi River. However, Giarrizzo and Krumme (2008) found a greater abundance of Ariidae in the estuarine system of the Caeté estuary in comparison to the Curuçá estuary. The authors conclude that this occurrence may be associated with greater input in the Caeté system and, hence, a larger drift of sediment, than an increase in the number of individuals from this family in the tidal creeks of the Caeté estuary.

In the São Marcos and São José bays, adults of the most abundant engraulids use the coastal habitat and migrate to the inner waters of the estuary to spawn. However, these fish use the area under the greatest influence by the ocean for recruitment and development (Pessanha *et al*., 2000). Spatial separation may reflect adaptations to different environmental conditions or a strategy to avoid competition (Silva *et al*., 2003). In the Caeté estuary, the increase in Engraulidae biomass is likely related to an increased production of plankton toward the mouth of the Amazon River (DeMaster and Pope, 1996; Krumme and Saint-Paul, 2010).

The considerable abundance of Haemulidae and Mugilidae is likely due to a strong marine influence on São Luís Island (Giarrizzo and Krumme, 2008). Moreover, Vieira and Music (1994) report the numerical dominance of Haemulidae and Mugilidae, mainly associated with the tropical estuaries of the region. These studies indicate a trend similar to that found in the tidal creeks analyzed in the present investigation.

Cynoscion acoupa occurred in both the outer and inner portions of the Maranhense Gulf, because fish of the family Sciaenidae tolerate a wide range of salinity, which allows them to inhabit estuaries under the strong influence of freshwater (Camargo and Isaac, 2003; Matos and Lucena, 2006). With regard to Tetraodontidae, Giarrizzo and Krumme (2008) state that the strong marine influence and huge tidal range in São Marcos Bay can influence the proportion of low-mass species from this family on São Luís Island.

Regarding the classification of species according to functional group based on estuary use, Elliot et al. (2007) argue that the low contributions of marine "occasional visitor" species and freshwater species reflects the physiologically stressful nature of transitional waters of the freshwater-seawater interface. The absence of marine "occasional visitor" species in the inner portion of the Maranhense Gulf was likely due to the low salinity (< 16), which is reported to be a stressor for marine fish, restricting the type and number of species in a particular area (Bulger et al., 1995).

Garcia and Vieira (2001) and Barletta and Saint-Paul (2010) argue that the greater relative biomass of freshwater species in estuarine environments may be due mainly to the high degree of river discharge. The authors also assume that the fresh water level and flow toward the estuary increase in the late rainy season, leading to a decline in salinity, which enables creatures from freshwater environments to reach estuarine environments. However, the group of marine species had a low contribution in catches in the tidal creeks on the coast of Pará, indicating that this group of marine species only enters this region to perform certain biological functions, such as feeding and breeding (Carvalho-Neta and Castro, 2008). According to Barletta-Bergan (2010), these habitats are not preferred by the larvae of many marine species due to the high degree of turbidity and seasonal variations in salinity. The author states that the sciaenid C. *acoupa* is the only marine species with extensive use of mangrove intertidal creeks in the Caeté estuary as nurseries.

According to a survey carried out by Andrade-Tubino et al. (2008), the northern and northeastern regions of the Brazilian coast have the highest numbers of estuarine-resident species. This pattern of occurrence is due to environmental characteristics and the behavior of species, which is mainly related to trophic and reproductive migrations, with a uniformity of occurrence among the fish fauna in estuarine environments (Castro, 1997).

Regarding the feeding pattern of the species, detritivores occurred preferentially along of estuarine systems of the coast of the state of Pará. In a previous study carried out in the same estuary region, Krumme *et al*. (2004) also found that detritivores dominated the fish fauna of the mangrove tidal creeks of the Caeté estuary. When the food supply is mainly based on the consumption of debris, most of the fish production is trapped in the near-shore estuarine system (Krumme and Saint-Paul, 2010). Studies addressing trophic guilds in the tidal creeks in the Maranhense Gulf indicate uniformity in the diet of the fish species caught, mainly because few tropical species have specialized feeding habits (Abelha, 2001). Most species are generalists, with some degree of preference in the use of available resources in the environment (Pereira et al., 2007).

Based on the feeding mode functional group, more than half the species occurring in the Maranhense Gulf were detritivores and zoobenthivores. In a comparative study, Giarrizzo and Krumme (2008) also found that the contribution of zoobenthivorous species in the creeks of Maranhão was approximately fivefold greater than in the creeks of Pará. In the present study, engraulids exhibited zooplanktivorous and herbivorous habits, especially

in tidal creeks under greater marine influence. Addressing the feeding habits of two species of Engraulidae, Sergipense et al. (1999) stress the fact that these are typically planktivorous fish. However, different species have different food preferences (zooplankton or phytoplankton).

The contrast of the low occurrence of piscivores in relation to the high abundance of juveniles in the Pará and Maranhão estuarine systems, demonstrates that intertidal mangrove creeks are important nursery areas for many fish populations along the northern coast of Brazil (Barletta-Bergan *et al*., 2002b; Giarrizzo and Krumme, 2008; Krumme and Saint-Paul, 2010). According to a number of authors, a high occurrence of juveniles may be associated with the high productivity of a given system (Clough, 1998; Dittmar and Lara, 2001), the low risk of predation due to the structural heterogeneity of mangrove habitats (Laegdsgaard and Johnson, 2001) and a high degree of water turbidity (Krumme *et al*., 2004). This underscores the importance of this ecosystem to the development of recruits (Dantas et al., 2010).

According to the information available in the relevant literature, the spatial and seasonal differences in the fish assemblages in each region may be linked to spatial heterogeneity and the characteristics of the adjacent marine areas as well as the considerable tolerance of species to variations in salinity. Moreover, landscape factors, such as the position of the creeks relative to the ocean or continent, likely also play a significant role in the differences in the composition of the fish fauna in intertidal creeks of mangroves, regardless of salinity (Giarrizzo and Krumme, 2007). This suggests that the combination of the geomorphology of the estuary and drainage of the river basin influences the distribution of fish assemblages in the ecocline of an estuarine ecosystem (Barletta et al., 2010).

Understanding the variations in the fish fauna on different spatial and temporal scales can provide valuable insights for management and conservation strategies (Barletta *et al*., 2010). Moreover, it is postulated that trophic relationships and breeding cycles also have critical importance in the spatial-temporal distribution of estuarine fish fauna (Andrade-Tubino *et al*., 2008).

In conclusion, the present investigation indicates that the coastal region between the states of Pará and Maranhão (Brazil) is characterized by high dynamics and environmental heterogeneity, particularly with regard to changes in river discharge and tidal fluctuations. In relation to the dominance of juveniles of almost all fish species, the estuarine systems analyzed provide important ecological conditions to the breeding of fish assemblages, which are targets for local fishing activities. Tetraodontidae were the most representative group on the coast of Pará and the abundance of species from this family was strongly influenced by the hydrodynamics of the Amazon River. Consequently, the increased discharge of fresh water in estuaries in the state of Pará favors the occurrence of this group.

The environmental characteristics of the northern coast of Brazil create favorable conditions for the occurrence of estuarine species, but do not limit the presence of marine and freshwater species, allowing these groups to contribute to local catches. Thus, the protection of estuarine systems should be considered an essential action for the management of fishery resources, since there is a strong relationship between abundance of fish fauna and composition of the habitat. However, although this coastal region is very rich and has one of the largest continuous areas of mangrove in the world, there is insufficient information on the northern coast of Brazil for an accurate determination of the general spatial relationship between the characteristics of the intertidal creeks of the mangrove and the fish assemblage structure. Therefore, additional studies on trophic ecology associated with other biological aspects of the species can provide important information for planning the rational management of fishery resources in the coastal region between the states of Pará and Maranhão, Brazil.

Acknowledgments

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Appendix

Supplementary material

Supplementary material associated with this article, containing a list of species according to estuary use and functional feeding mode in estuarine systems.

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