

Ecological Impacts of the African Catfish *Clarias Gariepinus* at Environmental Protection Area in Southeastern Brazil

Michelle Torres Dumith (✉ midumith@gmail.com)

Federal Fluminense University: Universidade Federal Fluminense <https://orcid.org/0000-0002-0081-1116>

Alejandra Filippo Gonzalez Neves dos Santos

UFF: Universidade Federal Fluminense

Research Article

Keywords: aquatic invasion impacts, habitat overlap, invasive alien fish, abiotic variables, climate change

Posted Date: January 7th, 2022

DOI: <https://doi.org/10.21203/rs.3.rs-1132915/v1>

License:   This work is licensed under a Creative Commons Attribution 4.0 International License.

[Read Full License](#)

Abstract

The African catfish (*Clarias gariepinus*) is considered one of the most important species of catfish for aquaculture. It has a great capacity to withstand several stress factors, such as harsh abiotic conditions, in addition to wide feeding flexibility. However, the species was detected in the Guapimirim Environmental Protection Area in southeastern Brazil, threatening native fish diversity and ecosystem functioning of this ecosystem. In 2018, during the dry and wet seasons, samples of the fish community were collected at thirty-two sites of the Guapi-Macacu River, in addition to abiotic variables (salinity, pH, temperature, turbidity, dissolved oxygen, and transparency) to diagnose which factors influence the distribution of the alien species along the river. Multivariate analyses indicated that African catfish dominate the region in the buffer zone to the Environmental protection area, benefiting from higher levels of dissolved oxygen and temperature. However, *C. gariepinus* does not dominate yet the most protected area of Guapimirim, where the highest percentage of native fish species inhabit. Climate change associated with changes in abiotic factors might significantly contribute to the dominance of the invasive alien species in this protected area, which might colonize the entire river.

Introduction

Invasive alien species (IAS) are considered one of the main threats to biodiversity and an important component of global environmental change (Clavero & García-Berthou, 2005). Once present and acclimated, IAS becomes difficult to control and result in marked changes to the native fauna, thus compromising the balance and stability of the ecosystem through reductions in their stocks, extinctions, competition, spreads of pathogens, and hybridization (Agostinho & Julio, 1996).

The African catfish, *Clarias gariepinus* (Burchell, 1822), is native to much of the African continent and parts of southwestern Asia such as Israel, Syria, and southern Turkey (Graaf & Janssen, 1996). It is considered one of the most important species of catfish for aquaculture (Osibona et al., 2006) and the third most important commercial species in countries such as Egypt (Khallaf & Gaber, 1991). Furthermore, its ability to move to the terrestrial environment and breathe atmospheric air through pseudo lungs confers exceptional capacity to tolerate adverse conditions of extreme temperatures and low oxygen concentrations (Graaf & Janssen, 1996).

Clarias gariepinus was introduced to Brazil in the 1980s for aquaculture and pay fishing (Agostinho et al., 2007). Currently, this species is produced commercially, mainly in Santa Catarina state (58.9% of the total fish production in 2007), followed by Espírito Santo (39.7%) and Rio de Janeiro states (1.3%) (IBAMA, 2009). However, because *C. gariepinus* is considered a carnivorous, vigorous, and highly resistant species, its escape from production systems into the natural environment has threatened several native fish species (Umbria, 2008), becoming a potent IAS for that ecosystems.

In Brazil, there are still few studies about invasive populations of *C. gariepinus* (Weyl et al., 2016). The riverside population knows the presence of African catfish of the Guapi-Macacu River and in the

Guapimirim Environmental Preservation Area in southeastern Brazil. However, we know little about its distribution and its possible impacts on native fish fauna. Thus, the objectives of our study are: 1) Analyze which environmental parameters influence the distribution of the fish species; 2) Identify the distribution of the population of African catfish, as IAS along the river; 3) Identify possible species of fish as bioindicators in the river, and 4) Identify what possible impacts of the IAS on the Guapi-Macacu River's ichthyofauna.

Methodology

Study area

The Guapimirim Environmental Protection Area (Guapimirim EPA) is at the bottom of the Guanabara Bay, one of the most critical coastal areas of the Brazilian coast, located in Rio de Janeiro - Brazil. The Guapimirim EPA is a Federal Conservation Unit created in 1984 with the primary objective of protecting the mangrove remnants located in its hollow and ensuring the permanence and survival of human populations that maintain a close relationship with the environment (Ecologus-Agrar, 2005). Inside the EPA, the Guanabara Ecological Station (Guanabara ESEC) is located. Guanabara ESEC has about 2,000 ha and is a fully protected Conservation Unit, with no entry allowed for people within its limits, except for scientific or educational purposes, with the consent of its managing body.

The low courses drain the Guapimirim EPA of several rivers and channels, and the Guapi-Macacu, Caceribu, and Guaxindiba-Alcântara rivers stand out due to the size of their flow. There are also the watercourses inland to the EPA, whose main representatives are the Guaraí and Guaraí-Mirim. The hydrographic region that contributes to the Guapimirim EPA, has about 2,890 km² and the main basins are those of the Imboaçú, Guaxindiba-Alcântara, Caceribu, Guapi-Macacu, Roncador, Iriri and Suruí rivers. Only three sub-basins flow directly into the Guanabara ESEC area: the Guapi-Macacu, Macacu/Caceribu, and Guaxindiba river basins.

The Guapi-Macacu River has the highest flow in the entire hydrographic region of the Guanabara Bay, the drinking water supplier for all the municipalities in its eastern part, except Bonito River. The Guapi-Macacu River has physiography divided into three segments or areas: the first one descends the slope of the Serra do Mar in the form of rapids and waterfalls, with its banks covered by Atlantic Forest. Short, a second area runs through a transition between the cliffs and the plains, with less rugged formation. In this segment, the rivers surrounded by riparian forest surround hills with rounded and massive shapes with altitudes below 1000 m. And a third area, formed by the low course, which is longer and runs through lowland areas, with flat terrain and minimal unevenness, is easily flooded and subject to tidal influences. The vegetation of the lower segment is composed of small shrubs, pastures, and mangroves (Costa, 1999). The most expressive urban centers in quantitative terms are the headquarters of Cachoeiras de Macacu and Guapimirim (Ferreira, 2012).

Sampling

We collected The fish in February (wet season) and August 2018 (dry season) in the Guapi-Macacu River, using nets with different meshes, traps, holes, hooks, and lines. Fishing gear was installed and used at night because the species under study has a nocturnal habit. At the same time, using a multiparameter probe Hanna model HI 9828, we measured, *in situ*, the physicochemical variables of water: temperature (°C); pH; dissolved oxygen (mg/L); transparency (cm); turbidity (FNU); and salinity (PSU). The sampling did distribute in thirty-two points: ten points between the mouth of the river and the inner limit of Guanabara ESEC (downstream area); 12 points between the outer boundary of Guanabara ESEC and the inner perimeter of the Guapimirim EPA (intermediate zone); and ten points distributed between the outer limit of the Guapirim EPA to the dam (upstream area), within the Buffer Zone of the Guanabara Ecological Station (Guanabara ZA), totaling 64 samples points in both seasons (Figure 1). We removed the waiting nets 24 hours after being installed. The fish were grouped in CPUE (Capture per Unit of Effort) at each sampling point and placed in plastic bags, labeled and refrigerated on ice, and then transferred to the Laboratory of Applied Ecology, UFF.

Laboratory activities, data processing, and statistical analysis

The fish collected were identified according to Reis et al. (2003); Figueiredo and Menezes (1978, 1980, 2000); and Menezes and Figueiredo (1980, 1985), weighed and measured. To characterize the fish communities were analyzed: richness, abundance, biomass, diversity, dominance, and evenness indices. We calculated the richness through the total number of species collected at each sampled point and the abundance from the total number of individuals collected. For diversity analysis, the Shannon-Wiener index, the Simpson dominance index, and Pielou's evenness were used (Magurran, 1988).

We the Multivariate Permutation Analyses of Variance (PERMANOVA) in Program R (R Core Team, 2020), available in the VEGAN package (Oksanen *et al.*, 2020), to test whether spatial and seasonal differences in physicochemical variables of water and ecological descriptors of ichthyofauna were significant ($p < 0.01$). PERMANOVA was also applied to test the spatial and temporal variation of species richness, abundance, and biomass of fish and the diversity, equitability, and dominance indices. PERMANOVA is similar in strength to traditional ANOVA and does not require the assumptions of normality and homoscedasticity (Anderson, 2001; McArdle & Anderson, 2001). Therefore, we use the Bray-Curtis distance in all PERMANOVA tests, with data exchanged 4999 times per analysis, as Manly (2018) recommended for tests with $p < 0.01$.

The *Multinomial Species Classification Method* (CLAM) was used, through the "CLAMTEST" function available in the VEGAN package (Oksanen *et al.*, 2020), to classify fish species into generalists or specialists in the rainy and dry seasons without excluding rare species (Chazdon et al., 2011). This method uses a multinomial model to estimate the relative abundance of species in two groups (A, B), minimizing adverse effects due to sampling differences or insufficiency within each habitat (Solymos, 2020). We stipulate a limit of 50% of specialization in each season, with a significance level of 95% for individual tests.

To analyze the spatial proximity and formation of groups, according to the abundance found, taking into account the river as a whole, Cluster Analysis was used, through the "*HCLUST*" function of the *DENDEXTEND* package, using the "ward. D2" (Galili, 2015), and the Bray-Curtis distance in the dissimilarity matrix of the *VEGAN* package (Oksanen *et al.*, 2020). The sum of squares criterion was utilized for this agglomerative method, producing groups that minimize the dispersion within the group in each binary fusion (Murtagh & Legendre, 2014). In addition, the specificity and fidelity (*IndVal*) of each species we calculated using a permutation test (with a significance of 0.05), using the "*MULTIPATT*" function, available in the *INDICESPECIES* package (De Cáceres *et al.*, 2020). Finally, we used the fidelity and specificity test to determine which indicator species are simultaneously between seasons (wet and dry) and river areas and only between river segments, regardless of the season.

Canonical Correspondence Analysis (CCA), considered one of the best methods for direct gradient analysis in community ecology (Ter Braak 1986, Rodriguez & Lewis, 1997), was used in the R program version 4.0.2 (R Core Team, 2020), available in the *VEGAN* package (Oksanen *et al.*, 2020), and applied to the matrix of environmental and biological data (excluding the rare species previously selected in the CLAM model), to identify which physical-chemical variables of water contributed most to the characterization of the points of the river in the wet and dry seasons, as well as to verify the distribution of the abundances of the fish species found, correlating them with the environmental variables (complete model). The multicollinearity of physicochemical variables was diagnosed to select redundant variables and obtain an adequate model. For this, the "*ORDISTEP*" function was used, which performs an automatic selection, which compares the model in which no environmental variable explains the variation in species composition and abundance (null model) with the complete model (where we used all environment variables), based on permutation test using the P-value. The variable selection procedure based on P-value seeks to find the ideal model, in which only the most significant environmental variables explain the model (Blanchet *et al.*, 2008). Subsequently, the significance of both models (complete and reduced model) did test, as well as which axes and terms were significant, by analysis of variance (ANOVA), using the "*ANOVA.CCA*" function. This function allows determining whether the environmental variables have an essential relationship and differences in the composition and abundance of species and how many axes are needed to present this relationship. Thus, an ideal and reduced model for the Guapi-Macacu River was obtained, which exposes which environmental variables can predict changes in the composition and abundance of the ichthyofauna and show which species will be affected in this relationship.

Results

PERMANOVA identified significant differences for all environmental variables among areas and seasons studied, except for temperature that did not show clear differences between the river segments (Table 1). Water temperature was higher in the rainy season. Salinity was much higher downstream of the river in the dry season but much lower in the rest of the groups (site and season combinations). Transparency was higher in the dry season and in the upstream sites. Dissolved oxygen (DO) was higher in the dry season than in the rainy season. Higher DO values occurred in the upstream segment during the dry season, followed by the intermediate and downstream areas. In the rainy season, DO was higher in the

upstream region, followed by the middle area and downstream. The pH was also higher in the dry season than in the rainy season. Higher values were recorded in the upstream segment during the dry season, followed by the downstream and intermediate zones. During the wet season, the pH remained the same for the three parts of the river. The highest turbidity values occurred in the rainy season downstream, followed by the intermediate and low segments. During the wet season, turbidity did not vary significantly between the three areas of the river (Figure 2).

Table 1
PERMANOVA analyses of environmental variables in the Guapi-Macacu River with segments and seasons (dry/wet) as factors.

	Area		Season	
	<i>F</i>	<i>p</i>	<i>F</i>	<i>p</i>
Salinity	19.93	< 0.001	11.799	< 0.001
Temperature	0.4311	0.660	299.6786	0.0002
pH	4.2159	0.020	92.8138	0.0002
DO	5.1768	0.008	27.1637	0.0002
Transparency	15.038	< 0.001	189.762	< 0.001
Turbidity	17.625	< 0.001	102.902	< 0.001

Thirty-one species were collected regarding the ichthyofauna, referring to 427 specimens, distributed in nine orders and 21 families (Table 2). The distribution of the relative abundance of the fish community along the Guapi-Macacu River between the areas and sampled seasons is exhibited in Figure 3. PERMANOVA detected significant differences for fish abundance in relation to the area ($F= 2.6214$; $p = 0.0454$) and the season ($F= 6.9902$; $p = 0.0020$). The highest abundance of medians occurred in the dry season downstream.

Table 2

List of species (authors), code in the analyses, abundance, biomass, size classes, and CLAM classification of the ichthyofauna collected in 2018 along the river Guapi-Macacu-RJ.

Species	Code	Abundance	Biomass (g)	Size class (mm)	Classification/season
<i>Acestrorhynchus lacustres</i> (Lütken, 1875)	ALA	4	261.068	130-257	Rare
<i>Astyanax altiparanae</i> Garutti&Britski, 2000	AAL	7	80.16	90-100	Rare
<i>Astyanax fasciatus</i> (Cuvier, 1819)	AFA	1	15.867	115	Rare
<i>Brevoortia pectinata</i> (Jenyns, 1842)	BPE	15	1000.303	143-300	Specialist/Dry
<i>Centropomus parallelus</i> Poey, 1860	CPA	28	5563.947	120-415	Specialist/Wet
<i>Centropomus undecimalis</i> (Bloch, 1792)	CUN	14	3365.919	125-455	Generalist
<i>Clarias gariepinus</i> (Burchell, 1822)	CGA	30	43970	345-830	Generalist
<i>Cynoscion acoupa</i> (Lacepède, 1801)	CAC	1	372	350	Rare
<i>Cyphocharax gilbert</i> (Quoy&Gaimard, 1824)	CGI	7	986.376	178-208	Rare
<i>Diapterus rhombeus</i> (Cuvier, 1829)	DRH	7	243.309	105-159	Rare
<i>Elops saurus</i> Linnaeus, 1766	ESA	8	758.023	201-293	Rare
<i>Eucinostomus argenteus</i> Baird&Girard, 1855	EAR	4	274.482	153-195	Rare
<i>Eugerres brasilianus</i> (Cuvier, 1830)	EBR	30	2794.393	114-370	Specialist/Dry
<i>Genidens genidens</i> (Cuvier, 1829)	GGE	57	5163.797	105-320	Generalist
<i>Geophagus brasiliensis</i> (Quoy&Gaimard, 1824)	GBR	8	30274.227	78-250	Rare
<i>Gymnotus carapo</i> Linnaeus, 1758	GCA	1	272	390	Rare
<i>Hoplias malabaricus</i> (Bloch, 1794)	HMA	10	12560	280-395	Rare

Species	Code	Abundance	Biomass (g)	Size class (mm)	Classification/season
<i>Hoplosternum littorale</i> (Hancock, 1828)	HLI	22	1528.875	86-190	Specialist/Wet
<i>Hypostomus auroguttatus</i> Kner, 1854	HAU	51	7647.396	180-334	Generalist
<i>Leporinus friderici</i> (Bloch, 1794)	LFR	1	242	264	Rare
<i>Loricariichthys castaneus</i> (Castelnau, 1855)	LCA	30	4379.137	259-354	Generalist
<i>Micropogonias furnieri</i> (Desmarest, 1823)	MFU	33	4003.924	110-335	Specialist/Dry
<i>Mugil curema</i> Valenciennes, 1836	MCU	1	148	250	Rare
<i>Mugil liza</i> Valenciennes, 1836	MLI	3	2043.7	230-425	Rare
<i>Oligosarcus hepsetus</i> (Cuvier, 1829)	OHE	6	414.461	128-223	Rare
<i>Oreochromis niloticus</i> (Linnaeus, 1758)	ONI	16	66070.369	126-362	Specialist/Wet
<i>Plagioscion squamosissimus</i> (Heckel, 1840)	PSQ	1	630	330	Rare
<i>Prochilodus lineatus</i> (Valenciennes, 1837)	PLI	1	13.461	110	Rare
<i>Rhamdia quelen</i> (Quoy&Gaimard, 1824)	RQU	11	129445.269	119-375	Generalist
<i>Trachelyopterus striatulus</i> (Steindachner, 1877)	TST	18	2496.304	154-225	Generalist
<i>Trinectes microphthalmus</i> (Chabanaud, 1928)	TMI	2	14.468	50-55	Rare

The PERMANOVA for species richness showed significant differences only between the dry and rainy seasons ($F= 4.8069$; $p = 0.0226$). Richness exhibited higher medians in the dry season downstream and the lowest median in the rainy season downstream. Biomass showed significant differences in PERMANOVA only between the dry and rainy seasons ($F=5.8107$; $p=0.0032$). The dominance showed differences between the segments of the river, detected by PERMANOVA ($F=3.6422$; $p=0.0326$).

PERMANOVA did not see significant differences between the other zones and seasons, as well as for diversity and evenness ($p > 0.05$, for all) (Figure 4).

The CLAM classification portrays that 22.6% of the species collected were classified as generalists in the dry and wet seasons, frequently occurring in the two seasons studied, while 9.7% were classified as specialists in the rainy season and 9.7% in the dry season. Rare species in the samples corresponded to 58.1% (Figure 5).

As for the cluster analysis results, this coincided with the previous demarcations shown in Figure 1, portraying the physiography of the Guapimirim EPA in the spatial separation of the ichthyofauna (Figure 6). The main species that make up the Guapimirim EPA were more on the left of the dendrogram. The species in the right part of the dendrogram are distributed in the upstream area and cover the entire river, and the rare species that make up the last two groups formed. In this classification, the target species *C. gariepinus*, appears close to groups with wide distribution in the river, such as *L. castaneus*, *T. striatulus*, and *H. auroguttatus*. Furthermore, *C. gariepinus* occurs similarly to *R. quelen* and *T. striatulus*, sharing the same habitats.

The specificity and fidelity analysis (*IndVal*) showed as indicators the most important species that make up the two main groups formed in the cluster analysis (continuous line and dotted line). Regarding specificity and fidelity between areas and seasons, the analysis selected six species. In the downstream dry season, the selected species were *B. pectinate* (67.9%; $p = 0.001$), *M. furnieri* (58.0%; $p = 0.008$), and *E. saurus* (48.0%; $p = 0.021$). *Genidens genidens* exhibited high fidelity and specificity in the downstream segment in the two sampled seasons (76.9%, $p = 0.001$). *Acestrorhynchus lacustres* were selected as an indicator species in the upstream segment in the rainy season (52.2%; $p = 0.008$), while *T. striatulus* in this same segment in the two sampled seasons (53.4%, $p = 0.035$). When we performed the *IndVal* analysis only for the river segments, seven species were selected, grouping them in the two analyzed stations. In the group formed only upstream, the species *C. gariepinus* (54.8%, $p = 0.013$), *T. striatulus* (52.6%, $p = 0.007$), and *A. lacustres* (39.7%; $p = 0.025$) showed fidelity and specificity. In the downstream segment, exclusive area of Guanabara ESEC, the function selected *G. genidens* (76.9%, $p = 0.001$), *B. pectinate* (52.2%, $p = 0.003$) and *M. furnieri* (45.2%, $p = 0.043$). The only species selected for both regions within the Guapimirim EPA (downstream and intermediate area) was *C. undecimalis* ($p = 0.022$), demonstrating 51.2% specificity and fidelity.

The CCA ordination diagram explained 40% (ANOVA, $F = 1.956$; $p = 0.001$) of the total distribution of species abundance (generalists and specialists selected in the CLAM model) with abiotic variables about the river segments and seasons rainy and dry (Figure 7). The complete model (Figure 7A) showed the distribution of species with all abiotic variables, with the first axis explaining 39.60% of the samples (ANOVA, $F = 4.9758$; $p = 0.003$) and the second axis explaining 22.58% of the samples (ANOVA, $F = 2.8375$; $p = 0.111$), with the relation between the differences in the distribution of fish species. Among the selected environmental variables, ANOVA revealed significant differences for dissolved oxygen ($F = 2.2514$; $p = 0.033$), transparency ($F = 2.0854$; $p = 0.028$), temperature ($F = 1.6246$; $p = 0.057$), and pH ($F = 3.7788$;

$p=0.017$), being related to the distribution and abundance of fish species, as well as the river segments. ANOVA did not show significant differences in CCA for turbidity ($F = 1.9987$ and $p = 0.061$), and salinity ($F = 1.0788$; $p = 0.372$).

On the other hand, the significance of the axes is changed in the reduced model, obtained through the "ORDSTEP" function (Figure 7B). In this second model, the three axes are significant ($p < 0.02$, for all), together explaining 73.19% of the samples. The most significant variables for each area of the river analyzed were distributed as follows: pH presented a significant correlation with the species distributed further downstream from the river ($F=3.3683$; $p=0.010$); transparency was mainly correlated with species in the intermediate area ($F=3.1519$; $p=0.001$); and the DO was the most crucial physicochemical parameter for the species upstream of the river ($F=2.5752$; $p=0.004$), all presenting high statistical significance.

Discussion

Abiotic variables in the Guapi-Macacu River

In the Guapi-Macacu River, salinity was higher downstream in both seasons, while the values of DO and pH were higher in the dry season upstream. Partially similar results were reported by Macêdo et al. (2000) in the Rio Formoso estuary (Pernambuco, Brazil), which detected the highest pH values in the lower estuarine area, beyond has higher DO and salinity. According to Macêdo et al. (2000), salinity and oxygenation levels are influenced by tidal cycles and photosynthesis and respiration rates. The existing neutralization capacity in the aquatic ecosystem due to the buffer effect prevents wide pH variations. Therefore, maximum values did obtain in areas with more significant saline influence. In the Guapi-Macacu River, the highest salinity at the mouth of the Guanabara Bay is expected because it is a coastal segment, and its intensity may vary with the rainy season, which favors its dilution. The higher DO and pH rates reflect a season without rain, with greater water transparency, favoring photosynthesis that removes CO_2 raising the pH of the water due to the consumption of H^+ ions.

When analyzed individually, it observed that temperature and pH were the environmental attributes that were not related to the different segments of the river but seasons. The highest temperature in the rainy season corresponds to the hottest season of the year in South America. However, there is collinearity of environmental attributes. When they are presented in the reduced model and correlated with species abundances, pH reveals as a variable with high significance for the downstream area, probably due to its higher value in the dry season. The association of the other variables analyzed, such as the predominance of increased transparency in the intermediate region of the river, contributed to a better distinction between the river segments in the dry and rainy seasons, corroborating the environmental characteristics of the Guapi-Macacu River in the Guapimirim EPA, and serving as predictors for related fish species in this habitat. According to Blaber (2000), fish from tropical estuaries are subject to a range of interactions of physicochemical and biological factors that determine their patterns of occurrence, distribution, and movement. According to this author, in the Rio Formoso estuary (Pernambuco, Brazil),

the temperature, salinity, pH, and dissolved oxygen were higher in the lower estuarine zone and dry season. In estuarine regions of Pernambuco, seasonal variations in water temperature and salinity are well evidenced, with the highest values being recorded in the dry season (Macêdo et al., 2004).

However, deficient levels of DO can be seen in the area downstream of the river, especially in the rainy season, coinciding with the lowest richness and abundance recorded. For Edokpayi et al. (2017), levels of DO concentrations below 5.0 mg/L adversely affect aquatic life. Furthermore, during the rainy season, Guanabara Bay drags organic materials and concentrates contamination during the dry season to the area downstream of the Guapi-Macacu River. In addition to the resuspension of sediments, explain less oxygenation during the wet season in this area.

The fish assemblage of the Guapi-Macacu River

The fish assemblage of the Guapi-Macacu River, within the Guapimirim EPA and its Buffer Zone, has freshwater species with marine species, many of which are euryhaline. Marine species were concentrated in the lower part of the river (downstream), at the mouth of the Guanabara Bay, with some species migrating to inland areas, such as bass, mullet, carapebas, and croakers. This segment was constituted by resident species, marine and freshwater migrants, which use the estuaries as feeding areas, for rearing larvae and juveniles, or for reproduction (Blaber, 2000). These habitats favor the presence of various fish populations on their margins (Vidy, 2000), consisting mainly of juveniles of marine species (Rozas & Zimmerman, 2000). The greater abundance of fish downstream of the Guapi-Macacu River is probably due to the food availability from primary production, structural complexity of mangrove vegetation, which provides refuge, especially for young fish, and high water turbidity. According to Loebman & Vieira (2005), the structure of the tropical estuarine fish fauna varies with the type of estuary and with differences in the spatial and temporal pattern of the community.

The lower abundance of fish in the rainy season may be related to the season of greater water volume in the river, providing greater availability of more sheltered areas, facilitating dispersal, and hindering fish collection. In estuarine environments, mangroves provide a natural refuge for young individuals due to the protection provided by the root structure of their trees. Most of the fish caught in tropical coastal areas enjoy this protection during their young phase and at the time of laying and thus depend closely on the integrity of this ecosystem (Lacerda, 1984). In general, the ichthyofauna remains with the most abundant species still well preserved, especially in the area further downstream from the river. For Teixeira *et al.* (2005), the determination of biodiversity, especially of the fish community and its spatial and temporal variation patterns, is of great relevance to assessing environmental quality.

The Siluriformes was the order with the most incredible abundance of fish in the Rio Guapi-Macacu. The dominance of Siluriformes over the others constitutes a characteristic pattern of the eastern region of Brazil, being particularly accentuated in areas of high river courses, where the condition of high hydrodynamics favors the occupation by demersal species (Bizerril & Primo, 2001). The site with the most increased occurrence of native species is also located downstream of the river, within Guanabara ESEC, the area of most preservation within the Guapimirim EPA and with better ecological indices, such

as abundance and richness of the species found, especially in the dry season. *Genidens genidens*, representative of the second most abundant family, Ariidae, occurs in coastal areas and is generally more significant in shallow coastal waters, on a muddy or sandy bottom (Araujo, 1988; Andreatta et al., 1989). The presence of *G. genidens* downstream of the river may be related to the spawning season. The species seek the mouth of the rivers performing oral incubation with males and rarely females, carrying eggs and initial forms of offspring until they complete embryonic development (Yanez-Arancibia & Sanchez-Gil 1988; Reis, 1986b), which explains the presence of specimens downstream in the Guapi-Macacu River. In addition, *G. genidens* had high levels of fidelity (59.09%) and specificity (100%), considered a perfect indicator species in the *IndVal* analysis. The *IndVal* method has some advantages compared to other bioindication methods, is calculated for each species independently, where the categorization of habitats occurs without restrictions and can be grouped subjectively or quantitatively (McGeoch & Chown, 1998).

Thus, the *IndVal* analysis establishes that for this specific area, regardless of the season analyzed, three species were considered indicators of this habitat *G. genidens*, *B. pectinata*, and *M. furnieri* (Figure 8A). In addition to these species, *E. saurus* was selected only for the dry season in the downstream area. All species chosen for the downstream area were considered asymmetric indicators, as they contribute more to habitat specificity than fidelity (Dufrêne & Legendre, 1997). This segment was also particularly evidenced in the cluster analysis, which showed that the main species selected in *IndVal* share this river segment.

The area within the Guapimirim EPA, disregarding the Guanabara ESEC (*i.e.*, the intermediate segment of the river), revealed ecological indices similar to the other parts of the river. However, greater abundance and richness can be observed (Figure 8A). Thus, the downstream and intermediate segments (*i.e.*, comprising Guanabara ESEC and EPA de Guapimirim) presented only *C. undecimalis* indicative of the EPA regardless of the time of the year approached (Figure 8A; 8B). *Centropomus undecimalis* belongs to the order Perciformes, the second most abundant in the Guapi-Macacu River. According to Peterson & Gilmore (1991), sea bass does not undergo large migratory cycles, being a relatively fast-growing fish that spawn a large number of eggs in brackish waters during late spring and early summer. Sea bass juveniles show a greater affinity for fresh water and survive in waters with lower oxygen levels than adults, being found upstream of rivers at all times of the year (Ager et al., 1976). Its primary or nursery habitat has been described as warm shallow streams or drainage channels, with low current and unvegetated bottoms or bordering the mangrove (Mcmichael *et al.*, 1989). As they develop, they move from shallow water habitats to estuaries, mangroves, and deeper water (Tucker & Campbell, 1988). According to the cluster analysis, the river segment shared with *C. undecimalis* and other species provides this species with a habitat with abundant food resources and protection for its development.

The river's intermediate region was characterized by a very winding zone with greater diversity in physiography, constantly flooded with deeper portions, and a salinity gradient that decreases from the river's mouth towards the interior. This segment presents vegetation composed of mangrove forests, riverside types. This area is directly related to larger transparency samples, evidencing *E. brasiliensis* and

O. niloticus with intermediate values of this attribute (Figure 8B). *Eugerres brasiliensis* is a species of marine origin that tolerates significant variations in salinity (Ramos *et al.*, 2006), is anadromous, migrating from the sea to rivers, living in coastal waters of warm seas, penetrating coastal lagoons and estuaries to complete its life cycle (Yañez-Arancibia, 1986). In addition, *E. brasiliensis* is a species with nocturnal habits, generalist and opportunistic; it is epibenthic and demersal. That is, it exhibits patterns strictly linked to the substrate, being did consider an excellent biological resource, mainly because it did regard as an abundant fishery resource (Cyrus & Blaber, 1983; Tapia-García & Ayala Pérez, 1996; 1997; Araújo & Santos, 1999; Barletta & Blaber, 2007; Barletta & Costa, 2009).

On the other hand, the cluster analysis did not evidence the intermediate region with a specific community for this segment of the river, showing itself as a transition area and occupied mainly by species that travel throughout the river, such as *H. littorale*, *H. auroguttatus*, and *L. castaneus* (Figure 8C). *Hypostomus auroguttatus* and *L. castaneus* belong to the most abundant family, Loricaridae, common in areas with muddy river bottoms and may even occur in lentic environments. That two species recorded in the three segments of the Guapi-Macacu River during the dry and wet seasons, considered generalists in the present study.

The species *A. lacustris* (Figure 5), considered rare in the analysis shown in CLAM TEST, was selected in *IndVal* for the upstream segment of the river, as well as in the rainy season, with high specificity and low fidelity, for Dufrêne & Legendre (1997), rare species may receive the same *IndVal* value as indicator species and are called asymmetric indicators. On the other hand, in this same river segment, without considering the attributes of the seasons (dry or wet), *IndVal* selected *T. striatulus* and *C. gariepinus* (Figure 8D), both with high specificity. Meaning that these fish can also be considered indicators asymmetric, which contribute to the specificity of the habitat, but they do not serve to predict groups (Dufrêne & Legendre, 1997).

From the CCA, we can see that the segment upstream of the river presents higher values of DO and abundance of *C. gariepinus*. The upstream part is the river's headwaters, which have a humid tropical climate, high and variable slope, determining the dynamic character of the fluvial system, with the presence of rapids, characteristic of mountain and plateau regions. Barella (2000) discusses the vital role of riparian forests in providing resources for feeding aquatic fauna and attracting dispersers, making the riparian environment a fundamental element in the sustainability of rivers and lakes and in the connection between the different systems that make up the rural landscape. The CCA also highlights the most protected area concerning the Guapimirim EPA, downstream of the river, with the most diversity and richness, exhibiting greater salinity, pH, and turbidity attributes. In general, the most abundant species in the river transit are intermediate values of the analyzed abiotic variables, except *C. gariepinus*, which correlates with larger samples of dissolved oxygen, and *M. furnieri*, which exhibits correlations with more significant correlations values of salinity. The species *C. parallelus*, *H. auroguttatus*, *H. littorale*, and *L. castaneus* express abundances related to intermediate values of transparency, revealing correlations in all river segments. Similarly to CCA, the cluster analysis also evidenced the group formed by *G. genidens*, *B. pectinata*, and *M. furnieri*, revealing sharing proximity in the same region, especially in the dry season,

with the dominance of *G. genidens*, as it presents greater abundance in this group. The CCA also highlights the similar spatial distribution of *T. striatulus* with *C. gariepinus* (with more representation in abundance), corroborating the cluster analysis.

African catfish in the Guapi-Macacu River

The African catfish, *C. gariepinus* was the third most abundant in the river, however in the most preserved area of the Guapimirim EPA, it still does not show significant abundance. It also notices that the species that present ecological equivalence to the African catfish, *R. quelen*, and *T. striatulus*, despite showing a similar distribution, give a lower abundance, which denotes the habitat overlap of the IAS over the native ones (Figure 9A). In addition, the population of *C. gariepinus* exhibited greater abundance contributions in the dry season, especially upstream, compared to the other species, demonstrating a high potential to colonize the entire river (Figure 9B).

Even though the CCA analysis does not show similar correlations of the abiotic factors *R. quelen* with *Clarias gariepinus*, the group exposed in the cluster analysis, it is clear that these species share the same segments of the river. *Rhamdia quelen* prefers lakes and river bottoms, preferring calmer water environments with a sand and mud bottom along the banks and vegetation (Gomes et al., 2000). They are omnivores with a clear preference for fish, crustaceans, insects, plant remains, and organic debris (Guedes, 1980; Meurer & Zaniboni Filho, 1997). Therefore, they are considered a generalist about food choice (Guedes, 1980). Among the many biological similarities that *R. quelen* has with *C. gariepinus*, highlighting the food preference and the use of habitat, however *R. quelen* has a disadvantage about its development, since females can reach up to 66.5 cm and males up to 52.0 cm (Gomes et al., 2000).

According to our analysis, dissolved oxygen was the attribute directly correlated with the distribution of *C. gariepinus* (Figure 7B). Thus, dissolved oxygen (DO) plays a fundamental role in regulating the body's metabolic functions, including the aquaculture community, in addition to being an environmental indicator of water quality (Anyachor & Sikoki, in press). On the other hand, African catfish can withstand low concentrations of dissolved oxygen (Adewolu et al., 2008) due to an air-breathing accessory organ, which can absorb oxygen from the atmospheric air (Moussa 1956), allowing fish to survive for many hours or weeks out of water or in muddy swamps (Idahor et al., 2014). Thus, the most significant contribution of DO may have acted as a facilitator for the development of the IAS, serving as an attraction for other species that could migrate to this segment of the river, in search of better environmental conditions, and probably due to the greater dominance of the IAS, have failed to establish themselves in this area.

Another significant environmental attribute in our analysis was temperature, and this seems to be an essential factor in the distribution of the species in the Rio Guapi-Macacu. The highest temperature values in the upstream area corroborate the results found in the CCA, where the greatest abundance of the species did correlate with this segment of the river. For Hecht (2013), African catfish larvae exhibit an optimal development around 28°C, whose value was recorded upstream in the rainy season. And this could be seen in the dry season, which showed a high increase in the IAS population, favored due to the

temperature rise previously recorded. On the other hand, our studies indicate that, despite the average temperature values measured in the Guapi-Macacu River not being considered ideal for the development of catfish, the species' adaptability has allowed it to develop well in this ecosystem and colonize other segments of the river. However, climate changes resulting from global warming can contribute to the gradual increase in temperature, significantly altering this scenario, which may favor the rapid development of this alien species and, possibly, the decline of native populations.

Salinity is also an attribute that limits the occurrence of alien species in the mouth of Guanabara Bay. That is because African catfish are stenohaline, with a limited capacity to withstand increased salinity in the environment, in more advanced stages (Hoogendoorn, 1981). Borode et al. (2002) conducted a study of the effect of salinity on the early-stage development of African catfish. They concluded that increased salinity delays the hatching and development of African catfish eggs and larvae but accepts up to 6 ppt variations for its growth. De Melo et al. (2014) detected an intrusion of salinity into the river in the dry season of the year, corroborating our findings, where salinity varied considerably in this season, reaching 31.

Even so, we can observe that despite the significant abundance of this species, the analysis of specificity and fidelity does not list *C. gariepinus* as an indicator species, taking into account both studied seasons and collection areas. However, this pattern diverges when considering only the upstream zone, when the species specificity index rises to 81% and the fidelity to 36% for this area, demonstrating *C. gariepinus* with the probability of 53% being an asymmetric indicator species of this area. For Dufrêne & Legendre (1997), a species can be an asymmetric indicator without high fidelity.

Conclusion

The analyses of the biological attributes of the African catfish populations, together with the environmental and biological descriptors of the segments of the Guapi-Macacu River, reveal that this species does not colonize Guanabara Bay. That is can also be explained by potential predators and competitors that occupy the downstream part of the river. The shallow areas downstream of the Guapi-Macacu River also harbor a larger contingent of typically estuarine juvenile fish, portraying this area as natural breeding and shelter for several fish species of ecological and economic importance. Imminent climate change factors can irreversibly alter this scenario, with more prolonged droughts in the hottest season and, consequently, increasing the temperature in other river segments to favor the habitat and, hence, the successful development of African catfish. As it is a generalist species found in the intermediate and upstream zones of the Guapi-Macacu River, has food versatility and robustness, it has probably been competing for food and habitats with native species, which have ecological equivalence, such as *R. quelen*, and *T. striatulus* and thus, impacting the local ichthyofauna, with the visible decline in the abundance of native species where African catfish establish themselves. Global climate change continues to impact fish habitat quality and biodiversity, especially about the dynamics of IAS. This study suggests that African catfish can benefit from the high temperatures predicted by climate change, facilitating their further dispersal and subsequent establishment in these environments.

Declarations

Funding

This study was conducted in the Project Invasion of African Catfish framework in Guanabara Bay - RJ, contemplated by Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq), Brazil - Universal Edict Process n. 405984 / 2016-2.

The Author Michelle Torres Dumith was supported by Coordenação de Aperfeiçoamento de Pessoal de Nível Superior

AUTHOR CONTRIBUTION

Author Contributions: MTD analyzed the data and wrote the manuscript. AFGNS performed field activities, analyzed the data, and wrote the manuscript.

DATA AVAILABILITY

The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

References

1. Adewolu, M. A., Adeniji, C. A., & Adejobi, A. B. (2008). Feed utilization, growth and survival of *Clarias gariepinus* (Burchell 1822) fingerlings cultured under different photoperiods. *Aquaculture*, 283(1-4), 64-67. <https://doi.org/10.1016/j.aquaculture.2008.07.020>
2. Arthington AH. 1991. The ecological and genetic impacts of introduced and translocated freshwater fishes in Australia. *Canadian Journal of Fisheries and Aquatic Sciences* 48(Suppl. 1): 33–44. <https://doi.org/10.1139/f91-302>
3. Ager, L., Hammond, D., & E Ware, F. (1976). Artificial spawning of snook. Florida Game and Fresh Water Fish Commission. In *Proceedings of the Thirtieth annual conference southeastern association of fish and wildlife agencies. Jackson, Mississippi*.
4. Agostinho, A. A., & Julio Jr, H. F. (1996). Ameaça ecológica: peixes de outras águas. *Ciência hoje*, 21(124), 36-44.
5. Agostinho, A. A., Pelicice, F. M., Petry, A. C., Gomes, L. C., & Júlio Jr, H. F. (2007). Fish diversity in the upper Paraná River basin: habitats, fisheries, management and conservation. *Aquatic Ecosystem Health & Management*, 10(2), 174-186. <https://doi.org/10.1080/14634980701341719>
6. Anderson, M. J. (2001). A new method for non-parametric multivariate analysis of variance. *Austral Ecology*, 26 (1), 32-46. <https://doi.org/10.1111/j.1442-9993.2001.01070.pp.x>
7. Andreatta, J. V., Saad, A. M., & Barbiéri, L. R. (1989). Associação e distribuição das espécies de peixes na laguna de Marapendi, Rio de Janeiro, no período de março de 1985 a fevereiro de 1987.

Memórias do Instituto Oswaldo Cruz, 84, 45-51. <https://doi.org/10.1590/S0074-02761989000800013>

8. Anyachor, C. P., & Sikoki, F. D. (in press). Assessing the nutritional and biochemical composition of the African catfish (*Clarias Gariepinus*) exposed to the antifoam polydimethylsiloxane. *Environmental Science and Pollution Research*. <https://link.springer.com/article/10.1007/s11356-021-15871-6>
9. Araújo, F. G. (1998). Adaptação do índice de integridade biótica usando a comunidade de peixes para o rio Paraíba do Sul. *Revista Brasileira de Biologia*, 58, 547-558. <https://www.scielo.br/j/rbbio/a/RLPcQVhxkMNtsCbYtM4LYDc/?format=pdf&lang=pt>
10. Araújo, F. G., & de Alcantara Santos, A. C. (1999). Distribution and recruitment of mojarra (Perciformes, Gerreidae) in the continental margin of Sepetiba Bay, Brazil. *Bulletin of Marine Science*, 65(2), 431-439. <https://www.ingentaconnect.com/content/umrsmas/bullmar/1999/00000065/00000002/art00009>
11. Araújo, F. G., de Azevedo, M. C. C., & Guedes, A. P. P. (2016). Inter-decadal changes in fish communities of a tropical bay in southeastern Brazil. *Regional Studies in Marine Science*, 3, 107-118. <https://doi.org/10.1016/j.rsma.2015.06.001>
12. Barcellos, C., De Lacerda, L. D., & Ceradini, S. (1997). Sediment origin and budget in Sepetiba Bay (Brazil)-an approach based on multielemental analysis. *Environmental Geology*, 32(3), 203-209. <https://doi.org/10.1007/s002540050208>
13. Barletta, M., & Blaber, S. J. M. (2007). Comparison of fish assemblages and guilds in tropical habitats of the Embley (Indo-West Pacific) and Caeté (Western Atlantic) estuaries. *Bulletin of Marine Science*, 80(3), 647-680.
14. Barletta, M., & Costa, M. F. (2009). Living and non-living resources exploitation in a tropical semi-arid estuary. *Journal of Coastal Research*, SI 56: 371-375. <https://www.jstor.org/stable/25737600>
15. Barrella, W., Petrere Jr, M., Smith, W. S., & Montag, L. D. A. (2000). As relações entre as matas ciliares, os rios e os peixes. *Rodrigues, RR; Leitão Filho; HF (Ed.) Matas ciliares: conservação e recuperação*, 2, 187-207.
16. Bizerril, C.R.S.F.; Primo, P.B. S. (2001). Peixes de águas Interiores do Estado do Rio de Janeiro. Rio de Janeiro: Fundação de Estudos do Mar. 417p.
17. Blaber, S. J., Cyrus, D. P., Albaret, J. J., Ching, C. V., Day, J. W., Elliott, M., ... & Silvert, W. (2000). Effects of fishing on the structure and functioning of estuarine and nearshore ecosystems. *ICES Journal of Marine Science*, 57(3), 590-602. <https://doi.org/10.1006/jmsc.2000.0723>
18. Blanchet, F. G., Legendre, P., & Borcard, D. (2008). Forward selection of explanatory variables. *Ecology*, 89(9), 2623-2632. <https://doi.org/10.1890/07-0986.1>
19. Borode, A. O., Balogun, A. M., & Omoyeni, B. A. (2002). Effect of salinity on embryonic development, hatchability, and growth of African catfish, *Clarias gariepinus*, eggs and larvae. *Journal of Applied Aquaculture*, 12(4), 89-93. https://doi.org/10.1300/J028v12n04_08

20. Buckup, P. A., Menezes, N. A., & Ghazzi, M. S. A. (2007). *Catálogo das espécies de peixes de água doce do Brasil* (Vol. 23). Rio de Janeiro: Museu Nacional.
21. Bunn SE, Davies PM, Kellaway DM. 1997. Contributions of sugar cane and invasive pasture grasses to the aquatic food web of a tropical lowland stream. *Marine and Freshwater Research* 48: 173–179. <https://doi.org/10.1071/MF96055>
22. Bunn SE, Davies PM, Kellaway DM, Prosser IP. 1998. Influence of invasive macrophytes on channel morphology and hydrology in an open tropical lowland stream, and potential control by riparian shading. *Freshwater Biology* 37:171–178. <https://doi.org/10.1046/j.1365-2427.1998.00264.x>
23. Clavero, M., & García-Berthou, E. (2005). Invasive species are a leading cause of animal extinctions. *Trends in Ecology & Evolution*, 20(3), 110. <https://doi.org/10.1016/j.tree.2005.01.003>
24. Chazdon, R. L., Chao, A., Colwell, R. K., Lin, S. Y., Norden, N., Letcher, S. G., ... & Arroyo, J. P. (2011). A novel statistical method for classifying habitat generalists and specialists. *Ecology*, 92(6), 1332–1343. <https://doi.org/10.1890/10-1345.1>
25. Cyrus, D. P., & Blaber, S. J. M. (1983). The food and feeding ecology of Gerreidae, Bleeker 1859, in the estuaries of Natal. *Journal of Fish Biology*, 22(4), 373-393. <https://doi.org/10.1111/j.1095-8649.1983.tb04760.x>
26. Costa, M. J., Vasconcelos, R., Costa, J. L., & Cabral, H. N. (2007). River flow influence on the fish community of the Tagus estuary (Portugal). *Hydrobiologia*, 587(1), 113-123. <https://doi.org/10.1007/s10750-007-0690-x>
27. Cunha, C. D. L. D. N., Rosman, P. C., Ferreira, A. P., & do Nascimento Monteiro, T. C. (2006). Hydrodynamics and water quality models applied to Sepetiba Bay. *Continental Shelf Research*, 26(16), 1940-1953. <https://doi.org/10.1016/j.csr.2006.06.010>
28. Cáceres, M. D., & Legendre, P. (2009). Associations between species and groups of sites: indices and statistical inference. *Ecology*, 90(12), 3566-3574. <https://doi.org/10.1890/08-1823.1>
29. Defeo, O., McLachlan, A., Schoeman, D. S., Schlacher, T. A., Dugan, J., Jones, A., ... & Scapini, F. (2009). Threats to sandy beach ecosystems: a review. *Estuarine, Coastal and Shelf Science*, 81(1), 1–12. <https://doi.org/10.1016/j.ecss.2008.09.022>
30. De Melo, G. V., Neto, J. A. B., Vinzón, S. B., de Oliveira, A. S., Vicente, M. A. F., Malm, O., & Silva, C. G. (2014). Salinity intrusion in the Guapimirim Estuary, Rio de Janeiro State, Brazil. *Brazilian Journal of Geophysics*, 32(1), 161-176. <http://dx.doi.org/10.22564/rbgf.v32i1.424>
31. Dufrêne, M., & Legendre, P. (1997). Species assemblages and indicator species: the need for a flexible asymmetrical approach. *Ecological Monographs*, 67(3), 345-366. [https://doi.org/10.1890/0012-9615\(1997\)067\[0345:SAAI\]2.0.CO;2](https://doi.org/10.1890/0012-9615(1997)067[0345:SAAI]2.0.CO;2)
32. Ecologus-Agrar (2005). Consórcio Ecologus-Agrar Plano Diretor de Recursos Hídricos da Região Hidrográfica da Baía de Guanabara. Relatório Final – Síntese. Governo do Estado do Rio de Janeiro / Programa de Despoluição da Baía de Guanabara. Rio de Janeiro.
33. Edokpayi J.N., Odiyo J.O., Durowoju O.S. Chapter 18. (2017). pp. 401– 416. Water quality. Intech; [(accessed on 22 September 2021)] <https://cdn.intechopen.com/pdfs/53194.pdf>

34. Eigenmann, C. H., & Eigenmann, R. S. (1891). *A catalogue of the freshwater fishes of South America*. US Government Printing Office. [(Accessed on 30 September 2021)]
35. FEEMA. (1998) Fundação Estadual de Engenharia do Meio Ambiente. Qualidade de Água da Baía de Guanabara (1990/1997). Programa de Despoluição da Baía de Guanabara/Programas Ambientais Complementares. Rio de Janeiro, 1 v.
36. Ferreira, C. E. G. (2012). Sistema de Suporte à decisão espacial aplicado à análise da vulnerabilidade dos recursos hídricos na bacia Guapi-Macacu / RJ. Dissertação de Mestrado, Rio de Janeiro, 152p. [(Accessed on 18 October 2021)]
37. Figueiredo, L. L.; Menezes, N. A. ,1978. Manual de peixes marinhos do sudeste do Brasil. II. Teleostei (1). 1ª ed. Museu de Zoologia de São Paulo, São Paulo.
38. Figueiredo, L. L.; Menezes, N. A. ,1980. Manual de peixes marinhos do sudeste do Brasil. III. Teleostei (2). 1ª ed. Museu de Zoologia de São Paulo, São Paulo.
39. Figueiredo, L. L.; Menezes, N. A., 2000. Manual de peixes marinhos do sudeste do Brasil. VI. Teleostei (5). 1ª ed. Museu de Zoologia de São Paulo, São Paulo.
40. Fowler, H. W. (1948). Os peixes de água doce do Brasil. *Arquivos de Zoologia*, 6, 1-204.
41. Galili, T. (2015). Dendextend: an R package for visualizing, adjusting and comparing trees of hierarchical clustering. *Bioinformatics*, 31(22), 3718-3720. <https://doi.org/10.1093/bioinformatics/btv428>
42. Géry, J. (1969). The freshwater fishes of South America. Biogeography and ecology in South America.
43. Graaf, G. D., & Janssen, H. (1996). Artificial reproduction and pond rearing of the African catfish *Clarias gariepinus* in sub-Saharan Africa. *FAO Fisheries technical paper*, (362). <https://www.cabdirect.org/cabdirect/abstract/19970104019>
44. Gomes, L. D. C., Golombieski, J. I., Gomes, A. R. C., & Baldisserotto, B. (2000). Biologia do jundiá *Rhamdia quelen* (TELEOSTEI, PIMELODIDAE). *Ciência Rural*, 30, 179-185. <https://doi.org/10.1590/S0103-84782000000100029>
45. Guedes, D.S. Contribuição ao estudo da sistemática e alimentação de jundiás (*Rhamdia spp*) na região central do Rio Grande do Sul (Pisces, Pimelodidae) Santa Maria RS, 1980. 99p. Dissertação (Mestrado em Zootecnia) - Curso de Pós-graduação em Zootecnia, Universidade Federal de Santa Maria.
46. Guimarães, G. P., & Mello, W. Z. D. (2006). Estimativa do fluxo de amônia na interface ar-mar na Baía de Guanabara: estudo preliminar. *Química Nova*, 29(1), 54-60. <https://doi.org/10.1590/S0100-40422006000100012>
47. Hecht, T. (2013). A review of on-farm feed management practices for North African catfish (*Clarias gariepinus*) in sub-Saharan Africa. *On-farm feeding and feed management in aquaculture*, 463-479. [(Accessed on 25 October 2021)] <https://www.fao.org/fishery/docs/CDrom/T583/root/17.pdf>
48. Hey, D.1941. Practical freshwater fish culture. Cape Town, Cape Nature Conservation, 118 pp.

49. Hogendoorn, H. (1981). Controlled propagation of the African catfish, *Clarias lazera* (C. & V.): IV. Effect of feeding regime in fingerling culture. *Aquaculture*, 24, 123-131. [https://doi.org/10.1016/0044-8486\(81\)90049-1](https://doi.org/10.1016/0044-8486(81)90049-1)
50. ICMBio (2021). Instituto Chico Mendes de Conservação da Biodiversidade. Ministério do Meio Ambiente. Brasil. [(Accessed on 25 July 2021)]. <https://www.icmbio.gov.br/apaguapimirim/>
51. Idahor, K. O., Yakubu, A., Umar, A. F., Yahaya, F., & Musa, L. A. (2014). Morphometric traits, spermatozoa microscopy and stripped eggs fertilization with milt collected from live African Mudfish (*Clarias gariepinus*). *Livest. Res. Rural Dev*, 26, 8.
52. INMET - Instituto Nacional de Meteorologia. Brasil (2018). [(Accessed on 15 July 2021)] www.inmet.gov.br/portal/index.php?r=home/page&page=rede_estacoes_auto_graf.
53. Jica. (1994). The study on recuperation of the Guanabara Bay ecosystem.
54. Khallaf, E. A., & Gaber, N. (1991). Analyses of stomach contents and intraspecific interaction over diet of *Clarias lazera* (Cuv. & Val.) in Bahr-Shebeen canal. *Bulletin of Faculty of Science Zagazig University*, 13(2), 481-499.
55. Lacerda, L. D. (1984). Manguezais: florestas de beira-mar. *Ciência Hoje*, 3(13), 63-70.
56. Loebmann, D., & Vieira, J. P. (2005). Distribuição espacial e abundância das assembléias de peixes no Parque Nacional da Lagoa do Peixe, Rio Grande do Sul, Brasil. *Revista Brasileira de Zoologia*, 22, 667-675.983. <https://doi.org/10.1590/S0101-81752005000300023>
57. Macêdo, S. D., Montes, M. D. J., & Lins, I. C. (2000). Características abióticas da área. *Gerenciamento participativo de estuários e manguezais. Recife: Editora Universitária da Universidade Federal de Pernambuco*, 7, 22.
58. Macêdo, S. J., Muniz, K., & Montes, M. F. (2004). Hidrologia da região costeira e plataforma continental do estado de Pernambuco. *Oceanografia: um cenário tropical. Recife, Bagaço*, 255-286.
59. Magurran, A. E. (1988). Ecological diversity and its measurement. London: Chapman and Hall, 192 p.
60. Manly, B. F. (2018). *Randomization, bootstrap and Monte Carlo methods in biology*. chapman and hall/CRC..
61. Mayr, L. M., Tenenbaum, D. R., Villac, M. C., Paranhos, R., Nogueira, C. R., Bonecker, S. L., & Bonecker, A. C. T. (1989). Hydrobiological characterization of Guanabara bay. *Coastlines of Brazil*, 124-138.
62. McAllister, M. K., & Ianelli, J. N. (1997). Bayesian stock assessment using catch-age data and the sampling-importance resampling algorithm. *Canadian Journal of Fisheries and Aquatic Sciences*, 54(2), 284-300. <https://doi.org/10.1139/f96-285>
63. McArdle, B. H. & Anderson, M. J. (2001). Fitting multivariate models to community data: a comment on distance-based redundancy analysis. *Ecology*, 82 (1), 290-297. [https://doi.org/10.1890/0012-9658\(2001\)082\[0290:FMMTCD\]2.0.CO;2](https://doi.org/10.1890/0012-9658(2001)082[0290:FMMTCD]2.0.CO;2)
64. McGeoch, M. A., & Chown, S. L. (1998). Scaling up the value of bioindicators. *Trends in Ecology & Evolution*, 13(2), 46-47.

65. McMichael Jr, R. H., Peters, K. M., & Parsons, G. R. (1989). Early life history of the snook, *Centropomus undecimalis*, in Tampa Bay, Florida. *Gulf of Mexico Science*, 10(2), 5. <https://doi.org/10.18785/negs.1002.05>
66. Menezes, N. A.; Figueiredo, L. L. (1980). Manual de peixes marinhos do sudeste do Brasil. IV. Teleostei (3). 1ª ed. Museu de Zoologia de São Paulo, São Paulo
67. Menezes, N. A.; Figueiredo, L. L. (1985). Manual De Peixes Marinhos Do Sudeste Do Brasil. V. Teleostei (4). 1ª Ed. Museu De Zoologia De São Paulo, São Paulo
68. Meurer, S., & Zaniboni Filho, E. (1997). Hábito alimentar do jundiá *Rhamdia quelen* (Pisces, Siluriformes, Pimelodidae), na região do alto rio Uruguai. *Encontro Brasileiro de Ictiologia*, 12, 29.
69. Moussa, T. A. (1956). Morphology of the accessory air-breathing organs of the teleost, *Clarias lazera* (C. and V.). *Journal of Morphology*, 98(1), 125-160. <https://doi.org/10.1002/jmor.1050980105>
70. Murtagh, F., & Legendre, P. (2014). Ward's hierarchical agglomerative clustering method: which algorithms implement Ward's criterion?. *Journal of classification*, 31(3), 274-295. <https://doi.org/10.1007/s00357-014-9161-z>
71. Oksanen Jari, F. Guillaume Blanchet, Michael Friendly, Roeland Kindt, Pierre Legendre, Dan McGlenn, Peter R. Minchin, R. B. O'Hara, Gavin L. Simpson, Peter Solymos, M. Henry H. Stevens, Eduard Szoecs, and Helene Wagner (2020). Vegan: Community Ecology Package. R package version 2.5-7. <https://CRAN.R-project.org/package=vegan>
72. Oksanen, J. (2011). Multivariate analysis of ecological communities in R: vegan tutorial. *R package version*, 1(7), 1-43.) [(Accessed on 15 January 2021)]
73. Osibona, A. O., Kusemiju, K., & Akande, G. R. (2006). Proximate composition and fatty acids profile of the African Catfish *Clarias gariepinus*. *Acta Satech*, 3(1), 1-5.
74. Peterson, M. S., & Gilmore, G. R. (1991). Eco-physiology of juvenile snook *Centropomus undecimalis* (Bloch): Life-history implications. *Bulletin of Marine Science*, 48(1), 46-57.
75. Reis, E. G. (1986). Reproduction and feeding habits of the marine catfish *Netuma barba* (Siluriformes, Ariidae) in the estuary of Lagoa dos Patos, Brazil. *Atlântica*, 8, 35-55.
76. Reis, R. E., Kullander, S. O., & Ferraris, C. J. (2003). Check list of the freshwater fishes of South and Central America. Edipucrs.
77. Rodríguez, M. A., & Lewis Jr, W. M. (1997). Structure of fish assemblages along environmental gradients in floodplain lakes of the Orinoco River. *Ecological monographs*, 67(1), 109-128. [https://doi.org/10.1890/0012-9615\(1997\)067\[0109:SOFAAE\]2.0.CO;2](https://doi.org/10.1890/0012-9615(1997)067[0109:SOFAAE]2.0.CO;2)
78. Rozas, L. P., & Zimmerman, R. J. (2000). Small-scale patterns of nekton use among marsh and adjacent shallow nonvegetated areas of the Galveston Bay Estuary, Texas (USA). *Marine Ecology Progress Series*, 193, 217-239. doi:10.3354/meps193217
79. Schaefer, S. A. (1998). Conflict and Resolution: Impact of New Phylogenetic Studies of the Neotropical Cascudinhos (Siluroidei; Loricariidae). *Phylogeny and Classification of Neotropical Fishies.*, 375-401.

80. Solymos P. (2020) Clamtest in Vegan: Community Ecology Package. R package version 2.5-7.
<https://CRAN.R-project.org/package=vegan>
81. Tapia-García, M., & Ayala-Pérez, G. (1996). Clave para la determinación de las especies de mojaras de México (Pisces: Gerreidae). *Revista de Biología Tropical*, 519-526.
82. Team, R. C. (2020). R: the R project for statistical computing. 2020.
83. Teixeira, R. L. (1994). Abundance, reproductive period, and feeding habits of eleotrid fishes in estuarine habitats of north-east Brazil. *Journal of Fish Biology*, 45(5), 749-761.
<https://doi.org/10.1111/j.1095-8649.1994.tb00941.x>
84. Ter Braak, C. J. (1986). Canonical correspondence analysis: a new eigenvector technique for multivariate direct gradient analysis. *Ecology*, 67(5), 1167-1179. <https://doi.org/10.2307/1938672>
85. Tucker Jr, J. W., & Campbell, S. W. (1988). Spawning season of common snook along the east central Florida coast. *Florida Scientist*, 1-6.
86. Verreth, J., Eding, E. H., Rao, G. R. M., Huskens, F., & Segner, H. (1993). A review of feeding practices, growth and nutritional physiology in larvae of the catfishes *Clarias gariepinus* and *Clarias batrachus*. *Journal of the World Aquaculture Society*, 24(2), 135-144. <https://doi.org/10.1111/j.1749-7345.1993.tb00002.x>
87. Volpe, A. V. (1959). Aspects of the biology of the common snook, *Centropomus undecimalis* (Bloch) of Southwest Florida.
88. Weyl, O. L. F., Daga, V. S., Ellender, B. R., & Vitule, J. R. S. (2016). A review of *Clarias gariepinus* invasions in Brazil and South Africa. *Journal of fish biology*, 89(1), 386-402.
<https://doi.org/10.1111/jfb.12958>
89. Yañez-Arancibia, A., & Sánchez-Gil, P. (1988). Ecología de los recursos demersales marinos. *Ed. México, DF*.

Figures

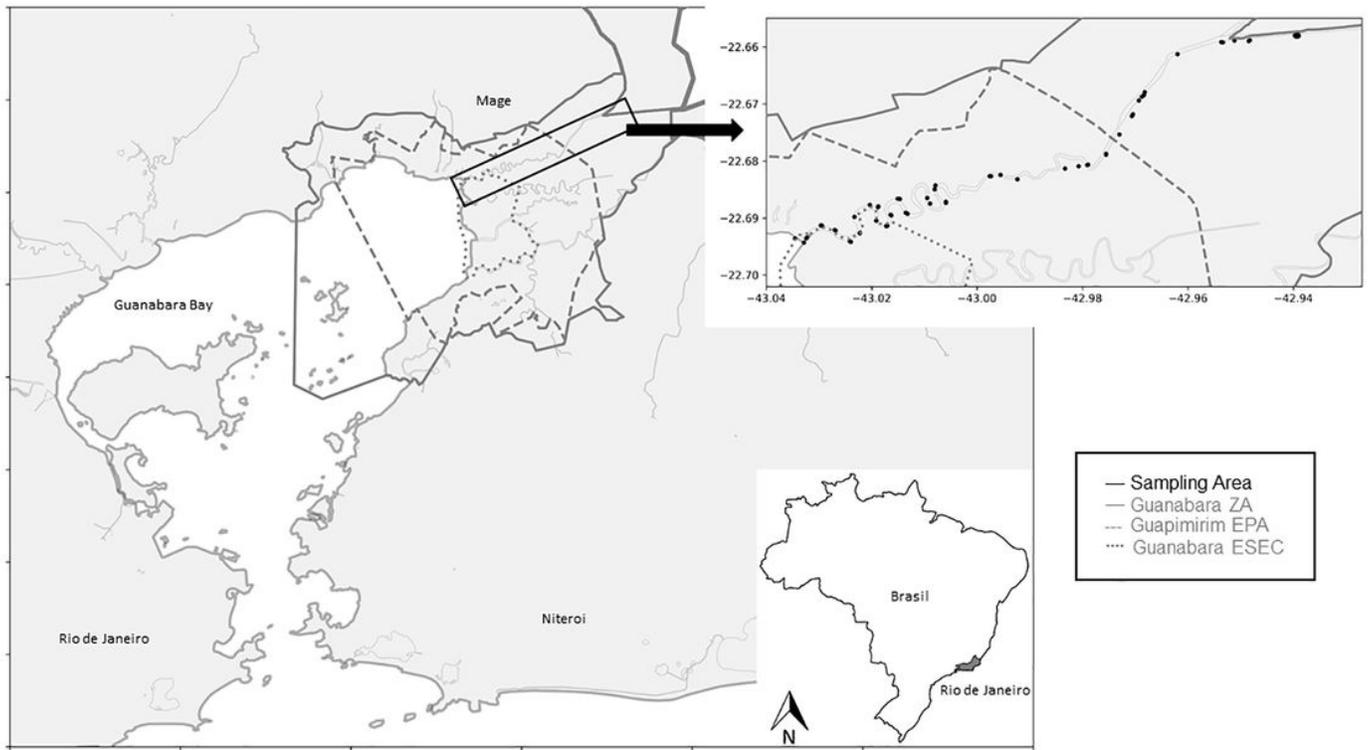


Figure 1

Guanabara Bay map with the representation of the limits of the Guapimirim Environmental Protection Area (Guapimirim EPA), the Guanabara Ecological Station (Guanabara ESEC), and the Buffer Zone of the Environmental Protection Area (Guanabara ZA). The sampling area is highlighted, with the sampling sites, in the dry and wet seasons distributed along the Guapi-Macacu River.

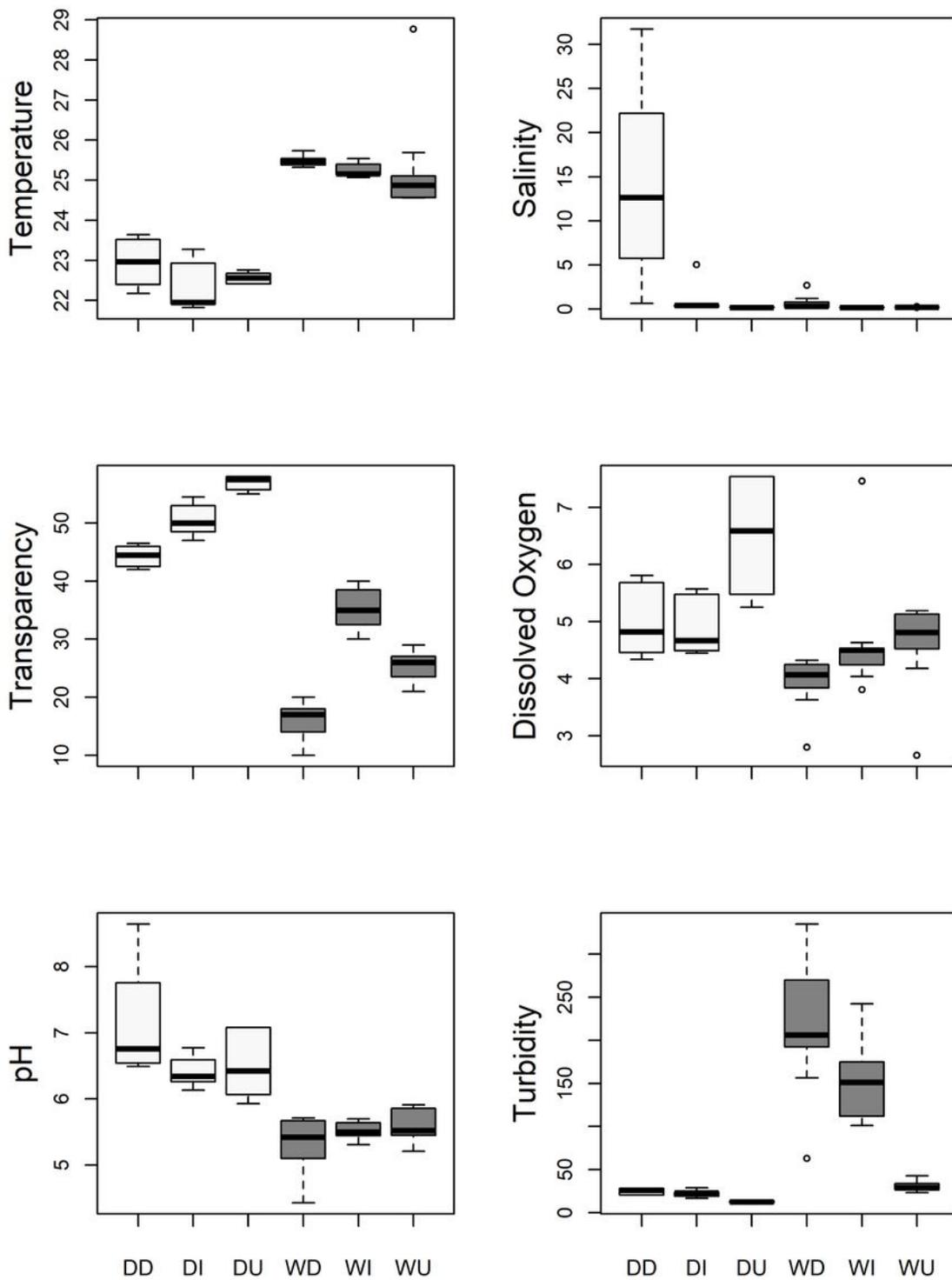


Figure 2

Boxplots of environmental variables by segments and seasons in the Guapi-Macacu River. DD: downstream dry; DI: intermediate dry; DU: dry upstream; WD: wet downstream; WI: intermediate wet; and WU: wet upstream.

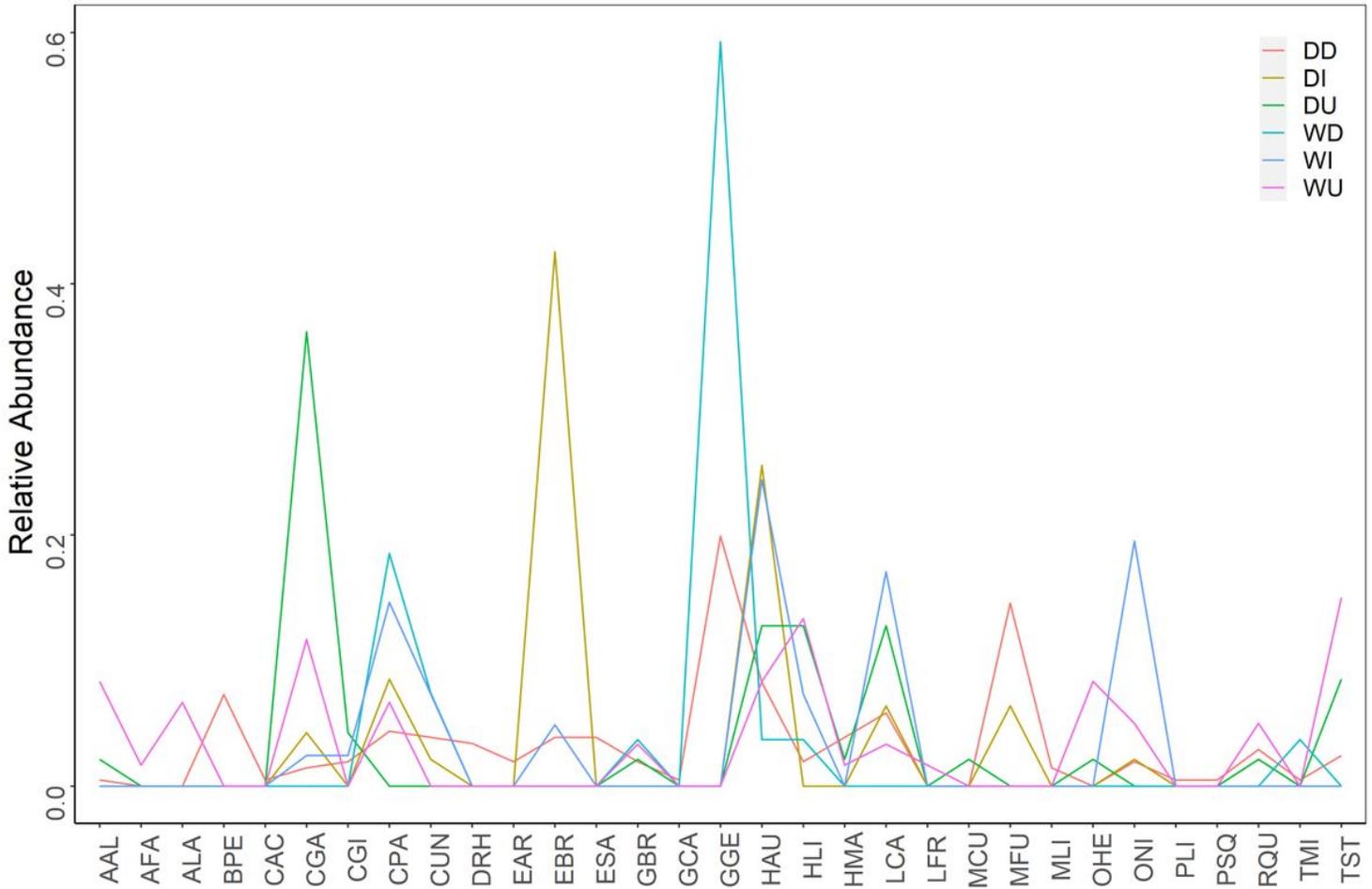


Figure 3

Distribution of the relative abundance of the fish community along the Guapi-Macacu River between areas and seasons. DD: dry downstream; DI: intermediate dry; DU: dry upstream; WD: wet downstream; WI: intermediate wet; and WU: wet upstream. The codes corresponding to each species are in Table 2.

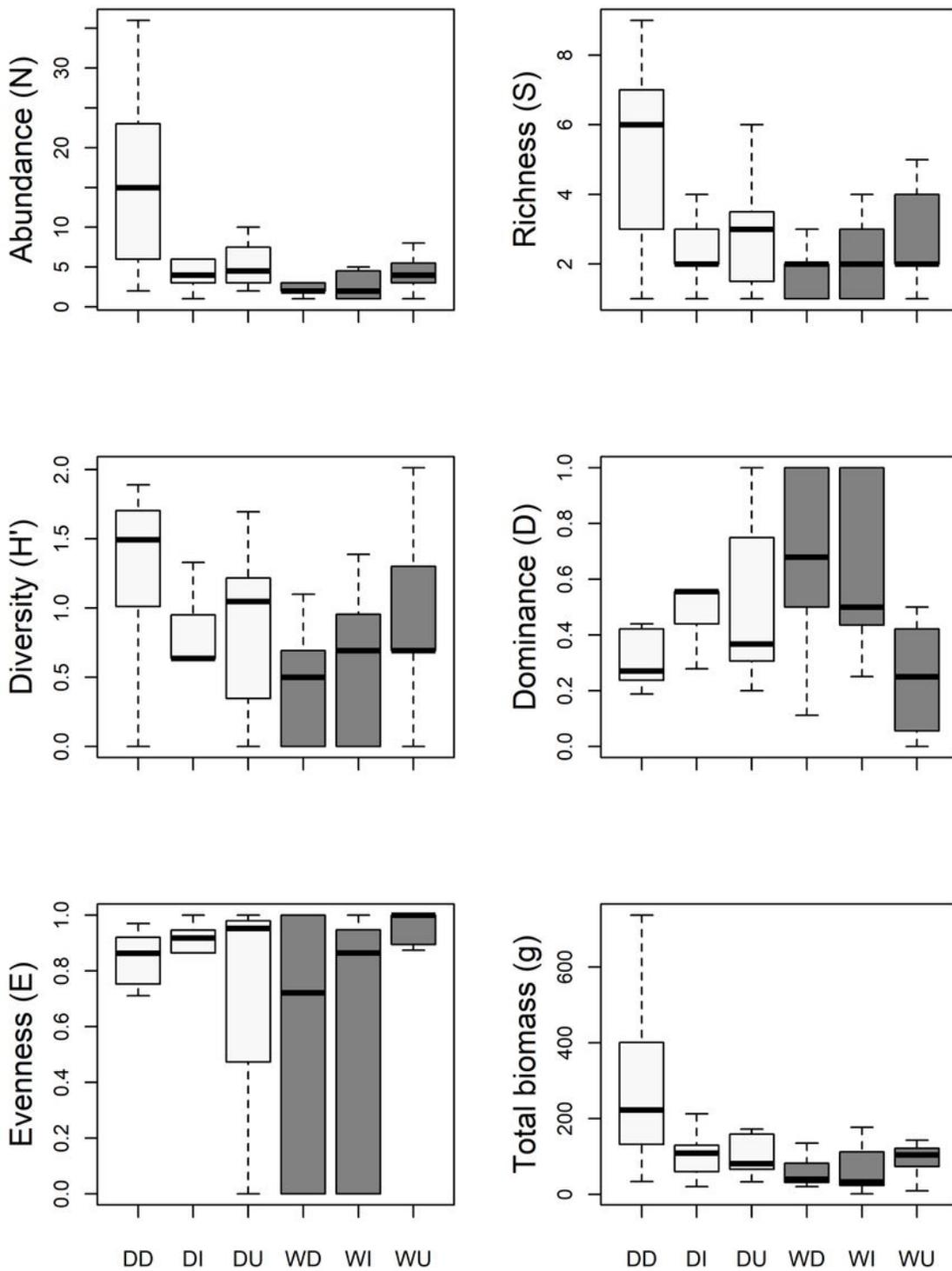


Figure 4

Boxplots with the distribution of abundance, richness, Shannon-Wiener diversity, Pielou Equitativity, Dominance, and total Biomass (g) between segments and seasons in the Guapi-Macacu River. DD: downstream dry; DI: intermediate dry; DU: dry upstream; WD: wet downstream; WI: intermediate wet; and WU: wet upstream.

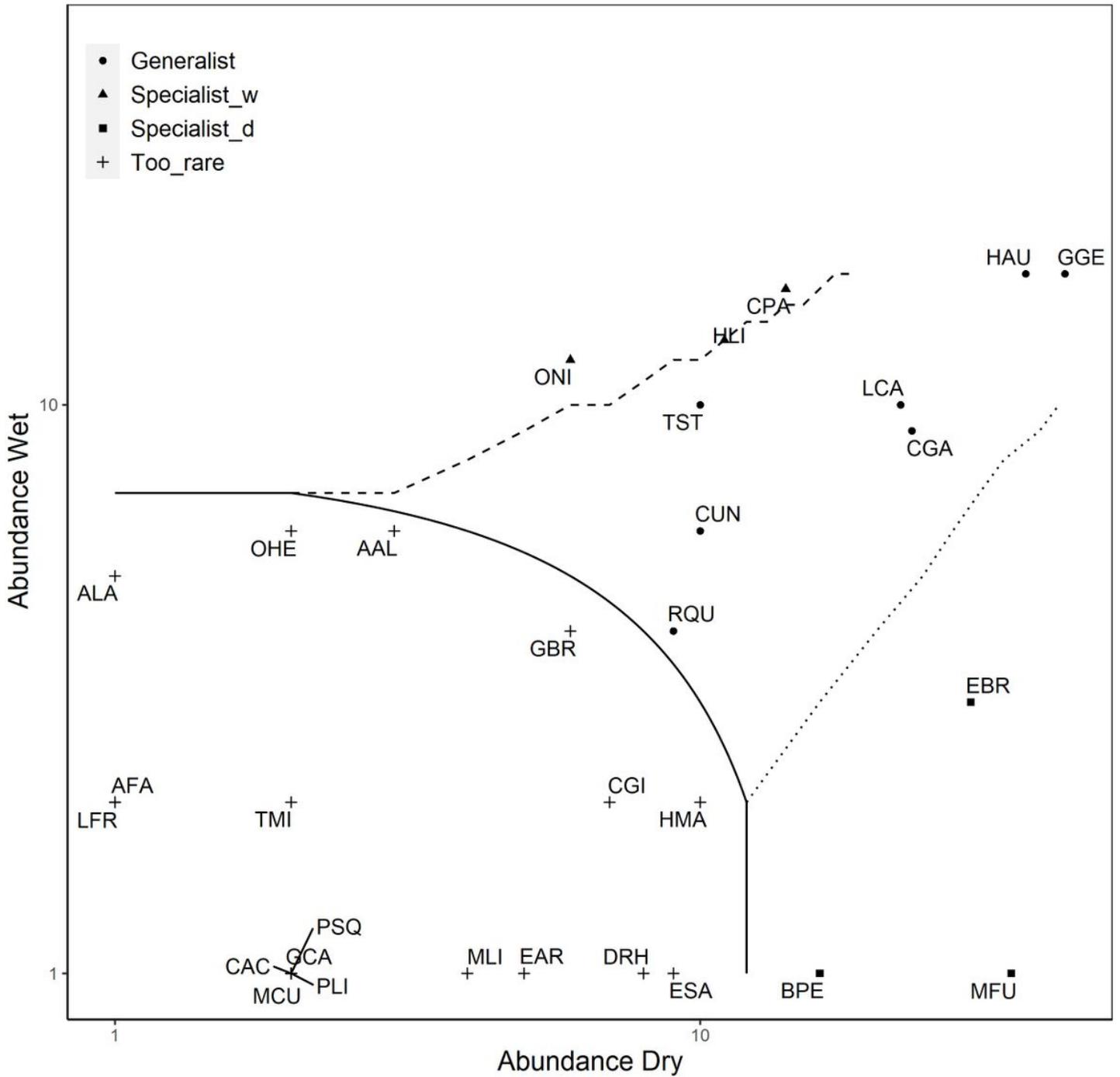


Figure 5

CLAM classification of the ichthyofauna in the dry and wet seasons ($p=0.05$). The lines represent the limit of specialization. Dashed line = wet season; dotted line = dry season; circle = generalist; triangle = wet season specialist; square = dry season specialist; and cross = rare species. The codes corresponding to each species are in Table 2.

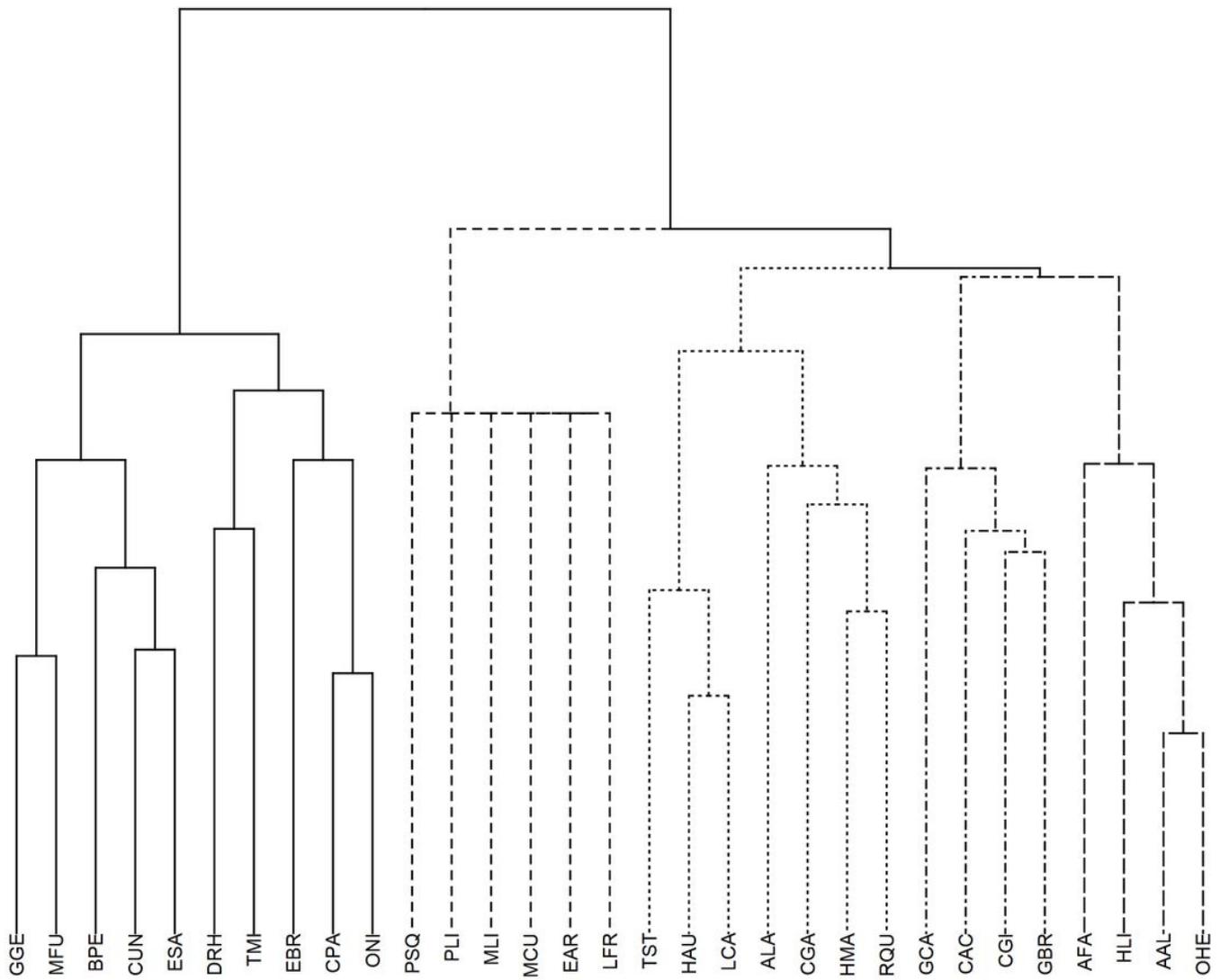


Figure 6

Cluster Analysis of fish abundance between areas of the Guapi-Macacu-RJ River. The different types of lines correspond to the groups formed. The codes corresponding to each species are in Table 2.

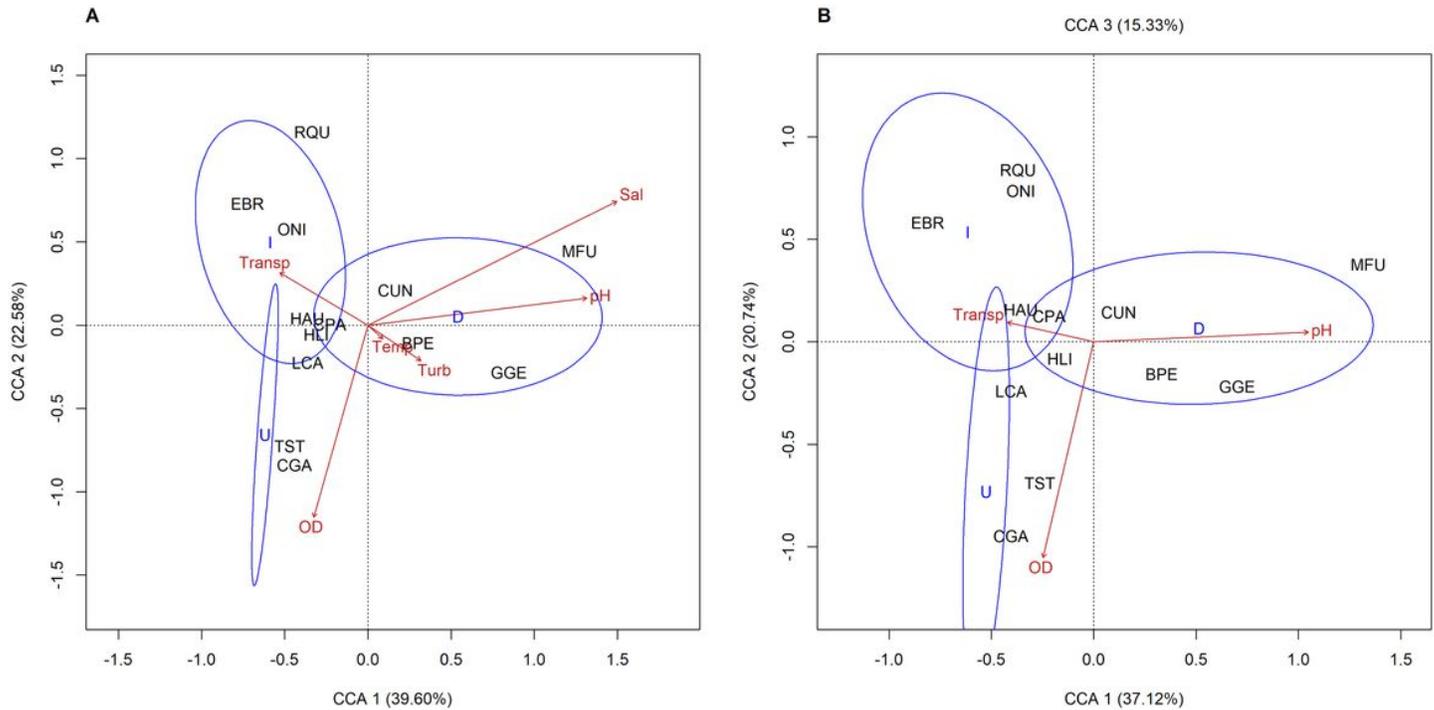


Figure 7

Canonical correspondence analysis (CCA) applied to the abundance matrix of generalist and specialist species selected in the CLAM model and environmental variables. In blue, the downstream (D), intermediate (I), and upstream (U) segments on the Guapi-Macacu River. In red, the arrows indicate the contribution of each environmental variable. The codes corresponding to each species are in Table 2. (A) Analysis of the CCA with all measured environmental variables; (B) Reduced model, obtained with the *ORDSTEP* function, removing multicollinearity from the environmental variables.

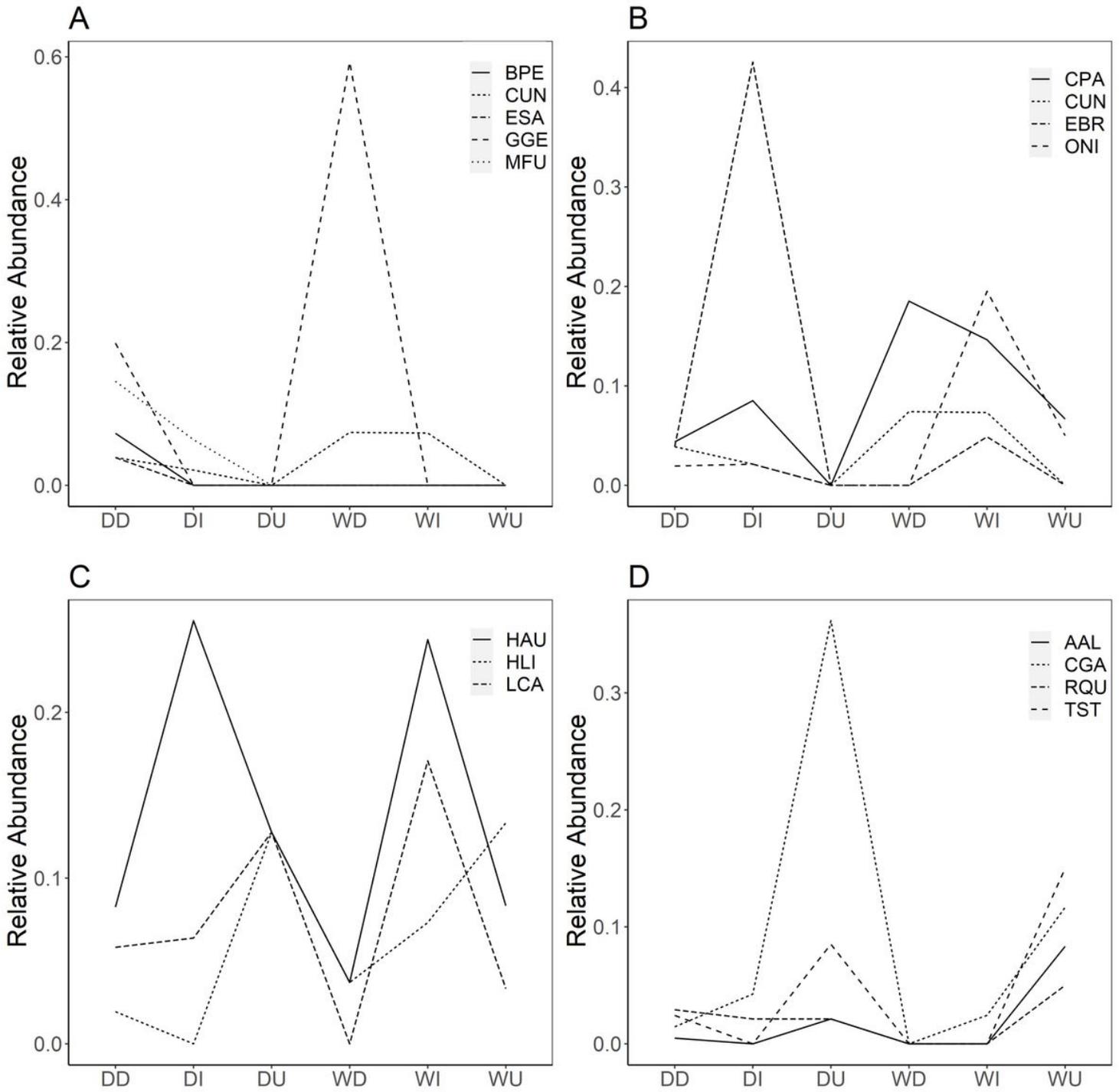


Figure 8

Relative abundance of the main fish species from the Guapi-Macacu River, which run through: (A) downstream area; (B) intermediate area; (C) the entire river, and (D) the upstream area. DD: downstream dry; DI: intermediate dry; DU: dry upstream; WD: wet downstream; WI: intermediate wet; and WU: wet upstream. The codes corresponding to each species are in Table 2.

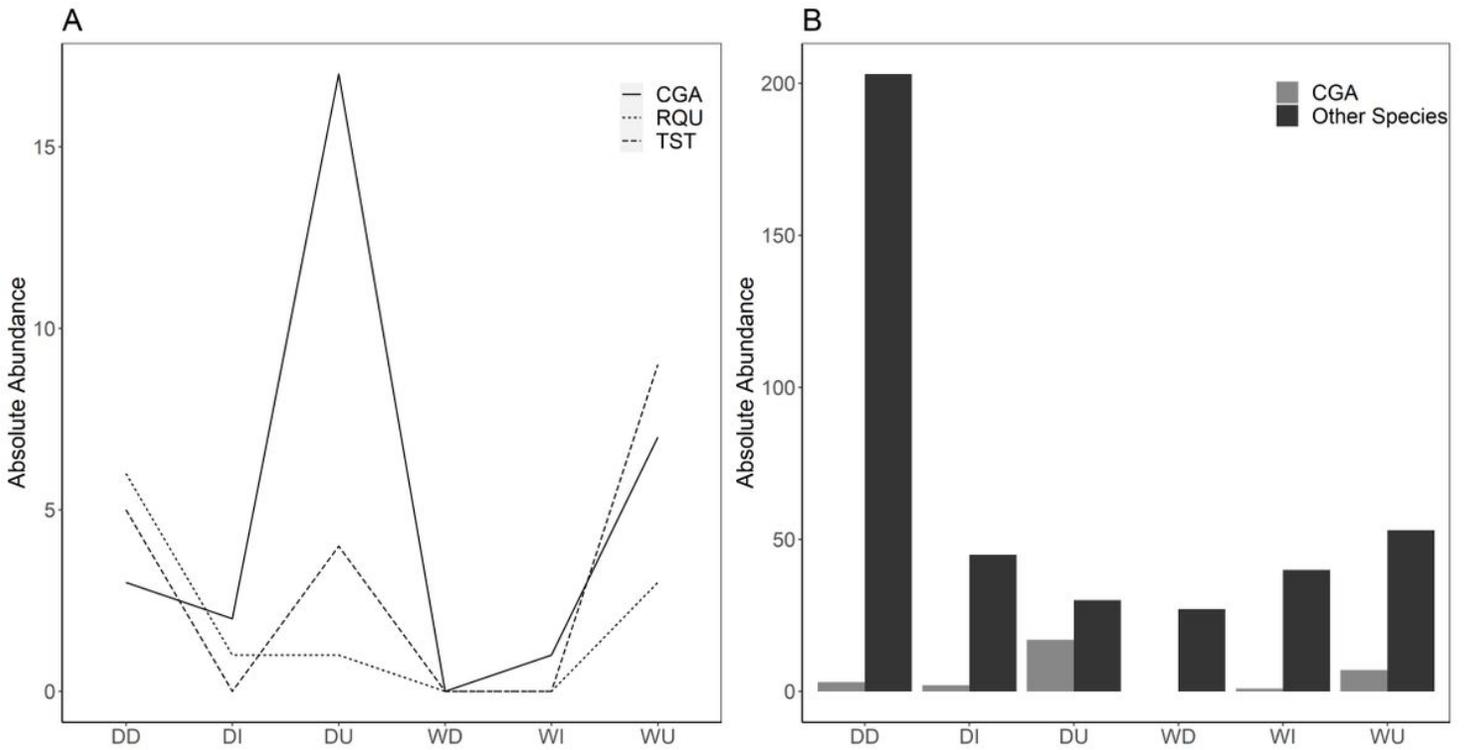


Figure 9

(A) Catches of the *Clarias gariepinus* population and the two species with ecological equivalent, between the different river segments and sampled seasons. (B) Catches of *Clarias gariepinus* and other species in the community, between the different parts of the Guapi-Macacu River and sampled seasons. DD: downstream dry; DI: intermediate dry; DU: dry upstream; WD: wet downstream; WI: intermediate wet; and WU: wet upstream. The codes corresponding to each species are in Table 2.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- [SupplementaryInformation.tif](#)