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Diversity and fish distribution at Rodrigo de Freitas Lagoon, Rio de Janeiro State, Brazil, using GIS

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ABSTRACT. Fish fauna is considered a good indicator of water quality. The Rodrigo de Freitas Lagoon is located in Rio de Janeiro city with a great scenic beauty. However, along the years, the Lagoon has been negatively impacted by human activities which can be seen in massive fish deaths and blooms of toxic algae. This study evaluated fish abundance and diversity in two historical periods, and between areas of capture. Multivariate data analyses were performed to find similar groups of fish fauna and to evaluate fish abundance and their seasonal and spatial variation. It was also used the algebraic language as a tool to combine raster layers as dissolved oxygen in surface, bathymetry and fish abundance by using rules and conditions involved in the fish zoning. The zone 2, located in the south-central area of the Lagoon, had the greatest number of species and higher values of dissolved oxygen. Mollies and menhaden had high abundance and occurred in all areas. There was a marked decrease in fish diversity and abundance in the second period. The results showed that surface dissolved oxygen and salinity were identified as important factors influencing the distribution and abundance of the main fish species at the Lagoon.

Keywords: ichtyofauna abundance, environmental variables, map algebra.

Diversidade e distribuição de peixes na Lagoa Rodrigo de Freitas, Estado do Rio de Janeiro, Brasil, usando o SIG

RESUMO. A fauna de peixes é considerada um bom indicador da qualidade da água. A Lagoa Rodrigo de Freitas está localizada na cidade do Rio de Janeiro com uma grande beleza cênica. Entretanto, ao longo dos anos, a Lagoa tem sido impactada negativamente por ações humanas podendo estas serem observadas nas mortandades de peixes e florações de algas tóxicas. Este estudo avaliou a abundância e a diversidade de peixes em dois períodos históricos, e entre as áreas de captura. Análises multivariadas de dados foram realizadas para encontrar grupos de fauna de peixes semelhantes e para avaliar a abundância de peixes e sua variação sazonal e espacial. Também foi utilizada a linguagem algébrica como uma ferramenta para combinar camadas matriciais como o oxigênio dissolvido na superfície, a batimetria e a abundância de peixes usando as regras e as condições envolvidas no zoneamento da ictiofauna. A zona 2, localizada na região Centro-Sul da Lagoa, teve o maior número de espécies e maior média de oxigênio dissolvido. Observou-se que barrigudinhos e savelhas tiveram grande abundância e ocorreram em todas as áreas. Houve diminuição marcada na diversidade e abundância de peixes no segundo período. Os resultados mostraram que o oxigênio dissolvido na superfície e a salinidade foram fatores importantes que influenciaram na distribuição e abundância das principais espécies de peixes na Lagoa.

Palavras-chave: abundância da ictiofauna, variáveis ambientais, álgebra de mapas.

Introduction

Species distribution modelling is widely used in terrestrial and aquatic systems to predict species occurrence and to better understand the processes influencing their geographical distributions (MARTIN et al., 2012). Habitat models are commonly developed from numerical estimates of species responses (e.g. occurrence, density) to changes in one or more environmental variables (MARTIN et al., 2012). According to Knudby (2010) the interaction between fish and their habitat operates over a wide range of spatial scales. The richness of native fish is considered to be an indicator of ecosystem health (IBARRA et al., 2003) due to their sensitivity to human disturbances, which alter community parameters (OBERDOFF et al., 1995). In aquatic ecosystems, the changes in species richness, relative abundance and species composition have been considered to reflect the loss of biodiversity or biotic integrity (KARR, 1981; SCHLEIGER, 2000). The predictive modelling of species distribution has become a powerful tool to support decisions in conservation and natural resource management (DREW et al., 2011).

The Rodrigo de Freitas Lagoon is located in the metropolitan area of the Rio de Janeiro City, Brazil, surrounded by a highly urbanized area and receives influx of polluted waters from some uncontrolled sewage systems and from storm sewer (SOUZA et al., 2011). The Lagoon receives its waters from different tributaries among these the Macacos River with a drainage area of 7.2 square kilometers (FEEMA, 2002), which was channelized and introduces salt water into the Lagoon. The other tributaries are the Rainha river with 4.3 square kilometers of drainage area and Cabeças River with the smallest drainage area of 1.9 square kilometers (FEEMA 2002). The water of the Lagoon has its origin in the damming of an opening to the sea which was caused by successive build-ups of land. The artificial channel of Jardim de Alah links the Lagoon with the Atlantic Ocean.

The Lagoon has been seriously impacted by negative human activities which can be seen in frequent mass fish deaths, eutrophication, waste solids, erosion and silting, domestic and hospital wastewater and gas stations that significantly change water quality (LUTTERBACH et al., 2001). Such incidents with massive mortalities of fish were recorded along the years. The first study about the aquatic biota of Rodrigo de Freitas Lagoon was conducted by Oliveira et al. (1957) which suggested probable causes for fish death. In February, 2010, 86.8 ton of fish were collected by Comlurb (municipal waste company), especially a Brazilian menhaden, *Brevoortia pectinata*, a filter-feeding fish.

Habitat loss and degradation threaten the ability of marine coastal areas to support artisanal fisheries (CREC'HRIOU et. al., 2008). Many studies have been done on the fish fauna of coastal lagoons of Rio de Janeiro, encompassing ecological aspects such as reproduction (ANDREATA, 2012); trophic relationships (MORAES; ANDREATA, 1994) and abundance (ANDREATA et al., 1997, 2002, 2004).The structure of fish communities can serve as a bioindicator of the environmental status and its monitoring provides useful information for various kinds of management.

Geographic Information System (GIS) has been widely used in many environmental studies (BLASCHKE; KUX, 2005) as biogeography and management of protected areas (MORAES, 2012). Although, far less attention has been paid to the development of landscape models to predict aquatic communities (MEIXLER; BAIN, 2012) and few river studies incorporate this technology for examining habitat variables and use of habitat by individual fishes (PYRON et al., 2011). GIS tools can be very usefull for investigating the complex spatiotemporal dynamics associated with fish, fisheries, and their ecosystems.

The aim of this study was to evaluate the distribution, diversity and abundance of fish species in different habitats according to some parameters, in two study periods:1992 to1999 and 2000 to 2007

Material and methods

Study area

The Lagoa Rodrigo de Freitas (Figure 1) is an urban lagoon located in the south zone (22° 59' 5''- 22° 57' 25''S; 43° 13' 26'' - 43° 11' 35''W) of Rio de Janeiro city, and its connection with the sea is artificially maintained by the channel of the Jardim of Alah. The Lagoon has an area of 2.25 square kilometers and perimeter of 7.7 kilometers. The bathymetry varied from 1 m to 10 m deep. Due to an inefficient water exchange, the water residence time is high which leads to an accumulation of organic matter in the system.

Fish specimens were sampled at four areas in the Lagoon. The Area 1 is closest to the Jardim de Alah channel, in the surroundings of Caiçaras club and is influenced by marine waters. The Area 2 is located in the southeast of the lagoonal system, in the surroundings of Cantagalo and Catacumba Parks. The Area 3 is closest to the Piraquê island and is influenced by the watershed from the Macacos, Cabeças and Rainha rivers. The inflow of the three rivers into the Lagoon is made by a single channel called "Tábuas". The Area 4 is located in the northeast of the lagoon.

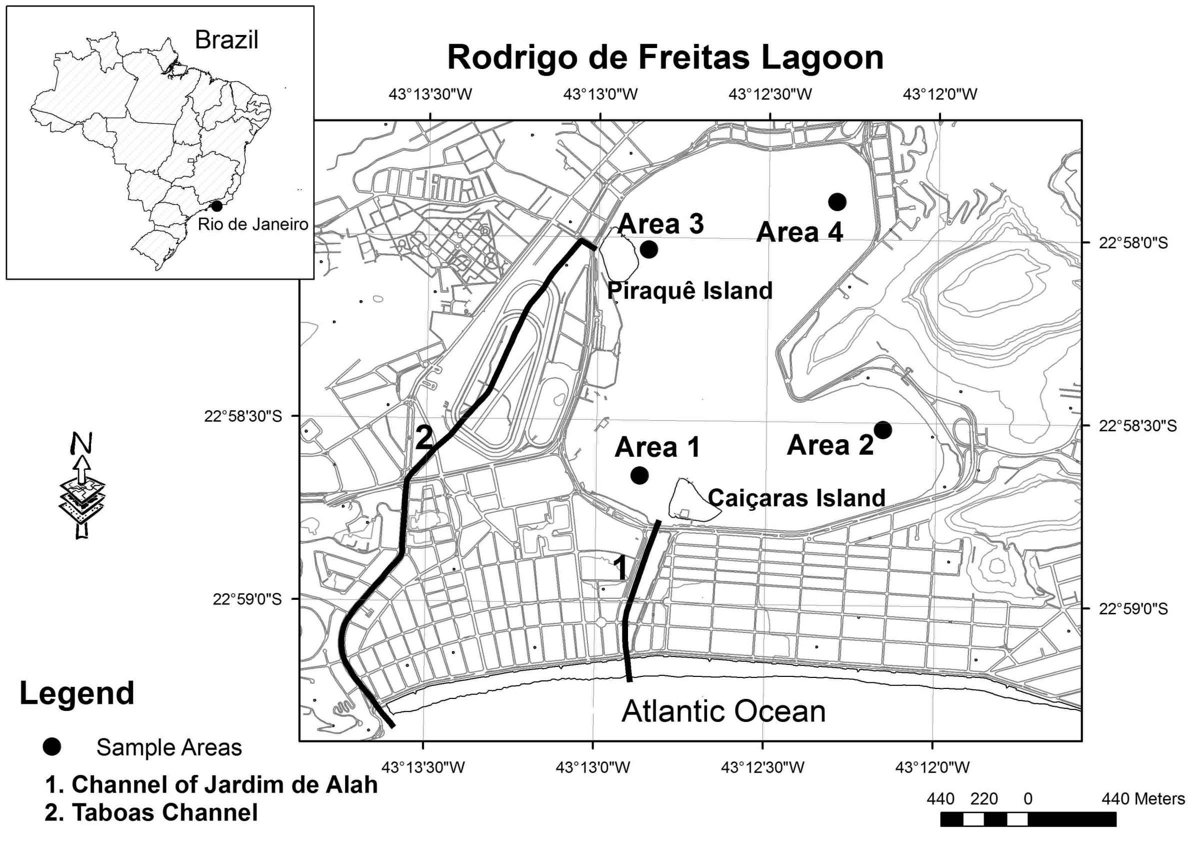

Figure 1. Rodrigo de Freitas Lagoon showing the four sampling areas. The Area 1 is closest to the Jardim de Alah channel; Area 2 is located in the southeast of the lagoonal system; Area 3 is closest to the Piraquê island and Area 4 is located in the northeast of the lagoon.

Field and laboratory methods

Fish samples were taken bimonthly from 1991 to 2007 at four sites in the Rodrigo de Freitas Lagoon by members of the Laboratory of Ichthyology of Santa Ursula University. Samples were taken during daylight, using four fishing tools (cast net, beach seine net, sieve and gill net).

The fishing tools used were: 1) cast nets with meshes of 15, 18 and 20 mm; 2) beach seine net called “picaré” with meshes of 3 and 15 mm; 3) sieve with 3 mm mesh size; 4) gillnets with mesh sizes 20, 25 and 35 mm, installed near to the Jardim de Alah channel at the start of sampling and removed at the end of all samplings.

Small fish were preserved in situ using 70% ethanol. In laboratory, specimens were identified and counted. Fish species were classified as benthic, pelagic or demersal. Fish data were separated in two periods between 1991 and 1999 and between 2000 and 2007, for observing the implications of anthropic impacts (e.g. dredging, floodgate operations, silting and organic matter inputs) on the abundance and diversity of fish fauna. According to Domingos et al. (2012) different floodgate operations have been made between 2000 and 2010, however, the water exchange between the Lagoon and the sea is not sufficient to promote a better oxidation of the bottom layer.

Data were analyzed according to relative abundance, richness (Margalef index) and diversity (Shannon-Weaver index). It was used the software PAST (HAMMER et al., 2001) to run the analyses of diversity and richness.

Parameters as salinity (‰), dissolved oxygen (DO) in the surface (mg L^{-1}), pH, and water temperature (°C) were analyzed in the four study areas. The Aquafauna refractometer was used for measuring water salinity. Dissolved oxygen was measured using a portable meter Aquacheck-3 OH-503. A digital potentiometer was used for measuring pH and a mercury thermometer for measuring water temperature. Batimetric data in .dxf format were obtained from the Rio Águas Foundation.

Multivariate analyses were performed using the software Statistica 8 (StatSoft Inc., Tulsa, USA). A quantitative cluster analysis (Euclidean distances) accomplished by UPGMA was used to observe similar groups of fish fauna between each sampled area. A Principal Component Analysis (PCA) was carried out to convert a set of correlated variables into a set of orthogonal, uncorrelated axes called principal components (LEGENDRE; LEGENDRE, 1998, ROBERTSON et al., 2001). PCA enables condensation of data on a multivariate phenomenon into its main, representative features by projection of the data into a two-dimensional presentation (JANŽEKOVIČ; NOVAK, 2012). In aquatic habitat studies, PCA has been applied for evaluating fish abundance and their seasonal and spatial variation (BLANCK et al., 2007).

Map algebra uses math expressions to combine raster layers using operators such as arithmetic, relational and boolean logic (WANG; PULARD, 2005). It was used the algebraic language as a tool to combine raster layers using the free software SPRING 5.1.7 (CÂMARA et al., 1996) through the Spatial Language for Algebraic Geoprocessing (LEGAL). Features as mean of dissolved oxygen in surface (mg L^{-1}), fish abundance (total number) and bathymetry (meters) were manipulated using Boolean algebraic expressions describing the rules and conditions involved in fish zoning in the Rodrigo de Freitas Lagoon. Image (orthophoto) and database in shapefile format (.shp) were acquired at Instituto Pereira Passos (IPP). The map of study area was made using Arcgis10 -ESRI®.

For the spatial zoning of fish species it was used the modelling below:

```
Between 91 and 99:
{
//Defining variables and categories
Thematic batimetry ("Lagoa.bat"); Thematic fish ("total.sp"); Thematic DO ("DOsup"); Thematic Bio ("zoning99");
//Retrieving names
batimetry= Retrieve (Name="bat"); fish= Retrieve (Name="sp1"); DO= Retrieve (Name = "fatDO");
//New plan
Bio=z among classes
Bio = Assign(CategoryOut = "zoning99")
{
"zone1": (batimetry.Class == "0-1" || batimetry.Class == "1-2" && fish.Class == "37-42" && DO.Class == "4.8-5"), "zone2": (batimetry.Class == "2-3" || batimetry. Class == "3-4" && fish.Class == "42-45" && DO.Class =="5-5.5"), "zone3": (batimetry.Class == "4-6" || batimetry.Class == "6-8" && fish.Class == "30-37" && DO.Class =="5.5-6")
};
}
Between 00 and 07:
{
//Defining variables and categories
Thematic batimetry ("Lagoa.bat");Thematic fish ("total.sp"); Thematic DO ("DOsup");
Tematico Bio ("zoning07");
//Retrieving names
batimetry= Retrieve(Name= "bat");fish= Retrieve (Name= "sp2");DO=Retrieve (Name="fatDO");
//New plan
Bio=New (Name="zoning07", ResX=1, ResY=1, scale=1000);
//Defining relations among classes
Bio = Assign CategoryOut = "zoning07")
{
"zone1": (batimetry.Class == "0-1" ||batimetry.Class == "1-2" && fish.Class == "19-24" && DO.Class == "4.6-5.1" ), "zone2": (batimetry.Classe == "2-4" ||batimetry.Classe == "4-6" && fish.Class == "24-30" && DO.Class == "5.1-5.3"), "zone3": (batimetry.Class == "4-6" ||batimetry.Class == "6-8" && fish.Class == "24-30" && DO.Class =="5.3-5.6"),
};
}
```

Results and discussion

Fish abundance

There was a sharp decline in abundance of fish species between the two periods. Most species collected were occasional and non-residents in the Lagoon. In both periods, the fish species with higher abundance had no commercial value, as "barrigudinhos", "savelhas" and "peixe-rei".

A total of 58 fish species were collected from 1991 to 1999, compared to only 39 between 2000 and 2007. In the first period, "peixe-rei", *Atherinella brasiliensis* was the most abundant fish species in the four areas followed by *P. vivipara*. In the second period, *Phalloptychus januarius* , a mollie fish called "barrigudinho", was the most abundant in the areas 1, 2, and 3. In the same period it was observed a drastic reduction of capture from 12,498 specimens in 2000 to only 96 specimens in 2007, representing eight fish species.

Figure 2 (a, c and e) shows the abundance of fish species more representative in relation to habitat and sample area in the first period (1991-1999). From 1991 to 1999, benthopelagic fish species were better represented by *Jenynsia multidentata* , totalling 14.37% of the catches and "carás", *Geophagus brasiliensis* representing 3.1%. *Eucinostomus aprion* was the most abundant demersal fish species totalling 2.0% of the fish caught, followed by "carapeba" *Microgobius meeki* with 753 specimens. The most abundant pelagic fish species were A. *brasiliensis*, *Poecilia vivipara* and *B. aurea* with 20.34, 19.51 and 13 of the total catch, respectively. *P. januarius* was not captured between 1991 and 1994, being more abundant between 1998 and 1999. *Mugil* sp was quite sampled between 1991 and 1994. Andreata et al. (1997) found that between 1991 and 1994 the most captured fish species were *Brevoortia aurea* (Spix, 1829); *Brevoortia pectinata* (Jenyns, 1842) and *Genidens genidens*. In the same period, the ichthyoplankton was dominated by *Brevoortia* sp and *A. brasiliensis* (ANDREATA, 2012). The study showed that, from 1994 to 1999, the menhaden was no longer regarded as the most abundant fish as noted by Andreata et al. (1997).

Figure 2 (b, d and f), show the abundance of fish species more representative in relation to habitat and sample area in the second period (2000 to 2007). Among the benthopelagic fish, *J. multidentata* was the most abundant in the four studied areas, especially in the area 4, totaling 13.9% of the catches in this period. The second most found fish species was *G. brasiliensis* in the area 1, with 520 individuals collected in the Lagoon. It was also observed that some species of Perciformes, called "amboré" and also

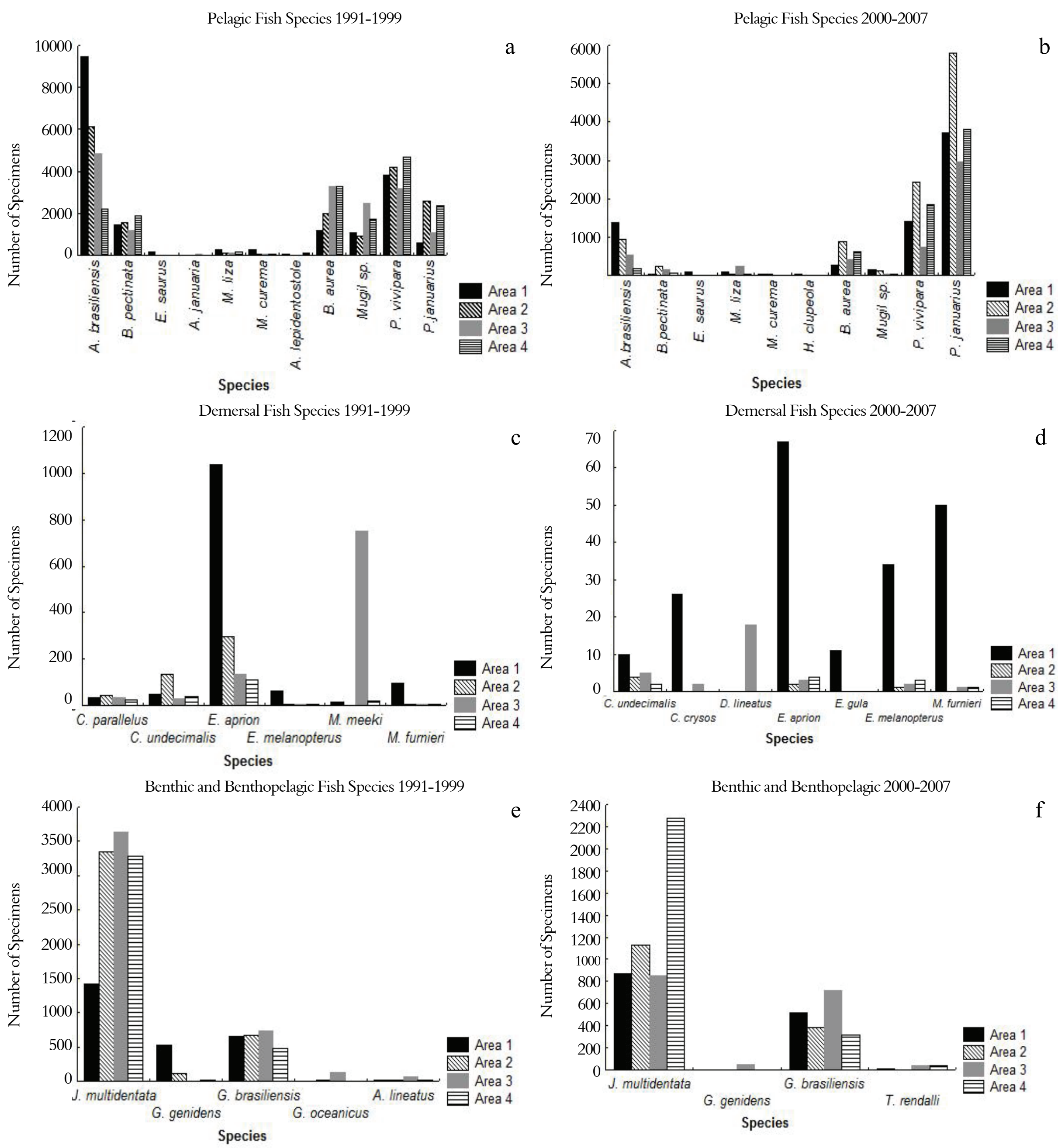

Figure 2. Fish species abundance in relation to habitat and area, in the first period (a, c, e) and in the second period (b, d, f).

Pleuronectiformes species commonly known as "linguado" were no longer found in the Lagoon. Among the pelagic fish species, *P. januarius* was the most abundant in the four areas totalling 44.3%, followed by *A. brasiliensis* with 6.97% of the catches. According to Andreata et al. (2004), between 1991 and 2004, *P. vivipara* was the most abundant, and represented 20.86% of the total capture. Between 2004 and 2007 *P. januarius* and *P. vivipara* remained the most abundant pelagic species, although *P. januarius* increased in number, totalling almost 50% of the total capture. Demersal fish species were better represented by "carapicús", *E. aprion,* although with a clear decrease in number if compared to the previous period. *Mugil sp*. occurred with low abundance totalling 374 specimens, among them 251 were caught in 2002. The capture of *G. brasilienses* remained relatively stable compared to previous period. Five species were collected only after 2002 with a very low abundance (< 6 specimens) as "amboré" *Eleotris pisonis* (Gmelin, 1789); "palombeta" *Chloroscombrus Chrysurus* (Linnaeus, 1766); "Nile tilapia" *Oreochromis nilloticus* (Linnaeus, 1758); "sardinha" *Sardinella janeiro* and "xaréu" *Pseudocaranx dentex*. These fish species occasionally enter the Lagoon.

Cluster analysis

Figures 3a and b show the the Euclidean distances among the four areas in the two study periods. In the first period, in the area 1, *P. vivipara* was the most captured species followed by *A. brasiliensis*, *B. pectinata* and *J. multidentata. E. aprion* was also abundant in this area. *P. januarius* was not captured between 1991 and 1994, being more abundant between 1998 and 1999. In the area 2, *A. brasiliensis* had a great abundance with an occurrence of 6,153 specimens, followed by *P. vivipara*, *J. multidentata* and *P. januarius*. In the area 3, *A. brasiliensis* was the most abundant fish species followed by *J. multidentata* and *B. aurea*. In the area 4, *P. vivipara*, *J. multidentata* and *B. aurea* were more abundant in this period. The areas 2 and 3 presented the highest abundance of *A. brasiliensis*. The two species of *Brevoortia* were registered in large numbers in the area 4. *E. aprion* had low abundance in the areas 2, 3, and 4. *Mugil* sp was found especially in the areas 3 and 4.

In the second period, the Euclidean distances among the four areas showed that, *P. januarius* and *A. brasiliensis* had the highest abundance in the area 2 with an occurrence of 5,817 and 942 specimens, respectively. On the other hand, *J. multidentata* was more captured in the area 4. *G. brasilienses* had the highest occurrence in the areas 1 and 3 and the two species of *Brevoortia* in the areas 2 and 4.

a

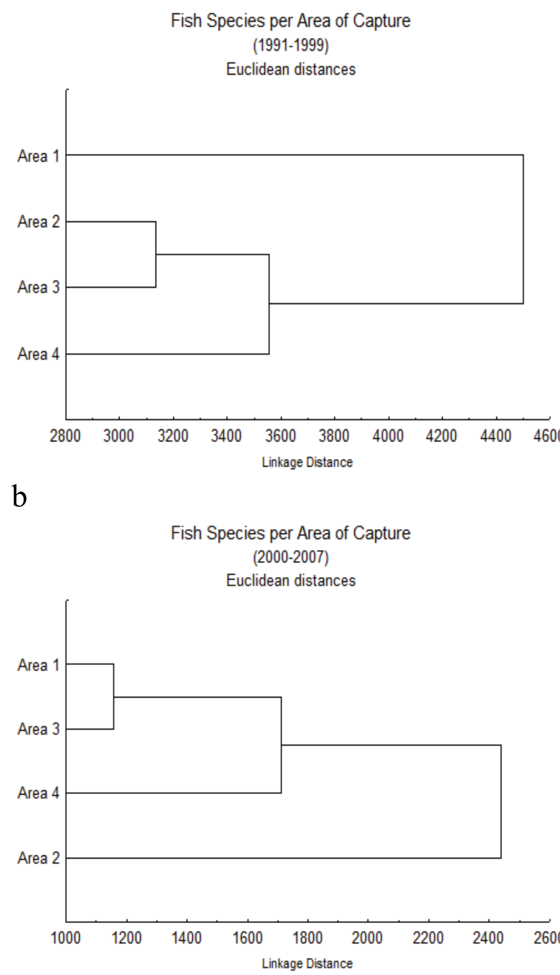

Figure 3. Cluster dendrogram of fish species per area of capture between 1991 and 1999 (a) and between 2000 and 2007 (b).

Richness and diversity of fish species

The richness and diversity of fish species (Figure 4) significantly declined between 1991 and 2007, with four critical periods: 1995, 2000, 2006 and 2007. In all these critical periods, there were mass fish deaths, demonstrating the instability of the Lagoon. The highest indices of richness and diversity were observed in 1992 and 1993, with 4.61, 4.14 and 1.94 and 2.10, respectively. In the second period, the highest richness and diversity indices were observed in 2002 and 2003 with 2.43 and 2.58 and 1.97 and 1.91, respectively. Although 63 species were found in the Lagoon, only five families were more representative as Poecilidae, mainly represented by the species *P. januarius* and *Poecilia vivipara*; Anablepidae, represented by J. *multidentata*; Atherinidade, represented by A. brasiliensis, Clupeidae, mainly represented by the species *B. aurea* and *B. pectinata* and Mugilidade, mainly represented by *Mugil liza*.

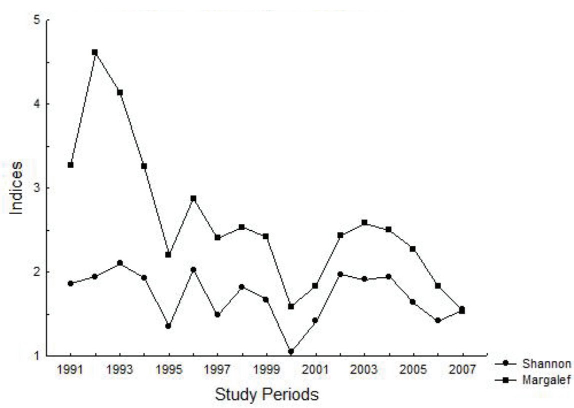

Figure 4. Diversity and Richness indices of fish species in the study periods.

Environmental Variables and relationship with fish distribution

Multivariate PCA allowed an interpretation of abiotic and biotic factors for correlating some physical variables with the three major species, chosen by the abundance and also due to their occurence in events of mass death in the Lagoon. The species of "barrigudinhos" remained abundant independent of changes in physical variables and therefore were not used in this analysis. The principal component analysis was carried out by sampled areas and study periods and showed that the first axis explained 26.48% of the variability and the second, 18.95% (Figure 5a and b, Table 1). PC1 best explained the variability of salinity and pH: these values increased with the increasing PC1. PC2 best explained the variability of water temperature: these values increased with the decreasing PC2. PC3 best explained the variability of dissolved oxygen in surface: these values increased with the decreasing of PC3.

Table 1. Principal Components for the three first axis.

Factor loadings (Unrotated) Extraction: Principal components (Marked loadings are >,700000)			
	Factor 1	Factor 2	Factor 3
Abiotic Factors			
Dissolved Oxygen	0.2463	0.2972	-0.6769
Salinity	0.8494	0.0686	-0.0009
pH	0.7816	-0.3240	0.0003
Water temperature	-0.0424	-0.7472	0.4542
Biotic Factors			
B.aurea	-0.3422	0.5475	0.3571
B. pectinata	0.5075	0.3068	0.2381
A. brasiliensis	0.2899	0.4199	0.6479
% Total Variance	26.48	18.95	18.12

Results showed that *B. aurea* was negatively associated with factor 1 and achieved its highest abundance in the area 3 in 1995 and 1996, and lower abundance in 2006 in all areas, with no specimen collected. The salinity was positively correlated with the factor 1, presenting higher values in 2007 in all sampled areas, varying from 15‰ in the area 4 and 20‰ in the area 3. According to Domingos et al. (2012) the increasing of salinity in the bottom layers, due to greater influx of seawater is probably responsible for the stratification of this water body. According to Domingos et al. (2012), when the Jardim de Alah channel remained closed and/or silted, the salinity levels declined.

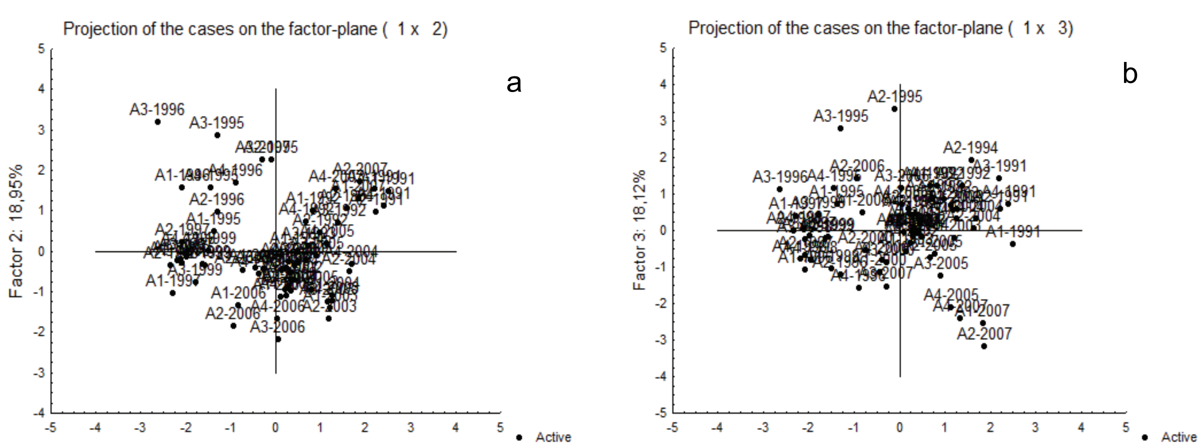

Figure 5. Two first PCA axes based on seven variables. Plot cases factor coordinates (areas and periods); a. 1st and 2nd factorial planes, b. 1st and 3rd factorial planes.

Silting also occurs at the downstream end, at the lagoon-channel intersection, which reduces water exchange time and volume (SOUZA et al., 2011). The water temperature was negatively correlated with factor 2, reaching its highest level in the area 1 in 1997. There was a negative correlation between salinity and water temperature, expecially in 1997 when it was observed very low salinities, which varied from 0.5 to 2.16 ‰ and higher water temperatures, varying from 24.9 to 29.16ºC, which corroborated the findings of Andreata et al. (1997) and Domingos et al. (2012). The amount of oxygen depends greatly on the temperature of the water. According to Souza et al. (2011), when the water temperature both at surface and at the bottom was high, the oxygen at surface was low and salinity was around 13, evidencing less exchange with the sea. The dissolved oxygen in surface was negatively correlated with factor 3, showing higher values in the areas 1 and 2 in 2007 and in the area 4 in 2005, varying from 7.1 mg L^{-1} to 8.7 mg L^{-1}. The lowest values of dissolved oxygen at the surface was observed in 2006 ranging from 1.7 mg L^{-1} to 3.5 mg L^{-1}. In this period, none specimen of *B. aurea* was found and only 12 specimens of *B. pectinata* were collected in the Lagoon. Andreata op cit., observed a clear sucession between the two species of *Brevoortia* and found that after fish deaths in 1993, *B. aurea* became dominant in relation to *B. pectinata*. The study showed that *B. aurea* remained abundant in 1995 with 6,809 specimens sampled. However, none specimen of *B. pectinata* was captured in the same period, corroborating the findings of Andreta et al. (1994).

Between 2006 and 2007 the salinities gradients varied from 8 to 9 and 15 to 20‰, respectively, showing an increase in salinity levels. The dissolved oxygen in the surface also increased between 2006 and 2007 from 1.7 to 2.7 mg L^{-1} and 4.3 to 8.2 mg L^{-1}, respectively. Domingos et al. (2012) verified a relevant increase of Cyanobacteria (annual median values) in 2006 and 2007. According to Loureiro et al. (2001), between June 2006 and March 2007 it was conducted a dredging operation about 2 km long and 100 m wide at the Rodrigo de Freitas Lagoon. The depth of sediment dredged was quite variable between 0.2 and 3.0m, and the removed material was deposited in different locations in the Lagoon itself (LOUREIRO et al., 2001). In the same period, none specimen of *B. aurea* and *B. pectinata* was found in the Lagoon. According to Domingos et al. (2012) the fish deaths in 2000 and 2001 occurred in the summer and was not related to heavy rains but was correlated with dominance (+90%) of Cyanobacteria species, mainly *Synechocystis aquatilis* f. *salina*. In 2000 a hundred tons of dead fish, especially menhaden, were collected in the Lagoon and the death was probably due to the toxin of the algae (AZEVEDO; CARMOUZE apud. DOMINGOS et al., 2012). According to Moraes and Andreata (1994), mollie species, as *P. januarius* and *P. vivipara*, feed mainly on Cyanobacteria and epibenthic algal community and seem to be more resilient and adapted to environmental changes. Also, the Cyprinodontiformes as *P. januarius* can reach gonadal maturity within few weeks (VAZZOLER apud. ANDREATA, 2012).

Figures 6 and 7 show the variations of the mean dissolved oxygen in the water surface between the areas, in the two study periods. Higher mean values were observed in the areas 1 and 2, in the south center of the Lagoon, influenced by marine waters.

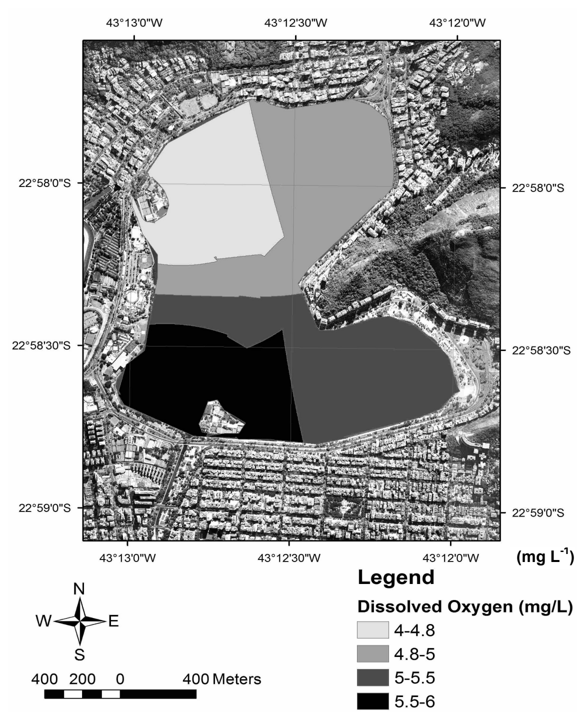

Figure 6. Variation of the dissolved Oxygen average (1st period).

Oxygen average (2nd period)

In lagoons with high biomass of plants or organic contamination, the measurement of dissolved oxygen provides an easy measure of water quality (NEWTON; MUDGE, 2005). Systems can alternate between supersaturated conditions during daylight hours due to photosynthesis and undersaturated at night due to respiration ((NEWTON; MUDGE, 2005). According to Souza et al. (2011) the water column circulation promotes re-suspension of bottom sediments and later organic matter oxidation, thus reducing the dissolved oxygen concentration in the water. Souza op cit. observed a chemical stratification of the water column in the Lagoon and a overall downward trend of dissolved oxygen during summer time which corresponded to a fish death period. According to FEEMA (2002), the Rodrigo de Freitas Lagoon belongs to the category of choked lagoons due to its long water residence time, feature that enhances eutrophication. The area 3, influenced by the Macacos and Cabeças Rivers, presented the lowest values. The lowest mean value occurred in 1999 in the area 3, with 2.82 mg L^{-1}. According to Souza et al. (2011) the lack of lagoon-sea water exchange, accelerates the accumulation of organic matter, which under high water temperature and consumption of dissolved oxygen reinforces the activity of sulphate-reducing bacteria (SRB) and releases sulphidric gas (H2S) to the water column (DOMINGOS et al., 2012); and implies in adverse conditions to fish species and eventually causes their death. The concentration of dissolved oxygen in the surface varied from 3.7 to 5.6 mg L^{-1} between 1995 and 1997 and from 1.7 to 2.7 mg L^{-1} in 2006, considered critical periods with the lowest indices of fish richness and diversity. This correlation showed how the Lagoon system depends on oxygen inputs which is, probably, the major contributor to fish deaths. Although there are other factors that can account for a sudden fish die-off in a water body, including toxic discharges. Water chemistry and species biology (e.g. metabolic rates and tolerances) make some fish species more vulnerable to environmental stress and low dissolved oxygen than others. As the Lagoon is considered a hypertrophic system (LOUREIRO et al., 2001) the menhaden, a filter-feeding clupeoid fish, is the most impacted species, especially in events of eutrophication, and dies first. According to Domingos et al. (2012) the phytoplankton community is the base of the food chain in this ecosystem, since macrophytes and macroalgae are systematically removed by COMLURB (Municipal Company of Urban Cleaning). The menhaden seems very important to control algal blooms. If the menhaden population decreases, the trend is the blooming of dominant algae, turning the Lagoon into a dead zone. The population of menhaden is decreasing over the years, although the two species of *Brevoortia* still use the lagoon for spawning and reproduction (ANDREATA, 2012), and remain the most abundant species in the cases of mass fish death.

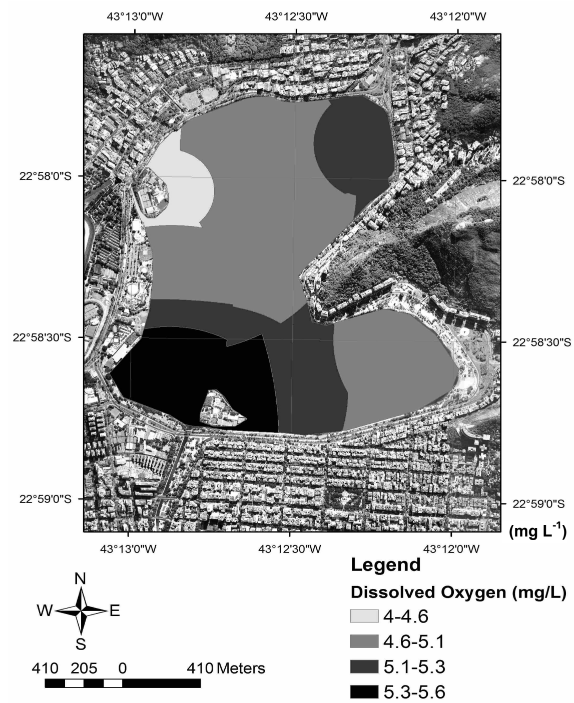

Figure 7. Variation of the dissolved Oxygen average (2st period).

Figures 8 and 9 illustrate the amount of fish species captured in the four areas. There was a marked reduction in the number of fish species in the Lagoon. The highest number of fish species was observed in the surroundings of the area 1, in the south-central of the Lagoon for the two periods.

Fish zonning

Most fish used the different zones of the lagoon (Figures 10 and 11) and were captured with different fishing tools. Some fish species tended to occupy shallow areas near the margins but with no clear sign of spatial separation among them. In the zone 1 with the lowest depth (≤ 2 m), with shallow areas, the major capture efficiency was obtained with sieve especially for species *P. vivipara*, *J. multidentata, A. brasiliensis* and *B. aurea*. Cast nets and beach seines presented the major capture efficiency for *B. aurea*, *B. pectinata*, *P. vivipara*, *M. liza*, *A. brasiliensis* and *J. multidentata*. Gillnets were more efficient for capturing *E. aprion*, *M. liza*, *G. brasiliensis* and *B. aurea*. In the zone 2, located in the south center of the lagoon, it was observed higher values of dissolved oxygen than in the zone 1 and also a greater amount of fish species in both periods. The zone 3 is located near the edges in the southeast and southwest of the lagoon with the highest bathymetry due to dredging activities. The abundant species were considered residents and were found in the three zones, including *M. liza* and *G. brasiliensis*. Nevertheless, there was no clear sign of spatial separation among the co-existing species in the lagoon.

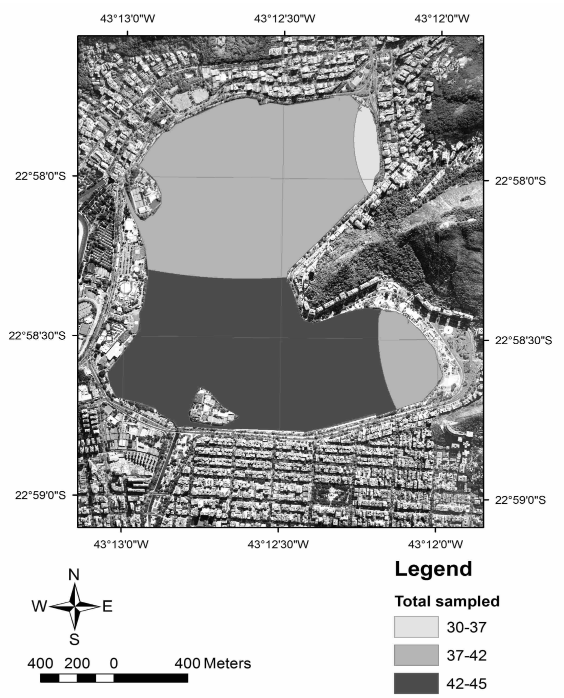

Figure 8. Variation in the amount of fish species (1st period).

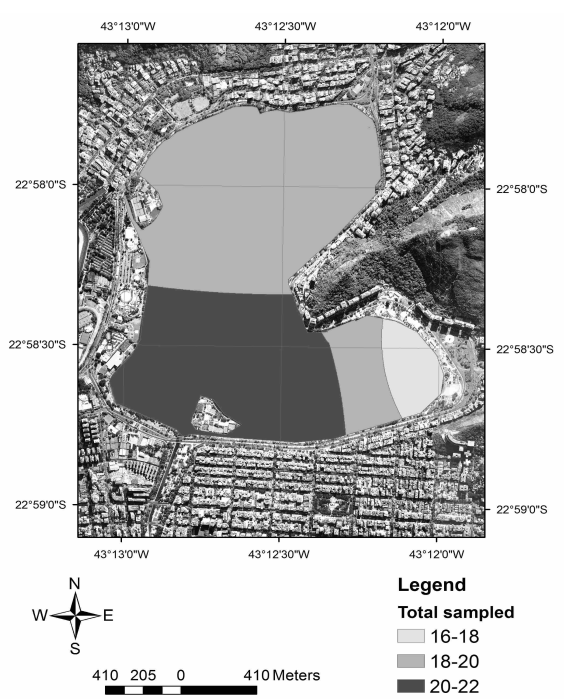

Figure 9. Variation in the amount of fish species (2nd period).

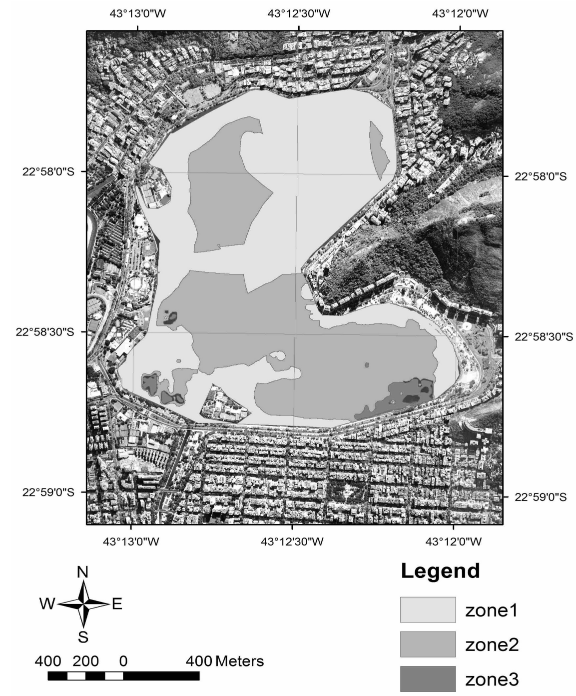

Figure 10. Fish Zoning (1991-1999).

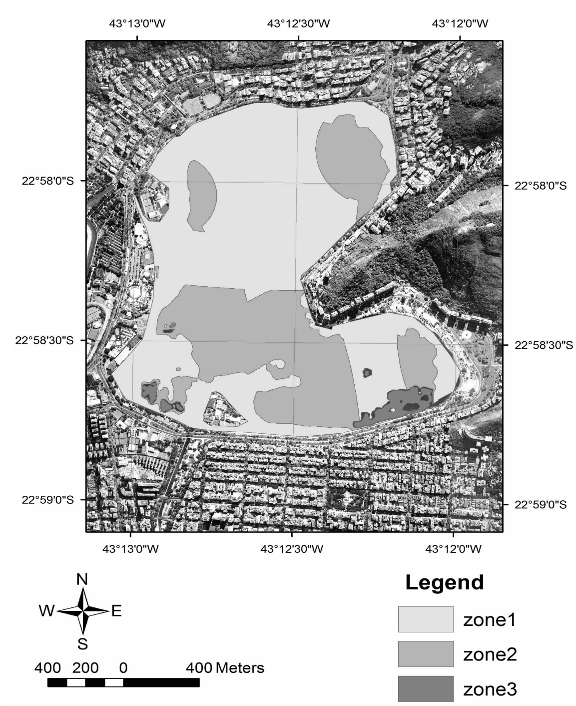

Figure 11. Fish Zoning (2000-2007).

Conclusion

There was a sharp decline in fish abundance and diversity. The majority of species was not resident and occurred in very low abundance. The higher diversity occurred in the areas with higher levels of dissolved oxygen and salinity. Despite that, prediction of the variables that constrain distribution within zones into the Lagoon depends on input data and also a broad knowledge of the biology and ecology of the species under study. The fish habitat requirements is a very important issue for decision-makers dealing with the restoration of the Lagoon . The improvement of water quality is probably the most important factor in providing sustainable habitat.

The decline of menhaden over the years is alarming since this kind of fish is an important link in the marine food chain. The fact that *Brevoortia* species use the Rodrigo de Freitas lagoon during its life cycle justifies the conservation of this ecosystem.

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