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Expedition on the Lower São Francisco: An X-ray of fisheries and agriculture, pollution, silting and saline intrusion

Expedição no Baixo São Francisco: um raio-X da pesca e agricultura, poluição, assoreamento e intrusão salina

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Brazilian Journal of Development

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ABSTRACT
The São Francisco River represents 2/3 of the Northeast Region freshwater availability. Its basin is divided into Upper São Francisco, Middle São Francisco, Sub-Middle São Francisco, and Lower São Francisco. The Lower São Francisco is one of the most impacted regions of the Northeast, considering factors related to fishing, electric power generation and city sewage pollution. The first Scientific Expedition of the Lower São Francisco aimed at evaluating the water quality, pollution, silting, deforestation of the ciliary forest, socio-economic survey, environmental education, ictiofaunal composition, analysis of metals in fish, fishing and catching and salt intrusion. The samples were collected in seven coastal municipalities in the states of Alagoas and Sergipe. The results indicate that all the municipalities studied have water pollution problems from household and diffuse sewages, pesticides, and organic matter deposited in the sediment. Much of the crops are dependent on the use of agrochemical in crops on the banks of the river, with a prevailing environmental degradation scenario. There was a decrease in the number of native fish species and predominance of exotic and invasive marine species. In addition, it was possible to detect the occurrence of catch methods with high impact on the fishes. The saline wedge is already 16 km from the river mouth, replacing agricultural activities by shrimp farming. Fish show metal content, but a large part of them are within acceptable limits and a georeferenced database with the results of the expedition was made available for consultation.

Keywords: Contamination, Ecotoxicology, São Francisco river, Fishing, Agriculture, Scientific Expedition.

RESUMO
O São Francisco representa 2/3 da disponibilidade de água doce da Região Nordeste. Sua bacia é dividida em Alto São Francisco, Médio São Francisco, Sub-Médio São Francisco e o Baixo São Francisco (cidade de Paulo Afonso- Bahia até a foz). O Baixo São Francisco é uma das regiões mais impactadas do Nordeste, quando tratamos dos fatores ligados a pesca, geração de energia elétrica e poluição oriunda dos esgotos das cidades. A 1º Expedição Científica do Baixo São Francisco, teve por objetivo avaliar estes impactos visando uma bioprospecção de aspectos como: qualidade da água, poluição aquática, assoreamento, desmatamento da mata ciliar, levantamento socio-econômico, educação ambiental, composição da ictiofauna, análise de metais nos peixes, pesca e captura e intrusão salina. Foram coletadas amostras em sete municípios ribeirinhos dos Estados de Alagoas e Sergipe. Os resultados indicam os municípios estudados, possuem problemas de poluição aquática decorrentes de esgotos domésticos, agrotóxicos e matéria orgânica depositada no sedimento. Boa parte das culturas é dependente da utilização de agroquímicos, em cultivos nas margens do rio, prevalecendo o cenário de degradação ambiental. Constatou-se diminuição do número de espécies nativas de peixes e predominância de espécies exóticas e marinhas invasoras, ademais foi possível detectar a ocorrência de métodos de capturas com grande impacto sobre a ictiofauna. A cunha salina encontra-se a 16 km da foz do São Francisco, substituindo atividades agrícolas pela carcinicultura. O pescado apresenta teores de metais, com boa parte estão dentro dos limites aceitáveis. Um banco de dados georeferenciados com resultados da expedição foi disponibilizado para consulta.

Palavras-chave: Poluentes, Ecotoxicologia, Rio São Francisco, Pesca, Agricultura, Expedição científica.

Brazilian Journal of Development

1 INTRODUCTION

The Lower São Francisco is one of the most impacted regions of the Northeast because it is located in an arid environment, where water is the main driving force of rural communities, contributing to the supply of riverside communities, animal drinking sources, irrigation, fishing, aquaculture, and electricity generation. However, it receives a large amount of pollution from city sewers, as well as problems related to silting, use of pesticides in crops along the river banks, deforestation of marginal vegetation, advance of the saline wedge, flow alterations, which impact directly the social, economic and environmental life of the communities of this region.

The flow regime in the Lower São Francisco is governed by reservoirs located upstream of the basin, such as the dams of Sobradinho, Itaparica, Paulo Afonso, and Xingó, whose affluence have been reduced in recent years due to the inadequate use of land, with reduction of water production in the basin and increased soil erosion, as well as successive periods of drought (CHESF, 2017). As a consequence, there is a gradual reduction of the minimum flows in the river, with significant impacts, including the advance of the saline wedge in the river mouth.

Associated with this issue, the lower purifying capacity of the river resulting from lower flows over longer periods contributes significantly to the maintenance of pollutants at concentrations harmful to the biota, consumption, and irrigation of crops (MEDEIROS et al., 2016). The São Francisco river flow was drastically reduced in recent years from 1,300 m^3/s in 2012 to 550 m^3/s in 2017 (resolution ANA nº 1,291/2017), as an immediate effect the increase of salinity was detected at the mouth of the São Francisco.

There are several consequences of this reduction to the Lower São Francisco, because the advance of the saline wedge on the river has brought significant impacts on ecosystems and the local population, with probable increase of the concentration of pollutants, harmful interference in economic activities such as fishing and rice-growing, and may make it impossible to use the waters for human supply purposes. Possibly, the effects of the salinization are promoting changes in the local biota, with increased competition between species, dwindling fishing stocks and the disappearance of some species of fish and crustaceans (SOARES et al., 2011; MEDEIROS et al., 2016; BARBOSA; SOARES, 2017; BARBOSA et al., 2018).

This scenario has worsened in recent years, and may have accelerated the excessive exploitation of natural resources, such as the removal of riparian forest in tributary rivers and the low level of urban sewage treatment in the municipalities of the region (CUNHA, 2015). The historical suppression of vegetation on the banks of the river contributes to the increase of silting and erosive soil processes, influencing the decrease of organisms (APARECIDO et al., 2016).

Brazilian Journal of Development

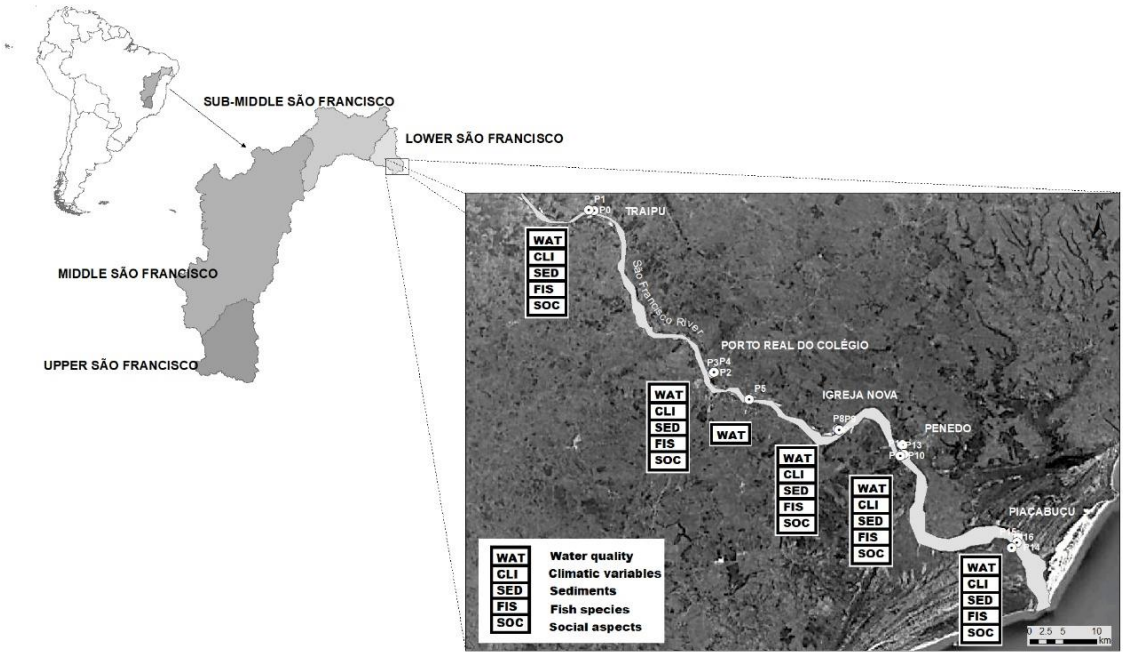
Data from the early 2010s indicated the currimatã-pacu *Prochilodus argenteus* and the piau *Leporinus obtusidens* as the most abundant species (BARBOSA; SOARES, 2009, SOARES et al., 2011), however reports from local fishermen suggest that, since 2015, these populations have declined, and these individuals, who together represented about 55% of the catches in the microregion of Penedo, may not be among the five main traded species (SOARES et al., 2011; BARBOSA et al., 2017).

In the case of other agricultural activities, there is a decrease in the productive capacity of the economic sectors that depend on the fluctuation of water levels, by shrimp farming, using the same nurseries previously used in rice cultivation, with small construction works of adequacy, reinforcement of the slopes and adequacy of the water supply floodgates (BARBOSA et al., 2018).

Because of all the changes that have happened on the Lower São Francisco, a major eight-day expedition was organized in seven data stations, in order to collect, learn, quantify, analyze, and investigate the economic, social, and environmental conditions, levels of pollutants and pesticides, survey of the fish fauna, limnology (physicochemical quality and the microbial in the environment), economic and social data, deforestation and silting up of the banks, marketing of the fish, and saltwater intrusion.

2 MATERIAL AND METHODS

The collections were carried out in the municipalities of Traipu, Porto Real do Colégio, Igreja Nova, Penedo and Piaçabuçu, in Alagoas, and the municipalities of Propriá and Neopólis, in Sergipe, all located in the Lower São Francisco region, making a route by waterway of approximately 140 km, during the month of October 2018 (Figure 1).



Brazilian Journal of Development

Figure 1. Locations travelled and collection stations of the I Expedition of the Lower São Francisco. WAT - Water Quality; CLI - Climatic Variables; SED - Sediment; FIS - Fish Collection; SOC - Social Data Collection

2.1 APPLICATION OF QUESTIONNAIRES, INTERVIEWS, AND MEETINGS

Visits were made to the secretaries of Environment and Agriculture, farmers association and fishermen colony of each targeted municipality of the study in conjunction with EMATER-Alagoas, where the groups and contacts were defined seeking to report the experience with agriculture, as well as the existing problems and potentials. Later, were applied a total of about 160 questionnaires, following the proposal of Walliman (2015), and then conducted the surveys in loco, through photographs and visits to the banks and riparian areas.

2.2 ENVIRONMENTAL EDUCATION ACTIONS IN COMMUNITIES

Visits were carried out in the schools of the riparian municipalities/towns where there were stops for collections of materials, information and application of questionnaires in five schools, one in each targeted municipality by the expedition, with objective of this activity was to know the local reality, the level of knowledge and involvement of young people with environmental problems, and to question the students and teachers of the schools about the current state of degradation of the São Francisco River.

2.3 SEDIMENT COLLECTION AND SOIL SAMPLES

The sediment collections and soil samples were carried out at random, and in each station (municipality) the collection of five samples was established. These samples were collected on both banks (Alagoas and Sergipe) and three river bed samples (channel) and sediment bank or islands resulting from the silting. The depth of sampling, at the margins and bank of sediments or islands, was 20 cm on average, as recommended for physical and fertility analysis of soils (FILIZOLA; GOMES; SOUZA, 2006).

Particle size analysis was carried through the screening process in a sieve stirrer, consisting of six distinct retention meshes (>2000 meshes; >600 meshes; >500 meshes; >425 meshes; >250 meshes and >212 meshes) and one passage mesh (< 212 meshes), the latter referring to silt + clay fractions, and part of the fine sand fraction with particle size smaller than 212 m.

2.4 CHARACTERIZATION OF METALS IN FISH

Immediately upon capture, muscle samples from the hake were obtained on board by removing portions of the laterodorsal region muscle amounting to about 30 g to 150 g, depending on the size of the fish for metal analysis, and were subsequently transported, refrigerated in thermal boxes. The fish were identified according to Lessa and Nóbrega (2000).

Brazilian Journal of Development

All biological material was packed in plastic containers previously immersed in an acid bath of HNO_3 10% v/v for 24 hours and rinsed with Mili-Q water (18 μΩ), properly identified and stored at temperatures below -15°C in a *freezer* until the time of freeze-drying.

In the digestion process, about 0.40 g of heavy lyophilized muscle was used directly in the digestion tubes and then added 10 mL of nitric acid (HNO_3) at the concentration of 7 M and 2 mL of hydrogen peroxide 30% v/v (H_2O_2, Merk, Emsure®) as adapted by Jarić et al. (2011). The quantitative determination of metals was analyzed by an inductively coupled plasma mass spectrometer (ICP-MS, Thermo, Germany). The validation of the analytical method used the certified reference material NIST - 1566b USA (fish tissue) based on analyte recovery values.

2.5 COLLECTION OF PHYSICO-CHEMICAL AND METAL PARAMETERS IN WATER

Sixteen points were selected for random sampling of water samples, seeking to represent the average behavior of the river measurement sections present in each municipality as far as possible.

The samples (about 45 water samples) were collected on the surface and bottom using a Van Dorn bottle. The water has been transferred from the on-board to a 500-mL polyethylene bottles, pre-cleaned with a mild detergent solution, and then bath acid in HNO_3 10% (v/v) for 24 hours and rinsed with water Milli-Q (18 μΩ), properly identified, transported, cooled in cooler boxes to the laboratory and stored at temperatures below -15 °C in a freezer until time of analysis.

The analyses of sodium (Na), copper (Cu), iron (Fe), manganese (Mn) and zinc (Zn) cations in water were done with Atomic Absorption Spectrophotometry (AAS). The calibration curves have been prepared with multi-elemental SpecSol® solutions. The physical/chemical parameters pH, water temperature, turbidity, electrical conductivity, oxide-reduction potential, dissolved solid totals, and salinity was measured *in situ* by using a multiparametric probe model Aquareead AP 2000.

The evaluation of the environmental condition and multiple uses of the sampled waters was carried out by comparing the limits established by Conama Resolution nº 357 of March 17, 2005; by the Consolidation Ordinance No 5 of 28/09/2017 of the Health Ministry on potability standards.

2.6 COLLECTION OF ICTIOFAUNAL

The fish were caught using 100 m mesh and 6 m mesh nets, both of which with 30, 40, and 50 between opposite knots, during a 6-hour work period. The fish caught have been identified, when possible at order level, family, genus, and species and then fixed with 10% formaldehyde, and after 48 hours fixed with 70%.

2.7 GEOPROCESSING AND GENERATION OF SHIPPING DATABASE

In each of the sixteen water collection sites, the geographical coordinates were obtained with the use of GPS and maps. It was possible to generate location maps of geospatial water collection

points along the expedition route on the Lower São Francisco using a free-version SIG, Quantum GIS (QGIS), version 2.18.21.

3 RESULTS AND DISCUSSION

3.1 AGRICULTURE

In the region of Porto Real do Colégio, considered a municipality, with an economy dependent exclusively on agricultural activities (IBGE, 2019), the expedition acted in the area comprising the irrigated District of Itiúba (area of 894 hectares) with small family farmers. The main economic activity detected was flood rice-production.

Rice-production uses water of the São Francisco River, through irrigation channels Intensive production requires many agricultural inputs, both to replenish nutrients from the soil and to control unwanted pests and plants. The use of pesticides is frequent, as there is a need for the use of fungicides, insecticides, rat poisoning, herbicides, as well as chemical fertilizers and urea.

The increase in pests, rats and birds, has forced farmers to make frequent use of pesticides, and with the predominance of monoculture, aggravated by the high level of deforestation on the banks of the rivers of the region, causes these animals to seek extensive rice plantations as housing and food source, causing damage to farmers.

Another major problem is the appearance of black rice, a grass with morphology similar to the rice produced commercially and considered an invader that reduces the quality of the final product.

The municipality of Igreja Nova has a diversified agriculture, especially the Boacica irrigation district, with 2,762 ha, being a major rice producer (38% of the area planted), however, bananas (59% of the area planted) is the main product, followed by sugarcane with 3% of the production (CODEVASF, 2019). 113 residents and farmers associated with a cooperative produce fruits, vegetables, and greenery in an agroecological system, as well as dairy cattle breeding. The existence of agriculture and livestock together allow the exploitation of manure for the fertilization of crops, with the commercialization of products through the National Program of School Feeding (PNAE), in fairs and markets of neighboring cities.

At the same time, there are cases of farmers engaged in sugarcane cultivation, favored by the incentive and contracts with sugar-alcohol mills. However, with the crisis of the sector in the last 10 years, payments have been occurring with delays and in a discontinued way, being always paid in subsequent years or relative to the last harvest, which has caused financial and social damage. In addition, the cultivation system adopted is highly dependent on the use of soluble fertilizers and

agrochemicals, favoring cultivation on the banks of the river, increasing the environmental degradation of the region.

In the Microregion of Penedo, the municipality of Piaçabuçu near the mouth of the São Francisco River has its economy supported by tourism, fishing activities, and services. Agriculture has low representativeness in the economy and has faced severe problems in recent years due to the increase in water salinity. Even though agriculture does not show any economic importance, the activity is essential for the family economy, especially in the production of self-consumption, contributing to the food security of families, including non-commercial fishermen.

In the municipality, the salinity level of the São Francisco River has increased significantly in the last 10 years, making agriculture in this region difficult. Even in this scenario, there are still rice crops adapted to this problem of the advance of the sea and the saline wedge over the waters of the river. These adaptations include the use of small ponds, with water captured from the levels of the "dead" tides - the period when the sea remains with fewer variations in height is that it is possible to capture the water of the São Francisco river, reducing the uptake in the environment with higher levels of salinity.

3.2 ICTIOFAUNAL AND FISHING

About 100 fish were collected, highlight Perciformes order (Cichlidae family: *Cichla monoculus* – 14 individuals, *Oreochromis niloticus*-11; Carangidae family: Caranx latus- 11 and Centropomidae family), Characiformes order (Serrasalmidae family: *Serralsalmus brandtii* – 11 individuals, *Myleus micans* – 9, *Pygocentrus piraya* -5; Erythrinidae family: *Hoplias malabaricus*-8, Anostomidae family; *Leporinus obtusidens* – 4, *Schizodon knerii*– 3; Prochilodontidae family; *Prochilodus argenteus* – 1 individual), with the Gerreidae and Eletridae families.

According to the studies carried out by Barbosa and Soares (2009) and Barbosa et. al., (2018), the fish fauna from the São Francisco river basin is made up of 32 families, 110 genres, and 241 species, belonging to seven orders: Clupeiformes, Characiformes, Siluriformes, Gymnotiformes, Cypriniformes, Sinbranchiformes, and Perciformes. The distribution of families, genres, and species, in this order, detach the orders of Characiformes, with 13 families, 44 genres, and 77 species, and the order Siluriformes, with the 10 families, 47 genres and 85 species, by the greater diversity of these taxa, demonstrating a high capacity for dispersal and speciation in these groups. The same authors concluded that, among the native species of the basin, several species are important as human food, and therefore heavily fished, specially: curimatans *Prochilodus* spp., dourado *Salminus franciscanus*, mandi-amarelo *Pimelodus maculatus*, mandi-açu *Duopalatinus emarginatus*, piaus *Leporinus* spp. and *Schizodon knerii*, traíras *Hoplias* spp.

Data from the studies of Soares et al. (2011) in the Microregion of Penedo, reported a prevalence of 22 species in 2007, and 18 species in 2008, and 17 species in 2009, of which close to five represent an average of 80% of the biomass of the landed fish, with the curimatã-pacu *Prochilodus argenteus*, a species that is endemic to the basin, with an average percent of 40.0%, followed by the families Anostomidae, having the piaus *Leporinus and Leporinus obtusidens*, with 22,0%, alternating between a representative of the family Engraulidae, the pilombeta *Anchoviella* sp.. When we're faced with the actual data obtained on this expedition, the decline of the native species composition of the catches is noticeable, with 17 species collected, highlighting the collapse of the curimatãs-pacus, pilombetas, and a decrease of the piaus, with a prevalence of fish of the order Perciformes, to the detriment of the Characiformes, which once was the most abundant, and the increase of the species eurihalinas, sea and the exotic compared with the native species. As for fishing activity in the Lower São Francisco, it employs small vessels, constructed with wood, with a length of between three and seven meters with propulsion engines of up to 5.0 hp or sail (SOARES et al. 2011).

The data by Porto Real do Colégio indicated that fishing activity has been alternating between fish and crab, which represented a large volume of capture in the last few years, due mainly to the decline in fish stocks, and as a result, the catch of the curimatã-pacu *Prochilodus argenteus*, a species once most plentiful on the Lower São Francisco, and pilombeta - *Anchoviella* sp. (SOARES et al., 2011), with the last capture record in 2012. The interviewees reported strong evidence of fishing with the use of dynamite and rice dumplings soaked in formaldehyde (methods prohibited by the legislation), and this, possibly allied to other factors, has been contributing to the decline of the activity, proven by the disappearance of species.

According to the associates of the Igreja Nova's fishermen colony, of the 1,100 active members, 300 had not received the Seguro-Defeso (government program to compensate periods where fishing is prohibited) in 2018, caused in part by the difficulties of access to the Prev Web system, belonging to the INSS, possibly by inconsistencies in the documentation.

As in studies of Soares et al. (2011), there is a strong presence of the middleman in the marketing of fish where the price can vary from R$ 10.00/kg in the direct sale to the consumer and R$ 5.00/kg to the middleman, called "moneychanger" in the region.

The municipality of Piaçabuçu is considered the main fishing pole in the region, due to great catch rates of Peneideos shrimp, with records of more than 242 tons of this resource caught in 2018. It is notable for the pluriactivity of fishing, an activity carried out in the waters of the estuary and the coast, due to alteration of salinity and diversity of environments (saline, estuarine, and freshwater). The data collected in the region indicate a fall in the catches of pilombeta, one of the resources that

represented about 18% of the catches in the mesoregion of Penedo equivalent to the third-largest catch (SOARES et al., 2011), practically disappeared from the region, and as possible causes, the low flow of the river, increased salinity, and high levels of contaminants from the sewers of the cities may have contributed to this decrease. As noted in the other municipalities, fishermen reported a drop-in catches of currimatã-pacu and piaus, as well as robalos, and an increase in catches of siris *Calinectes* spp., and camuripim *Megalops atlanticus*.

In addition, the interviewees reported certain types of fisheries that contribute to the over-fishing of the leading stocks such as: beat fishing, trawl, harpoon, purse seine, or lambuda (mesh smaller than permitted by the environmental authorities), beyond the competition with fishermen from other regions, difficulties with the discharge of the oil from the engines of larger boats, and protective measures for species with an increase in monitoring.

As observed by Soares et al. (2011), the perception of small-scale fishing in Lower São Francisco is related to low fishing productivity, to the capture (incidental or non-incidental) of species whose fishing is prohibited or controlled, and to the difficulties of monitoring and regulating the "Seguro defeso" for non-commercial fishermen.

The record of socio-environmental conflicts in Lower São Francisco comes from relationships with cattlemen, in the privatization of the riverbanks and their marginal lagoons. Furtado (1993) states that "the territoriality of fishing is an area built and disputed by several other categories". The disputes go beyond the fishing stocks since water is the abundant resource passed over. The small-scale fishing practiced in these waters is the activity that suffers the most damage due to a series of dams that the São Francisco River has in its length, or a change in the normal flow, which in turn generates a shift beyond the reproductive cycle of its species of fish, resulting in a reduction of the inventory levels.
It is worth mentioning the report of a new agrarian conflict arising from the appropriation of islands formed by sandbanks, as a consequence of the silting and low flow of the river. These new territories are quickly habited by the cattle of local producers, and fenced, being known from then on as "islands of so-and-so". Of course, these islands become good attractions for fish stocks, increasing fishing points. The dispute over the territory is settled since the extractivists are not allowed to dock on these newly acquired Islands.

3.3 ENVIRONMENTAL EDUCATION, POLLUTION, SILTING, DEFORESTATION AND SEDIMENT

The Lower São Francisco River receives a huge load of sewage from the cities bordering the river. All samples collected in the cities of Traipu, Porto Real do Colégio, Igreja Nova, Penedo and Piaçabuçu, showed high rates of fecal coliforms. There is also drainage water for irrigation projects which, for the most part, are not treated before released into the river stream. In general, all the

municipalities bordering the Lower São Francisco have enormous financial difficulties in establishing a local sewage treatment policy, a fact that favors the high rates of fecal coliforms found in all the municipalities studied.

All the teachers interviewed stated that planning and development of environmental educational activities, focused on addressing the issues, are dealt with in a cursory way, both in the school and in the community. Evidence of this is that the majority of the students interviewed were not aware of the impacts caused by silting, deforestation, and pollution of the environment (anthropogenic).

There are reports about the poor performance of the environmental monitoring bodies. The perception is that, in most cases, surveillance activities are carried out only in specific locations and at certain periods of the year. The riverside population itself points to the need to strengthen the FPI (Integrated Preventive Inspections) and that, if they had a permanent character.

In the path between Traipu and Penedo, it is observed that the margins, on the side of the state of Sergipe, are better preserved than the marginal areas of the state of Alagoas, where a few isolated remnants of ciliar forests are recorded, however, the fragments of ciliar forests on Sergipe's side are far from complying with environmental legislation.

There are no effective actions or implementation of solutions to recover or mitigate the current degradation of the São Francisco River. It is noticeable that there are efforts by groups of activists and defenders of the Velho Chico, but the extent of environmental and social problems supplant the actions taken by them.

It is possible to verify the occurrence of the intense erosive action of the water on the banks of the São Francisco River, even with low flow, provoking cliff and drag of the ciliar forests and sediments to the river channel. The existence of different laminar layers of deposition and composition points to significant variations in the water regime of the river, year by year, but without a specific date.

The incidence of sandbanks and a load of mineral and organic sediments resulting from the process of water erosion and silting are visible throughout the covered river area, from Traipu to Piaçabuçu, and presents a dynamic of drag and formation very variable with the flow of the river. Although navigable throughout, the main channel of the river has severe limitations on the traffic of large vessels where, due to the silting and reduction of the flow of the river, in many stretches, the average depth is less than 2 m.

The deposition of sediments of variable particle size, besides reducing the average depth of the river, promotes the emergence of new sediment outcrops above the water mirror. In terms of composition, the new sediment banks (with up to 3 years of formation) consist of fine and medium

sand and silt, with material much reworked by the waters, while in the older banks there is a visible and more massive presence of silt and clays.

The sediments found in the sample collection sites, between banks, sediment bank, and bed of the main channel, are predominantly composed of sand (medium and thin), silt and clay, with a particle size ranging from 0.001 to 0.60 mm, and also have some aggregates supported by mud and lytic fragments. However, in the samples of the main channel of the river, a small fraction with a particle size above 0.6 mm (characterized as medium and thick sands) was found.

In Piaçabuçu, it is possible to see a reduction in the size of the particles of the sediment, both in the still waters and in the islands and banks. On the other hand, in the main channel, with running water, there is the occurrence of sediments with predominant particle size composition of medium sand, mixed with a fraction consisting of slime and organ-clay material (mud).

3.4 METALS IN FISH

The mean concentration of arsenic was 0.44 ± 0.09 mg/kg. The mean minimum content of 0.05 ± 0.00 mg/kg was detected in the piau caught in Traipu and the higher content of 2.42 ± 0.63 mg/kg in the baiacu from Piaçabuçu. Values above the LMT of 1.0 mg/kg for arsenic (ANVISA, 2013) were found for baiacu (2.42 ± 0.63 mg/kg) and bagre (1.96 ± 0.34 mg/kg), both caught in Piaçabuçu.

Inorganic arsenic at chronic doses can cause irritation of the stomach, intestine, lung, and skin, as well as decrease in red and white blood cell production (DESESSO, 2001), hyperpigmentation and diabetes (TSENG et al., 2000) and the intake of significant amounts of this element can intensify the development of cancer, in particular, lymph, skin, lung and liver cancer (ATSDR, 2007).

With the exception of one sample of the pirambebas, caught in Traipu/AL, which had a cadmium content of 0.01± 0.00 mg/kg, all other samples of the fish species analysed showed levels below the detection limit of 0.023 mg/kg (ANVISA, 2013).

Anthropic contributions of cadmium to the environment can come from industrial processes and also from the use of chemical fertilizers. The health implications of cadmium exposure are aggravated by the relative inability of humans to excrete cadmium (DURAL et al., 2007).

The mean zinc concentration was 7.74 ± 0.94 mg/kg, and the lowest mean value of 4.54 ± 0.37 mg/kg was observed in the robalo and the highest mean value of 16.61 ± 4.39 mg/kg in baiacu. None of the species analyzed in this study had zinc levels above the LMT of 50 mg/kg provided in the Brazilian legislation according to Decree n° 55,871 of 03/26/1965.

Fish with an average zinc content of about 3 to 5 mg/kg is a good source for this essential element. (OEHLENSCHLAGER, 2002). Zinc deficiency causes disorders such as diarrhea, brain

function disorders, retardation of growth, a decline in immune defense, damage to eyes and skin, impaired healing of wounds and other skin diseases (ROTH; KIRCHGAESSNER, 1991).

Lead has been detected in only three species; pacu and piau with a content of 0.03 ± 0.01 mg/kg and pirambeba of 0.02 ± 0.01 mg/kg. None evaluated fish species had lead concentrations above the LMT of 0.3 mg/kg (ANVISA, 2013). Lead accumulation in organisms can cause adverse effects such as neurological damage, kidney disease, cardiovascular and reproductive effects. The organic form is the most toxic and absorbed by organisms, but the inorganic form is the most frequent (GARZA et al., 2006).

The mean chromium concentration in this study was 0.37 ± 0.05 mg/kg. The lowest and highest average levels found in the muscle tissue of the fish were 0.11 ± 0.02 mg/kg in the sole specimen of xaréu caught in Penedo/AL and 1.25 ± 0.09 in carapebas caught in Piaçabuçu/AL. All evaluated species had average concentrations of chromium higher than the LMT of 0.1 mg/kg prescribed in Decree Nº 55,871 of 03/26/1965 for any food. Several studies indicate that chromium (VI) compounds may increase the risk of lung cancer (ISHIKAWA et al., 1994).

The average manganese content was 0.79 ± 0.14 mg/kg, with the lowest average value of 0.44 ± 0.21 mg/kg detected in the single copy of sargo caught in Piaçabuçu/AL, and the highest in the single copy of curimatã-pacu was 1.33 ± 0.07 mg/kg caught in the Igreja Nova/AL. There are no maximum limits in Brazilian legislation in hake prescribed for this metal. Manganese is an essential element for humans, and Mn deficiency causes skeletal and reproductive abnormalities (SIVAPERUMAL et al., 2007). This metal occurs naturally and can be released into water bodies through runoff or leaching facilitated by agricultural activities, while anthropogenic sources include pesticides.

The mean level of copper found in fish was 0.45 ± 0.09 mg/kg, and the lowest and highest mean values were 0.30 ± 0.05 mg/kg in tucunarés fished along the RSF, and 0.62 ± 0.03 mg/kg in the single copy of xaréu caught at Penedo/AL, respectively. All fish evaluated in this study had copper levels below to the LMT of 30 mg/kg, laid down in Decree No 55,871 of 03/26/1965. Copper is an essential metal for the organism and is easily regulated by metabolism, which makes bioaccumulation very difficult (PEREIRA et al, 2010).

3.5 SALINE INTRUSION

The waters collected, both on the surface and on the bottom, from point 0 in Traipu (140 km to the mouth) to point 13, between Penedo and Neopólis, both 30 km from the mouth, were framed as 'fresh waters' (waters with salinity of 0.5 ‰ or less), according to Conama resolution nº 357 of 17 March 2005. The mean salinity was 0.02 ± 0.004 ‰ and minimum values of 0.02‰ and maximum values of 0.03‰.

The sodium levels (Na^+) of surface and background water from Traipu to Penedo had an average concentration of 3.69 ± 0.49 mg/L, minimum values of 3.20 mg/L, and maximum values of 3.50 mg/L. These values of the sodium concentration in the water are below the potability limit of 200 mg/L defined for this parameter by the Consolidation Decree No. 5 of 09/28/2017 of the Ministry of Health, being viable for human consumption.

The average concentrations of copper (0.01 ± 0.00 mg/L), iron (0.05 ± 0.02 mg/L), manganese (0.01 ± 0.01 mg/L), and zinc (0.01 ± 0.01 mg/L) were observed in the water collected between Traipu and Penedo, presenting values below the limits of 2.0 mg/L, 0.3 mg/L, 0.1 mg/L, and 5.0 mg/L, respectively, which were established by the same decree as above. According to Bassoi and Guazelli (2004), copper values below 0.02 mg/L are common in freshwater, as well as zinc in concentrations of 0.001 to 0.10 mg/L and manganese in the range of 0.2 mg/L, rarely exceeding 1.0 mg/L. The values described by the authors above are in the same order of magnitude or higher than those obtained in the fresh waters of Lower São Francisco.

In points 14 and 15 (Piaçabuçu) (16 km away from the mouth) and point 16 (large breezes/SE), water collected in surface and background water has been classified as 'brackish water' (waters with salinity above 0.5 ‰ and below 30‰), according to Conama resolution. The surface salinity ranged from 2.59‰ to 4.50 ‰ and from 5.48‰ to 16.98‰ in the background waters along the São Francisco River in the Piaçabuçu/AL-Brejo Grande/SE locality. The water sampled at the bottom showed the highest salinity because higher levels of dissolved salts in these waters confer higher water densities, that are distributed below surface waters of lower salinity and densities.

For the sodium content of brackish water in the Piaçabuçu locality, the lower value of 334.0 mg/L was observed in surface water and the higher content of 4,400.0 mg/L in bottom water. These values are above the potability limit of 200 mg/L defined for this parameter by the Consolidation Decree Nº 5 of 09/28/2017 of the Ministry of Health, being impractical to use them for human consumption. About the set boundaries for the rest of the cations contained in this decree, the average levels in the surface water and the bottom to the copper was 0.02 ± 0.00 in mg/L and 0.03 ± 0.01 mg/L; iron, 0.04 ± 0.02 mg/L and 0.05 ± 0.02 mg/L; manganese, 0.01 ± 0.01 mg/L; and zinc 0.02 ± 0,00 mg/L and 0.02 ± 0.01 mg/L, respectively, which are below the limit for human consumption. There is a trend of higher concentrations of these cations in groundwater relative to the surface of the Piaçabuçu station, and the same behavior has been recorded for electrical conductivity with lower average values of 6.47 ± 2.35 dS/cm on the surface, and greater than 19.23 ± 12.31 dS/cm in-depth, values that frame these waters in water of severe risk for use for irrigation of crops according to FAO.

The problem of salinization of the São Francisco River in the mouth region, like Piaçabuçu, is linked to the decrease of maximum levels (released leaks), that is, the reduction of floods that manage to push the saline wedge back to the sea.

The data on nitrite and ammonia were greater in the collections carried out in the municipalities of Porto Real do Colegio, Penedo, and Piaçabuçu, with average values of 0.5 ± 0.1 mg/L and 2.5 ± 0.3 mg/L, respectively. For alkalinity and stiffness, these were statistically higher in Piaçabuçu with mean values of 2.01 ± 0.2 mg/l, 48.00 ± 1.5 mg/L, and 196.5 ± 3.7 mg/L, respectively.

3.6 DATABASE OF INFORMATION COLLECTED ON THE EXPEDITION

To facilitate access to all the information collected, results analysis, graphics, photos and routes, it was created with the Google Maps *My Maps* Platform, an interactive online map that, through layers (*layers*), any user can view the information that makes up the database obtained by the expedition in a specialized way, that is, with its location in point form on the surface, and the information detail on each point. The collection of expedition data is available in *https://goo.gl/s2LxL2*.

4 CONCLUSIONS

The agriculture present frequent use of pesticides, and with the predominance of monoculture, aggravated by the high level of deforestation. The saline intrusion extension is of 16 kilometers of estuary. All samples of water collected in the cities showed high rates of fecal coliforms and high levels of nitrogen, phosphorus and sulfates. Occurred the decline of the native fish species in the composition of the catches. The heavy metals were observed in every fishes, but with levels accepted by literature.

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