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Impacts of dam construction on the macroinvertebrate community in the Poxin-Açú, in a tropical region

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ABSTRACT

River regularization plays an important role in socio economic development. However, it also modifies the natural flow system of the river and its biotic and abiotic characteristics, causing significant impacts on rivers. To evaluate the impacts on the macroinvertebrate community caused by dam construction on the Poxim-Açú River, metrics of composition and community structure of the macroinvertebrates were analyzed, as well as ecological and biological traits of the region. Macroinvertebrates were collected at three sites located downstream the dam, before (2013) and after (2015) dam construction. The water quality was classified as "good" to "excellent" according to the biotics indices. The alterations of the flow regime of the river after the dam construction influenced the macroinvertebrate communities, modifying their diversity, equitability, richness, and the number of individuals.

Keywords: bioindicators, dam impacts, environmental monitoring.

Impactos da construção de barragem na comunidade de macroinvertebrados no rio Poxim-Açu numa região tropical

ABSTRACT

A regularização de rios tem papel fundamental para o desenvolvimento socioeconômico de uma região, porém resulta em alterações em larga escala no regime de fluxo natural e modifica potencialmente uma ampla gama de fatores abióticos e bióticos, sendo considerado um dos impactos ambientais mais significativo nos rios em todo o mundo. Este estudo tem como objetivo avaliar os impactos na comunidade de macroinvertebrados ocasionado pela construção de uma barragem para armazenamento de água no rio Poxím-Açú, bem como características biológicas e ecológicas locais. Foram realizadas coletas de macroinvertebrados em três pontos a jusante da barragem em dois períodos distintos: anterior a construção da barragem (2013) e posterior a barragem (2015). A qualidade da água foi classificada como de boa e excelente qualidade, respectivamente, por meio dos índices bióticos. Alterações nas comunidades de macroinvertebrados foram observadas devido as modificações do regime de vazão, como resultado da construção da barragem, que influenciou na composição e estrutura das comunidades de macroinvertebrados e se reflete nas mudanças na diversidade, equitabilidade, riqueza e número de indivíduos no período anterior e posterior a barragem.

Palavras-chave: bioindicadores, impactos de barragens, monitoramento ambiental.

1. INTRODUCTION

In the last two decades, it has become evident that several anthropic activities in aquatic environments are connected with the imbalance of biological communities (Camargo *et al.*, 2019). Among them, the damming of the rivers potentially modifies various biotic and abiotic conditions in the lotic ecosystems, being considered one of the most significant anthropic impacts on rivers worldwide (Tonkin *et al.*, 2018; Krajenbrink *et al.*, 2019).

Dam construction could discontinue the connections between habitats upstream and downstream of the river (Dynesius and Nilsson, 1994), altering physical, chemical, and biological components of the lotic and lentic environments (Brooks *et al.*, 2018). Generally, physical impacts are related to the flow regime of the river, water temperature, water transparency, and reduction of sediments downstream of the dam (White *et al.*, 2017; Wu *et al.*, 2019). The most common chemical impacts are the reduction of dissolved oxygen in water and the reduction of phosphorus and nitrogen nutrients. The biological impacts could be related to the avoidance of migratory movement, reduction of the reproduction rate, reduction of the physiological efficiency due to the absence of oxygen, shifts in the diet pattern of the species, increase in the abundance of the most dominant and tolerant species, facilitation for the colonization process and establishment of exotic species.

To monitor environmental quality, aquatic macroinvertebrates are generally used, since several groups of these animals are highly sensitive to anthropogenic changes (Baptista, 2008). Macroinvertebrates are useful indicators, due to their specificity with certain types of impacts, as many species are demonstrably sensitive to one type of pollutant, or more tolerant to others (Pompeu *et al.*, 2005). Most studies around the world discuss the effect of dam construction on the ecological structure of the aquatic communities (Wang *et al.*, 2019).

However, there is a lack of this information on tropical regions, especially related to the Brazilian Northeast portion; direct comparison between macroinvertebrate communities in the periods before and after the construction of the dam has been impossible due to the absence of monitoring data (Maynard and Lane, 2012). Most studies have compared sites downstream of dams with control sites that do not represent natural conditions downstream (Holt *et al.*, 2015). On the other hand, this work compares macroinvertebrate occurrence data downstream of the reservoir before and after the damming of the river.

The main objective was to identify differences in the structure and composition of the macroinvertebrate community related to the construction of the Jaime Umbelino de Souza Dam on the Poxim-Açú River.

2. MATERIAL AND METHODS

2.1. Study site

The Poxim-Açu River is the main tributary of the hydrological basin of the Sergipe River (10°55’S, 37°12’ W). The micro-basin has an area of 128,08 km², with a main river channel of 26.7 km and an altitude range of 478 m (Figure 1). It is possible to observe different land cover and land uses over the Poxim-Açú River course, including livestock (50.30%), seasonal forest (36.56%), cultivated agricultural areas, exposed soil (6.97%), riparian forest (3.11%), and degraded areas (2.31%) (Rocha *et al.*, 2014).

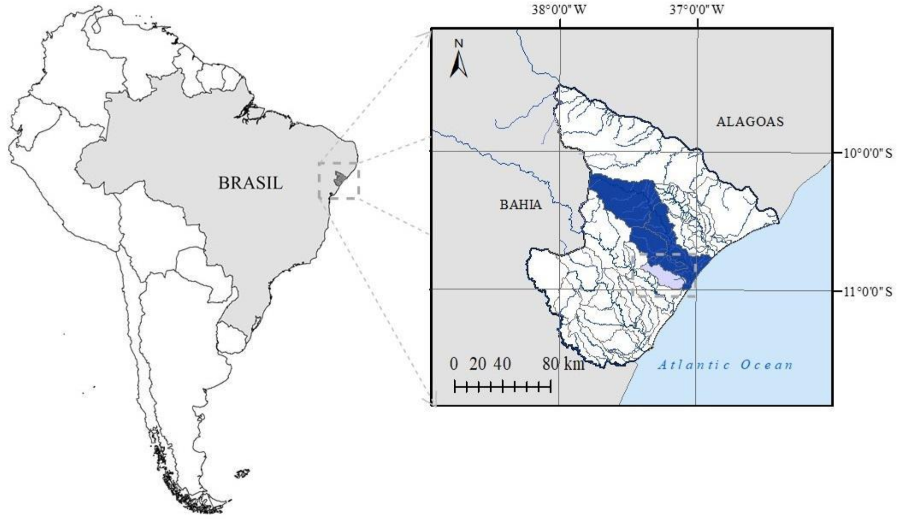

Figure 1. Representation of the Poxim-Açu River Basin, showing the location of the data collection downstream from the dam.

The region has a humid tropical climate, with a dry season from August to March and a rainy season from April to July, with an annual average precipitation varying from 1,600 to 1,900 mm and annual average temperature of 27°C, varying from 23 to 31°C. The Jaime Umbelino de Souza Dam was built over the Poxim-Açu River in Sergipe, and it was inaugurated in 2013 for the purpose of water storage. The dam is located at Timbo's village, Municipality of São Cristóvão, Sergipe department. The dam's reservoir has an area of 5.2 km^2 and a water storage capacity of 32 million cubic meters (Rocha *et al.*, 2014).

2.2. Insects Collection

Collection of macroinvertebrates and abiotic data was carried out monthly in three places on the river in the period before (January to August 2013) and after (August 2014 to July 2015) dam construction. The characteristics of the sampling points downstream of the dam with average distances of 300 m were: Point 1 (10º55'183" S, 37º11'264" W, altitude 38 m) - presenting substrate with pebbles and gravel, with less than 5% of the disposal of the sludge at the bottom of the river and a lack of it at the backwaters. More than 50% of the river bottom has diversified habitats with the presence of submerged trunks and gravel. There are changes in the river channel with the opening of ditches, felled trees, related to the channeling of the dam's mains, dragging sediment, and contributing to the siltation of the river.

Point 2 (10º55'188" S, 37º11'180" W, altitude 30 m) - substrate mainly composed of gravel and some pebbles. Ten to 30% of the habitats are stable, but substrates are frequently modified by anthropic actions that increase gravel, sand, and sludge disposal. In addition, 5 to 30% of the river bottom is affected by these actions, causing some disposal at the river's backwaters.

Point 3 (10º55,195' and S 37º11, 119' W altitude 27 m) - a substrate formed by gravel, sand, and some pebbles is predominant. The type of bottom is considered medium, where there are 10 to 30% of stable habitats; substrate frequently modified mainly by increasing gravel, sand or mud; 5 to 30% of the affected amount; gentle deposition in the backwaters.

The insects were collected using a "D" net with a 0.05 mm mesh opening over marginal vegetation, bottom sediments, and water column. The entomological material was sorted in the field with the help of tweezers, plastic trays and placed in bottles with 70% alcohol. The material was taken to the Entomology Laboratory of the Federal Institute of Sergipe, Campus São Cristóvão, and identified at the family level with the aid of a stereoscopic microscope and specialized literature (Magnai *et al.*, 2010).

2.3. Biotic Index and Data Analysis

Initially, all data were evaluated for normality using the Shapiro-Wilk test, aiming to determine the application of parametric or nonparametric analyses. To assess the diversity of the three sampling points, the total richness (S), Shannon-Wiener Log Base 10 index (H'), Pielou equitability (J'), and the dominance of the main taxon (k) were used. The latter is defined by the percentage of occurrence of the most abundant taxon with the others. To determine these indices, the PAST Software was used (Hammer, 2017).

To assess water quality, the Biological Monitoring Working Party (BMWP) index was applied. This index is a scale from 1 to 10, along which the sensitivity of various insect and other macroinvertebrate families are scored, with the highest scores assigned to species most sensitive to organic pollution. To interpret the total scores of the BMWP index, the table of values proposed by Alba-Tercedor (1996) was used, correlating these values to the water quality in the three sampling points shown respectively (Table 1).

Table 1. BMWP index scores interpretation according to Alba-Tercedor (1996).

Class	BMWP	Water quality
1	>150 101-120	Excellent
2	61-100	Good (Acceptable)
3	36-60	Medium (Doubtful)
4	16-35	Bad (Critical)
5	<15	Very Bad (Very Critical)

Another index used was the EPT (proportion of Ephemeroptera, Plecoptera, and Trichoptera), where all organisms of the orders Ephemeroptera, Plecoptera, and Trichoptera present in the sample are considered, and the relative abundance of these orders concerning the total number of organisms in the sample is calculated, the result is obtained through the Equation 1:

$$EPT\% = \frac{nº\ Indivíduos\ (Ephemeroptera + Plecoptera + Trichoptera)}{nº\ total\ de\ indivíduos}\ x\ 100 \quad (1)$$

The result of this index is compared with the values that Gonçalves (2011) proposed (Table 2) below.

Table 2. EPT index scores interpretation, according to Gonçalves (2011).

EPT (%)	Water quality
75% -100%	Very Good
50% - 74%	Good
25% - 49%	Average
0% - 24%	Bad

3. RESULTS AND DISCUSSION

In this study 12,362 individuals were collected, distributed into 32 families. Among these, 12,356 belong to Class Insecta, and the others to Class Crustacea (04) and Phylum Annelida (02). The number of individuals of each taxon and each sampling point is presented in Table 3.

Table 3. Macroinvertebrates were collected at three points of the Poxim-Açú River before (BD) and after (AD) the construction of the Jaime Umbelino de Souza Dam.

Orders	Families	Score	Before the Dam (BD) (2013)				After the Dam (AD) (2015)			
		BMWP*	P1	P2	P3	Total	P1	P2	P3	Total
Hemiptera	Veliidae	3	160	207	556	923	287	155	303	745
	Belostomatidae	3	7	1	3	11	22	20	30	72
	Notonectidae	3	0	1	0	1	5	10	7	22
	Gerridae	3	27	8	35	70	42	24	41	107
	Nepidae	3	0	2	0	2	8	1	5	14
	Naucoridae	3	0	0	0	0	1	1	5	7
	Mesoveliidae	3	0	0	0	0	0	0	5	5
Ephemeroptera	Leptophlebiidae	10	131	198	60	389	417	371	236	1024
	Leptohyphidae	6	654	475	678	1807	150	59	35	244
	Baetidae	4	52	44	57	153	29	20	22	71
	Caenidae	4	0	0	0	0	1	2	4	7
Diptera	Culicidae	2	0	0	0	0	0	3	0	3
	Simulidae	2	8	10	7	25	27	22	0	49
	Tipulidae	4	1	1	1	3	4	6	3	13
	Empididae	2	0	6	0	6	0	0	3	3
	Chironomidae	2	224	82	36	342	27	47	29	103
	Ceratopogonidae	2	0	0	0	0	0	1	0	1
Trichoptera	Hydropsychidae	5	162	267	44	473	608	481	180	1269
	Polycentropodidae	7	0	0	0	0	54	42	72	168
	Philopotamidae	8	0	0	0	0	402	592	227	1221
	Leptoceridae	10	0	0	0	0	0	0	1	1
	Xiphocentronidae	7	0	0	0	0	0	1	0	1
Megaloptera	Corydalidae	4	0	0	0	0	7	21	7	35

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Odonata	Aeshnidae	8	0	0	1	1	14	2	0	16
	Libellulidae	8	86	160	114	360	323	462	311	1096
	Corduliidae	8	0	0	0	0	7	0	7	14
	Calopterigidae	8	43	21	44	108	107	239	215	561
	Dicteriadiadae	8	0	0	0	0	0	16	0	16
	Megapodagrionidae	10	0	0	0	0	2	1	2	5
	Perilestidae	8	0	0	0	0	0	0	3	3
	Coenagrionidae	6	15	8	6	29	83	111	98	292
	Gomphidae	8	2	4	24	30	50	38	51	139
Coleoptera	Gyrinidae	3	0	0	0	0	68	92	75	235
	Dytiscidae	3	1	0	0	1	11	0	1	12
	Crysomelidae	3	0	0	0	0	0	1	0	1
	Staphilinidae	3	1	0	0	1	1	0	2	3
	Elmidae	5	4	6	4	14	0	6	2	8
Lepidoptera	Pyralidae	7	3	0	14	17	0	6	1	7
Crustacea	Isopoda	3	0	0	0	0	0	2	0	2
Phylum Annelida	Hirudinea	1	0	0	0	0	1	0	0	1
	Total	-	1581	1501	1684	**4766**	2758	2855	1983	**7596**

BMWP- Biological Monitoring Working Party Index, according to Alba-Tercedor (1996); P=Sampling collection points.

Before the construction of the dam, 4,766 individuals were collected, divided mainly into five orders: Ephemeroptera (49%), Hemiptera (21%), Odonata (11%), Trichoptera (10%), and Diptera (8%), with all the other orders representing less than 1%. In the period after the construction of the dam, 7,596 individuals were collected, divided mainly into five orders: Trichoptera (35%), Ephemeroptera (28%), Odonata (28%), Hemiptera (13%), and Coleoptera (3%), with all the other orders representing less than 2%.

It is noteworthy that there was an increase in the number of Trichoptera in the period after the construction of the dam. This can be explained by the control of the river's flow, which maintained the stability of the habitats and reduced the carrying of particles and organisms (Copatti *et al.*, 2014). This action contributes to the improvement of the BMWP biotic index due to the presence of a greater number of families (Bispo *et al.*, 2001), but there was a reduction in the EPT index (Table 4).

Table 4. Abiotic parameters before and after the dam construction.

Parameters	Sampling Periods	
	Before the dam	After the dam
Maximum Flow Regime ($m^3\ s^{-1}$)	6.94	4.71
Average Depth (m)	0.34	0.28
pH	7.10	7.70
Turbidity (NTU)	43.10	7.68
Nitrate (mg L^{-1})	3.02	0.86
Total Phosphorus (mg L^{-1})	0.40	0.07
Chlorophyll (µg L^{-1})	21.10	3.09
OD (mg L^{-1})	7.40	7.47

Comparing the sampled sites and periods of macroinvertebrate collection, the greatest diversity, equitability, richness, and number of individuals were recorded after dam construction. These results can be explained by the regularization of the river, which favored the fixation of the macroinvertebrate community downstream of the dam in the Poxim-Açu River. The abiotic changes that occurred in the Poxim-Açu River in the period before and after the construction of the dam can be seen in (Table 4), there was a reduction of the maximum flow values (6.94 $m^3\ s^{-1}$ to 4.71 $m^3\ s^{-1}$) and the average depth reduction (0.46 m to 0.34 m). Among the water quality alterations, the turbidity was reduced (43.1 NTU to 7.68 NTU), as well as the nitrate (3.02 mg L^{-1} para 0.86 mg L^{-1}) and the chlorophyll (21.01 µg L^{-1} to 0.86 µg L^{-1}).

Flow regularization contributes to increasing the availability and variety of habitats, increasing the composition of biotic communities (Callisto *et al.*, 2011). Studies on macroinvertebrate communities after dam construction showed shifts in the structure, biodiversity, and richness of the communities, due to changes in the type of substrate, river-flow speed and water temperature upstream of the dams (Kjaerstad *et al.*, 2018; Phillips *et al.*, 2015; 2016). In addition, another study showed that the construction of dams cause an increase of biomass and a reduction of macroinvertebrate taxon richness at sites upstream of the dam (Wu *et al.*, 2019).

Galdean *et al.* (2000) clarify that the study of the diversity of habitats offers an opportunity for a proper assessment of the levels of anthropic impacts on river basin sites, constituting an important tool for Environmental Monitoring Programs. For a better estimation of the

Macroinvertebrate Biodiversity parameters, the Shannon-Wiener Diversity Index (H'), the Pielou Equitability Index (J'), the EPT Index (Ephemeroptera, Plecoptera and Trichoptera), the Total Richness (S), Total Number of Individuals (n) and the Dominance (k) for each sampling site and period were calculated (Table 5).

Table 5. Shannon-Wiener Diversity (H'), Pielou Equitability (J'), EPT; Total Richness(S), Number of Individuals (n) and Dominance (k) for each Sampling Site before and after Dam Construction.

Estimators	Periods of Data Collection							
	Before the Dam (2013)				After the Dam (2015)			
	Point 1	Point 2	Point 3	Mean	Point 1	Point 2	Point 3	Mean
H'	1.90	1.95	1.68	1.84	2.39	2.37	2.53	2.43
J'	0.66	0.67	0.59	0.64	0.72	0.68	0.74	0.71
S	18.00	18.00	17.00	17.66	28.00	32.00	31.00	30.33
N	1581.00	1501.00	1684.00	1588.66	2758.00	2855.00	1983.00	2.532.00
K (%)	0.22	0.18	0.28	0.22	0.12	0.13	0.10	0.11
EPT (%)	63.18	65.55	49.82	59.51	60.22	54.92	39.18	51.44
BMWP	93.00	93.00	102.00	96.00	147.00	155.00	164.00	155.33

In this study, dam construction also affected the community structure of macroinvertebrates. The Coleoptera order increased in the number of individuals, from 16 (0.33%) before the dam construction to 259 (3.4%) after the dam construction. The Coleoptera species are known to be generalists, exploring a diversity of habitats, and are also very tolerant to pollutants. On the other hand, there was a decrease in the number of individuals of the Orders Hemiptera from 1007 (21.12%) to 972 (12.79%) and Diptera from 376 (7.88%) to 172 (2.26%). Among the orders sensitive to disturbances and pollution, there was a reduction in the number (2,349 - 49.28%) of Ephemeroptera to 1,346 (17.71%); however, the Orders Trichoptera 473 (9.92%); 2,660 (35.01%) and Odonata 528 (11.07%); 2,142 (28.19%) increased in many individuals and proportions.

In addition, Vallania and Corigliano (2007) showed that the distribution of macroinvertebrate functional feeding groups was also affected after dam construction, presenting an increase in the number of filter-feeding macroinvertebrates, scrapers, and predators and a decline in the number of collectors and shredders after dam construction.

In this study, 6.828 specimens of the Ephemeroptera and Trichoptera orders were collected (55.23% of the total of individuals collected). The order Ephemeroptera was the most abundant in the number of individuals (3.695), distributed in 4 taxons, while the order Trichoptera was represented by 3.133 individuals distributed in 5 taxons.

Among aquatic insects, these orders play an important role as bioindicators of water quality, mainly due to their great abundance in the structure of benthic communities and due to their contribution to species' diversity (Callisto *et al.*, 2001). Taking into consideration the EPT environmental quality index, the values obtained for Points 1 and 2 allow us to classify the water quality as "Good" for both periods, with values of 63.18 and 65.55 for the period before the dam and values of 60.22 and 54.22 after the construction of the dam, while Stretch 3 presents values that classify them as "Regular".

The BMWP index presented an average score of 155 after dam construction (Table 4), classifying the water quality as "Excellent" (Class 1; >150) (Alba-Tercedor, 1996) (Table 1). This result differed from that of Oliveira (2013), before dam construction, where the water quality was classified as "Good" (Class 2; BMWP=96; Table 1). The BMWP index is qualitative, and it considers only the presence or absence of families. The greater the Family score, the greater the Family sensitivity to anthropic impacts along the river, comparing different degrees of environmental integrity. Some families have an exceedingly small weight in the index, which is not representative, so they are not considered for the BMWP index analysis.

4. CONCLUSION

The construction of the Poxim-Açu River dam affected the composition and structure of the macroinvertebrate community. After the construction, there was an increase in diversity and species richness.

The BMWP index calculated after the dam construction indicated an improvement of water quality when comparing the two periods, probably because the damming of the river and the control of its flow favored the stabilization of the macrofauna, while the EPT index indicated no change in the quality of the water.

Further research is needed to determine the long-term impacts of dam construction on biodiversity of aquatic communities, especially with a focus on the migration routes dynamics, habitats fragmentation, shifts in the river-flow rates, temperature, water quality, sediments and substrates dynamics, food availability and on other physical-chemical parameters at sites upstream and downstream of the damming.

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