UNIVERSIDADE FEDERAL DO PARÁ

NÚCLEO DE ECOLOGIA AQUÁTICA E PESCA DA AMAZÔNIA

PROGRAMA DE PÓS-GRADUAÇÃO EM ECOLOGIA AQUÁTICA E PESCA

OLIVER DOS PASSOS LISBOA

EFEITO DA BARRAGEM PORTO PIMENTAL NA ESTRUTURA TROFICA DAS ASSEMBLEIAS DE PEIXES DO RIO XINGU. COMO AS REPRESAS PODEM MUDAR A VIDA DOS PEIXES?

Belém/PA

2020

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Dissertação submetida ao Programa de Pós-Graduação em Ecologia Aquática e Pesca do Instituto de Ciências Biológicas, da Universidade Federal do Pará, como requisito parcial para a obtenção do título de Mestre em Ecologia Aquática e Pesca.

Orientador: Prof. Dr. Marcelo Costa Andrade.

Coorientador: Prof. Dr. Tommaso Giarrizzo.

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BELÉM 2020

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norteENERGIA
USINA HIDRELÉTRICA BELO MONTE

Dedico à
meu pai Jorge e a minha mãe Vânia.
Obrigado por todo apoio, dedicação, carinho e muito amor.

“Seu sonho só deixa de existir quando você
deixa sua esperança morrer”

Hashirama – (Naruto)

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For the Horde!

SUMÁRIO

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Resumo

O rio Xingu é atualmente o local que comporta a terceira maior hidrelétrica do mundo em potência instalada (11233 MW) e a segunda maior do Brasil, depois de Itaipu (14.000MW). A construção de barragens impacta seriamente a biota aquática, incluindo as assembleias de peixes e seus recursos alimentares. O pulso de inundação é importante para os rios em todo o mundo, e a construção de barragens interrompe-processos físicos como o fluxo de sedimentos e hidrologia, que afetam os processos dos ecossistemas na montante e jusante do rio. Estudos sobre diversidade e nicho trófico fornecem informações importantes sobre como as alterações antropogênicas e as mudanças climáticas afetam a dinâmica da cadeia alimentar em ecossistemas aquáticos. A análise de isótopos estáveis fornece informações sobre a diversidade e nicho trófico dos organismos, e é amplamente usada para examinar a estrutura de teias alimentares de qualquer espécie. As amostras desta dissertação foram coletadas a cada seis meses em abril (estação da cheia) e outubro (estação de seca) de 2014 e 2015 (período pré-barragem) e 2016 e 2017 (pós-conclusão) em três setores de influência direta da Usina Hidroelétrica de Belo Monte. Constatamos que a criação da usina hidrelétrica e a formação do lago artificial levaram a mudanças na estrutura trófica das redes alimentares em toda a área afetada pela barragem e isso pode ser atribuído a respostas diferenciais das espécies com base nos ambientes onde as espécies foram confinadas e, com o tempo, certamente terão maiores consequências nesses ambientes.

Palavras-chave: Monte; Isótopos estáveis; rio Xingu; sazonalidade.

Abstract

The Xingu River is currently the location that holds the third largest hydroelectric dam in the world and the second largest in Brazil. The construction of the dam as the potential to seriously impact the aquatic biota, including the community assemblage of fishes and their food resources. The flood pulse is important in rivers throughout the world and the construction of a dam interrupt physical process such as sediment flux and hydrology that can ultimately affect ecosystem process at upstream and downstream. Studies about diversity and trophic niche can provide important insights about how anthropogenic alterations and climate changes can affect the food web dynamics in aquatic ecosystems. Stable isotope analysis can provide insight as to organism's trophic niche and is widely used to examine food web structure of any given species. Samples were collected every six months in April (wet season) and October (dry season) from 2014 to 2015 (pre-dam time) and 2016 to 2017 (post-completion) in three sectors of direct influence of the Hydroelectric power plant of Belo Monte. We found that the creation of the hydroelectric plant and the formation of the artificial lake led to changes in the trophic structure of the food webs throughout the area affected by the dam and this can be attributed to differential responses of species based on the environments where the species were confined, and over time they can have greater consequences in these environments.

Keywords: Belo Monte; stable isotopes; sazonality; Xingu river.

1. INTRODUÇÃO GERAL

A saúde de um ecossistema depende das interações entre os seres vivos e o ambiente em que habitam (Mello, 1987; Silva et. al., 2005). Essas interações são definem o nicho ecológico ocupada por cada (McConnell, 1999). Segundo Weiher & Keddy (2000) estudos de ecologia buscam principalmente compreender os mecanismos responsáveis pelos padrões que moldam a composição e a estrutura dos organismos em seu ambiente natural.

Dentre as interações populacionais, a competição e a predação são as principais determinantes da estrutura das assembleias (Sobral & Cianciaruso, 2012). Levando em consideração que as características tróficas dos organismos são reflexos do ambiente e dos recursos utilizados, modificações ambientais afetam diretamente a estrutura das assembleias, interferindo em inúmeros traços comportamentais e alimentares, alterando seu posicionamento trófico na teia alimentar (Ou et al., 2017)

Nos ecossistemas, os organismos apresentam vários níveis tróficos, desde o mais baixo representado pelos produtores primários, até os mais elevados preenchidos pelos consumidores (Giacomini & Petrere, 2014). Esses níveis são relacionados às complexas teias alimentares, específicas para cada ambiente, consistindo na interação presa–predador–(Giacomini & Petrere, 2014). Recentes estudos ecológicos têm focado sua atenção para análises químicas dos organismos, verificando a composição dos componentes, mais especificamente os componentes isotópicos, que podem responder a indagações sobre o nicho ecológico (Newsome et al., 2007; Abrantes et al., 2014).

Numa abordagem mais recente, a análise dos isótopos estáveis, principalmente do isótopo do nitrogênio (δ^{15}N) de produtores e consumidores têm auxiliado em acuradas estimativas para o posicionamento trófico com auxilio de análises estatisticas (Zanden et. al., 1999). Isso porque a análise de isótopos estáveis permite verificar a transferência energética entre os produtores (primeiro nível trófico) e consumidores (segundo nível em diante) (Layman et. al.,2007).

Estudos sobre a ecologia trófica de organismos aquáticos são de grande importância, auxiliando os pesquisadores a entender melhor o seu funcionamento, especialmente quanto à posição na estrutura trófica de determinadas espécies (Fitzgerald et al., 2017).

Sabendo a relevância que os peixes têm no ambiente aquático, estudos sobre sua diversidade e nicho trófico fornecem informações importantes sobre como as alterações antropogênicas e as mudanças climáticas podem afetar a dinâmica da teia alimentar das do ambiente aquático (Mason et al., 2012). Na bacia amazônica, a riqueza e a diversidade de peixes existente são as mais altas de todas as espécies em água doce, forte endemismo (Mol et al., 2007). O sistema hídrico amazônico sofre fortes influências do pulso de inundação, que alaga sazonalmente grandes áreas (Junk et al., 1989).

A bacia do rio Xingu se destaca como a maior bacia de águas claras da Amazônia (Sawakuchi et al., 2015). Nela podemos destacar sistemas de água corrente (ou lóticos), como por exemplo, rios e riachos, e sistemas de água parada (ou lênticos) como as várzeas-(Lowe-McConnell, 1999). Diante de tais condições, as assembleias de peixes estão sujeitas a fortes variações naturais na disponibilidade e tipo dos recursos (Lowe-McConnel, 1999; Behn & Baxter, 2019).

A estrutura das redes alimentares das assembleias de peixes sofre grande influência de acordo com o volume de água que um ambiente pode comportar. No caso do rio Xingu, como em todos os rios tropicais, ele é fortemente influenciado pelo regime hidrológico, e também por conta de sua geologia, possui atualmente a terceira maior barragem hidrelétrica do mundo e a segunda maior do Brasil em potência instalada (Andrade et al., 2016; Sousa Júnior & Reid, 2010). O represamento de um rio implica na interrupção de um sistema contínuo de transporte de sedimentos, matéria e migração de animais por um sistema de acumulação fechado, que realiza mudanças que transformam as margens dos rios em sistemas semi-lênticos e semi-lóticos e geração de um lago artificial (Baxter, 1977). Seu regime hidrológico é fortemente sazonal, com descargas diárias variando de 32.000 m3 · s^{-1} durante o período cheio (janeiro a maio) a 500 m3 · s^{-1} durante o período de seca (agosto a novembro) (Zuluaga et al., 2016)~~.~~ Com a recente construção da UHE de Belo Monte no baixo rio Xingu no ambiente, como o desvio no fluxo natural do rio para a formação do lago artificial, com isso as alterações no pulso de inundação dos trechos a montante e a jusante da barragem passam a ser diferentes por conta do volume de água existente agora. Alterações ambientais proporcionadas por represamentos causam drásticas mudanças no nicho ecológico das assembleias ~~(~~Agostinho, 2008). Portanto, avaliar as modificações que ocorreram no curso natural do rio Xingu são ~~é~~ de extrema importância, pois se faz necessário para a compreensão da estrutura trófica das suas assembleias de peixes desse rio recentemente afetado levando em consideração considerando as fases de seca e cheia.

2. OBJETIVOS

1.1. Geral

- Avaliar as modificações na estrutura trófica das assembleias de peixes do rio Xingu, entre-as fases de seca e cheia, decorrentes da modificação provocada pela barragem da UHE Belo Monte.

1.2. Específicos

- Estimar as variações na amplitude de nicho isotópico das assembleias de peixes nesses dois períodos.
- Descrever as possíveis mudanças na diversidade trófica das assembleias de peixes após o barramento.
- Verificar as variações no nível trófico entre as assembleias de peixe de acordo com as fases hidrológicas nos períodos de pré- e pós-barramento.

3. REFERÊNCIAS DA INTRODUÇÃO GERAL

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Artigo: **EFFECT OF PORTO PIMENTAL DAM AT TROPHIC STRUCTURE OF XINGU RIVER FISH ASSEMBLAGE. HOW CAN DAMS CHANGE THE FISH'S LIFE?**

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EFFECT OF PORTO PIMENTAL DAM AT TROPHIC STRUCTURE OF XINGU RIVER FISH ASSEMBLAGE. HOW CAN DAMS CHANGE THE FISH'S LIFE?

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Authors' contributions

OPL, TG and MCA conceived the ideas and designed methodology;

OPL, TG and MCA collected the data;

OPL, CJ and MCA analysed the data;

OPL, CJ, TG and MCA led the writing of the manuscript.

All authors contributed critically to the drafts and gave final approval for publication.

Abstract

The Xingu River is currently the location that holds third largest hydroelectric dam in the world and the second largest in Brazil. The construction of the dam as the potential to seriously impact the aquatic biota, including the community assemblage of fishes and their food resources. The flood pulse is important in rivers throughout the world and the construction of a dam interrupt physical process such as sediment flux and hydrology that can ultimately affect ecosystem process at upstream and downstream. Studies about diversity and trophic niche partitioning can provide important insights about how anthropogenic alterations and climate changes can affect the food web dynamics in aquatic ecosystems. Stable isotope analysis can provide insight as to organism's trophic niche and is widely used to examine food web structure of any given species. Samples were collected every six months in April (wet season) and October (dry season) from 2014 to 2015 (pre-dam time) and 2016 to 2017 (post-completion) in three sectors of direct influence of the Hydroelectric power plant of Belo Monte. We found that the creation of the hydroelectric plant and the formation of the artificial lake led to changes in the trophic structure of the food webs throughout the area affected by the dam and this can be attributed to differential responses of species based on the environments where the species were confined, and over time they can have greater consequences in these environments.

KEYWORDS: Belo Monte; stable isotopes; sazonality; Xingu river.

1. INTRODUCTION

The human capacity to use tools to transform mechanical energy into electrical energy was a major milestone in our evolution, we got to take the power of nature with a perpetual engineering without using fuel, with the creation of small wooden mills until the construction of large hydroelectric plants.

Large dams are built and programmed to be built according to local geology. Rivers are the target water bodies of these developments, and they must necessarily have a hydroelectric potential (Pelicice et al., 2015; Vitule et al. 2017). However, rivers have a continuous natural flow, which contains numerous species that inhabit along their cost, and in addition to constantly cycling nutrients, they have numerous ecological services that provide numerous benefits through energy flows between environmental factors in interactions ecological present in nature, services that bring balance to ecosystems, product generation and maintenance of climatic and geological cycles(Baxter, 1977). The sedimentary dynamics of the Xingu River, in Volta Grande, and its downstream sector will be displaced in the next years due to the construction of dams associated with the Belo Monte hydroelectric project. Impacts on river biodiversity and the carbon cycle is predicted, mainly due to likely changes in the sedimentation and riverbed characteristics.

Knowing the relevance that fish have in the aquatic environment, studies about diversity and trophic niche can provide important insights about how anthropogenic alterations and climate changes can affect the food web dynamics and others assemblages of the aquatics environment (Cardinale et al., 2012; Lowe-McConnell, 1999). Ecological studies often seek to understand the mechanisms responsible for the patterns of a healthy ecosystem that shape the composition and structure of organisms in their natural environment (Arias-gonzález et al., 2004; Weiher & Keddy, 2000). Trophic niches of organisms reflect the environment a species lives in and what resources they are using, and any alteration to this environment can affect the food web (Correa & Winemiller, 2014).

The food webs in fresh water environments have numerous trophic relationships, is a complex ambient, with high diversity and abundances, since small producers at to top-predatory fish (Giacomini & Petrere, 2014). Although many species are adapted to environmental changing and some even have a high plasticity they all are vulnerability at environment change as natural like hydrological season or anthropic impacts as a hydroelectric dam, all this water flow can be a factor to environment alteration, and can change the food webs in your trophic diversity and niche (Behn & Baxter, 2019).

The ecology of freshwater aquatic organisms is also built in consequence of seasonal periods, the rainfall and the volume of water the river can hold to provide flooded areas, is called flood pulse effect, that among the many benefits provides food resources for various trophic guilds (K. O. Winemiller & Jepsen, 1998). The flood pulse is high relevance in locations that comport dams, when a river has your continuous flux stopped can result in significant impacts on the food chain structure of fish communities (Zuluaga et al., 2016).

The Amazon rivers suffer from the implementation of dams each year, and the representatives lead to extreme changes in aquatic habitats (Agostinho et al., 2015). This river already has a lot of number of dams, with many being built and designed (Mello, 1987)

Considered a clearwater river, the Xingu is one of the largest tributaries of the Amazon River, it has a system that has a geological formation that end up becoming a river with landscapes formed by several rapids channels, full of rocks and he is affected for the flood pulse, the hydrologic regime is strongly, sustain a high fish diversity (Sawakuchi et al., 2015; Zuluaga et al., 2016). Recently this river holds the third largest hydroelectric dam in the world and the second bigger in Brazil (Andrade et al., 2016; Sousa Júnior & Reid, 2010). The project for the construction of the Belo Monte HPP started initially in 1975, with the beginning of the studies of the Hydroelectric Inventory of the Xingu River basin, making the first mapping of the river, analyzing its geology for the implementation of the project.

Due to the environmental changes caused by a Hydroelectric Power Plant, studies on the fish communities of the Xingu River are necessary, as they are more affected by these developments due to large changes in the natural flow of the river, a reduction in trophic diversity from some ecological guilds. The data provided by the isotopic carbon and nitrogen signatures provide us information on the trophic structure of each species, helping to understand how changes in the trophic diversity of fish assemblages occur in response to the Belo Monte HPP construction. This study analyzes the effects of Belo Monte dam on the trophic structure of fish assemblages in three sectors of the Xingu River which suffering different influences of the dam, a sector upstream dam, other downstream, and an artificial lake as a new environment. To better understand the functioning of trophic relationships before and after the dam construction, the study still taking into account hydrological conditions of wet and dry seasons.

2. MATERIAL AND METHODS

2.1. Study Area

The study was conducted in the lower Xingu River, more precisely in the area of direct influence of the Belo Monte dam (completed in 2016), and divided into three collection sectors, one consisting: The Main River (MR) formed in the bed itself. from the river upstream of the dam site; low water stretch or Volta Grande (VG), located downstream of the dam, characterized by extensive rapids; and the Artificial Lake (AL), the artificial reservoir formed by the bypass channel that controls and supplies the water to main powerhouse of Belo Monte Dam. The MR and VG sectors precede the construction of the dam, as well as after the completion of the dam (Figure 1). The AL sector did not exist prior to construction of the dam (2016) and as such was only sampled following completion of the dam.

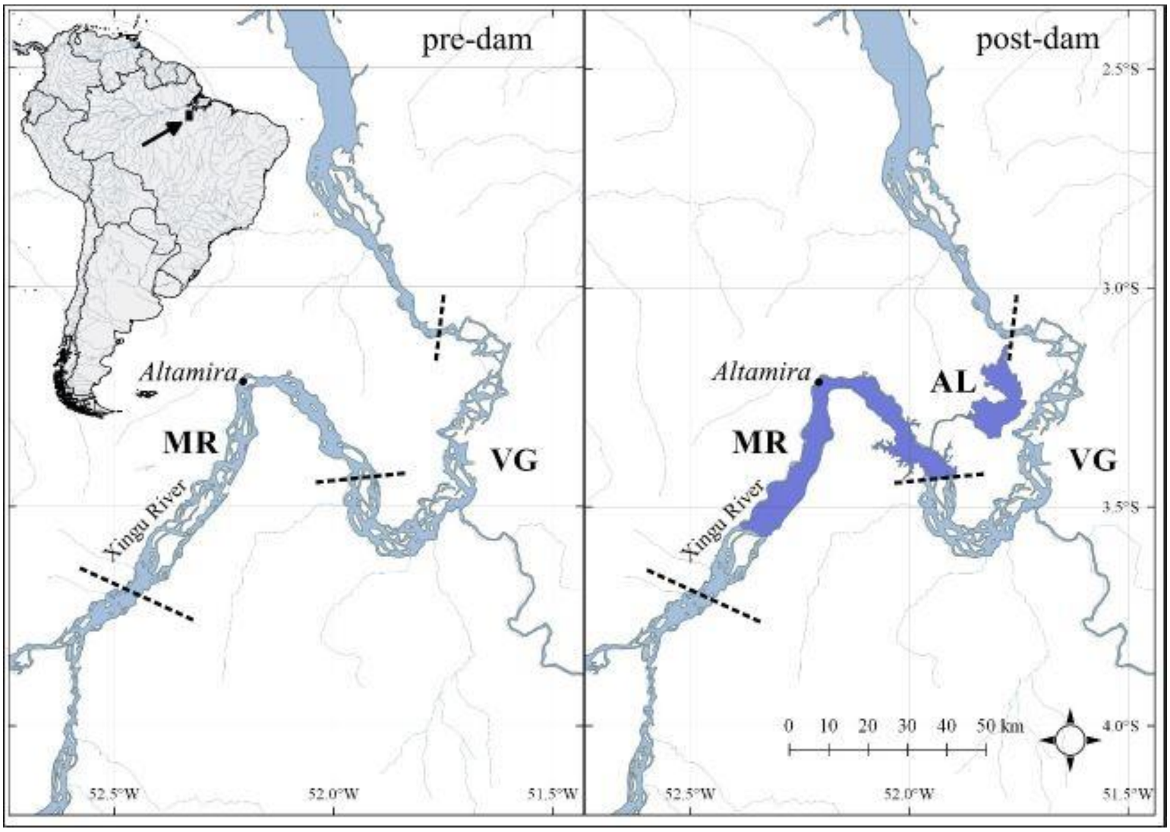

FIGURE 1: Lower Xingu River near Altamira pre-dam (2014/2015) and post-dam (2016/2017). Sectors of the study include: Main River (MR), Volta Grande (VG) and post-dam Artificial Lake (AL).

2.2. Sample Collection

Collection campaigns were carried out every six months in April (wet season) and October (dry season) from 2014 to 2015 (pre-dam time) and 2016 to 2017 (post-completion). Each of the three sectors were directly influenced by Belo Monte HPP, but in different ways. The MR sector changed from purely riverine to a mix of riverine and reservoir habitats. The VG sector remained riverine, but flows were reduced. The AL sector did not exist prior to construction of the dam and is a newly constructed lentic environment.

Pelagic fish were collected using gill nets and longlines were used to collect benthic species. Gill nets were grouped into three separate sets, each with seven nets (10m long by 1.5m high) of different mesh sizes (2, 4, 7, 10, 12, 15, and 18 cm). longlines were placed simultaneously near the gill net sets, each containing 30 hooks, using size 12/0 and 14/0 j-hooks. Hooks were baited using either whole fish or cut pieces of fish. All sample collections were standardized with the same deployment of nets and longlines.

In the field, five individuals per species were selected in each sector, then the muscle tissue of the fish was removed from the dorsal region, using a sterile scalpel blade and placed in small plastic bags and sealed. The tissue samples were placed on ice until transported to the laboratory. In the laboratory, the tissues were frozen until they could be processed for stable isotope analysis. To prepare samples for analysis, the frozen tissue samples were thawed and placed in an oven for 24 h at a temperature of 60 ºC. Once dry, the samples were macerated in pestle and mortar until a fine powder was obtained. They were weighed on an analytical balance with precision to five decimal places and encapsulated in tin (*tin caps, Costech Analytical*). The carbon and nitrogen isotope ratios were determined using a Delta-V isotope ratio mass spectrometer coupled to a CHN combustion, Carlo-Erba NA1500 analyzer through a Thermo Conflo III interface, at the *School of Biological Sciences* - *Washington State University.*

Stable isotope results were expressed as values of δ, $\delta^{13}C$ and $\delta^{15}N = 1{,}000 \times [(R$ sample – R standard / R standard) - 1], where R sample and R standard are the ratios of ^{13}C / ^{12}C or ^{15}N / ^{14}N of the sample and international standard, respectively. Internationally considered standards are Vienna Peedee Belemnite limestone (V-PDB) for carbon and atmospheric N2 for nitrogen. Units are expressed in parts per mil (‰).

We collected a total of~~,~~ 3,403 fish from pre- and post-dam construction periods between the dry and flooding seasons: 737 fish in the pre-dry period, 711 in the pre-wet, 1107 in the post-dry and 848 in the post-wet between collections from April 2014 to October 2017. The richness was represented by 113 species analyzed in the pre-dry period, 102 in the post-dry period, 99 pre-wet and 117 post-wet.

TABLE 1: Total of fish were collected from pre- and post-dam construction periods between the dry and wet seasons.

	Pre-dam		Post-dam	
Sector	**2014**	**2015**	**2016**	**2017**
MR	373	422	357	433
VG	235	418	281	472
AL			220	192

2.3. Diversity and Trophic Niche

With stable isotopes it is possible to perform analysis about niche area and overlap of different guilds. To do this, we used Bayesian Ellipsis Areas (SEAc) through the statistical analysis program R (version 3.5.0) using the Stable Isotope Bayesian Ellipses in R package (SIBER). The output places fish assemblages in graphical space by sampling sector. Analyses were broken up season and during the pre- and post-dam periods. Isotopes of $\delta^{13}C$ and $\delta^{15}N$ were used for this analysis.

The description of the trophic structure of fish communities was characterized using the metrics of Layman et al. (2007) between the three sectors (MR, VG and AL) between the dry and flood phases, and in the pre- and post-dam time periods. The six Layman‘s metrics, to be analyzed include:

1- CR (carbon range): Demonstrates the distance between species according to access to food sources showing the most and least enriched carbon (i.e. $\delta\ ^{13}C$ maximum, minimum $\delta^{13}C$). An increase in this metric is expected in food networks where there are several basal resources with variations in the $\delta^{13}C$ values, i.e. it demonstrates the niche amplitude or the trophic diversity of the individual in relation to the exploitation of basal resources in the food web;

2- NR (nitrogen range): shows the distance between species seen at the variation in consumption of trophic sources with different enrichment at $\delta^{15}C$ (i.e. $\delta^{15}N$ maximum $\delta^{15}N$ minimum), a vertical variation that suggests their trophic position in the food web;

4- CD (average centroid distance): This is the average Euclidean distance from each species to the centroid $\delta^{13}C$ - $\delta^{15}N$, where the centroid corresponds to the average value of $\delta^{13}C$ and $\delta^{15}N$ for all species in the local food chain. The metric gives a measure of the average degree of trophic diversity within the food web. Since in some cases where some extreme species may affect TA differentially, this measure may better reflect the overall degree of trophic diversity in the food web. However, this measurement is also a function of the degree of spacing between species, as well as the following metric;

6- SDNND (standard deviation of trophic redundancy): shows the standard deviation of the nearest neighbor, which verifies the uniformity between the points and the cluster density of the assemblies. Low SDNND values suggest more distribution of trophic niches.

3.4. Calculation of the Trophic Level

To estimate the functional trophic level of the assemblages, we assessed based on nitrogen analysis of each individual through the method proposed by Vanderklift & Ponsard (2003). The trophic level (TL) was calculated by the following formula:

$$TL = [(\delta 15N_{Fish} - \delta 15N_{reference}) / 2.54] + 2$$

Where $\delta^{15}N_{Fish}$ is the individual fishes $\delta^{15}N$ Signature, $\delta\ ^{15}N_{reference}$ is the average consumer signature with the least enriched nitrogen signature within each periods represented by the analyzed period (i.e., pre- or post-, dry or wet); 2.54 is the average enrichment of $\delta^{15}N$ per trophic level, and 2 corresponds to the trophic level of the primary consumer.

Thus, it is possible to estimate the trophic position of the assemblages by time period analyzed. Potential TL differences between periods are tested as to the assumptions for parametric analysis of variance, and when not met, the non-parametric test is chosen. After confirming the non-normality of the data by the Shapiro-Wilk test, non-parametric Kruskal-Wallis (H’) analysis of variance was used to show differences between the pre- and post-dam trophic levels, as well as between the dry and flood hydrological phases.

4. RESULTS

Trophic level was calculated using the species that had the lowest nitrogen enrichment index according to each period, as follows: Pre-dry *Cyphocharax festivus* ($\delta^{15}N$ 4.80), pre-wet *Curimatella immaculata* ($\delta^{15}N$ 5.18), post-dry *Leporinus maculatus*

($\delta^{15}N$ 4.53) and post-wet *Curimata inornata* ($\delta^{15}N$ 4.86), so that the difference between sources and consumers were compatible at the four moments (pre-dam dry and wet; post-dam dry and wet).

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4.1. Trophic Niche

The SIBER analysis shows the total area (TA) per period where the isotopic niche space is represented. The assemblages occupy by sector according to the hydrological phases in the pre- and post-dam periods, may have isotopic alteration in $\delta^{13}C$ and $\delta^{15}N$ may alter isotopic ellipses area, with corresponds to the isotopic niche that is an equivalent of trophic niche. SEAc analysis between communities showed that the Volta Grande (VG) sector was the largest isotopic niche among all periods, except in the post dam full (Figure 2). The Main River (MR) sector at the pre-dam sampling period and the Artificial Lake (AL) sector post-construction were the sectors with the smallest TA and SEAc spaces, and consequently the smallest isotopic niches.

Bayesian ellipses being represented by SEAc based on the isotopic composition of δ^{13}C and δ^{15}N graphically demonstrated the niche amplitude being higher in the pre-dry period, with greater niche variation or amplitude along δ^{13}C distribution than in other periods (Figure 2). Carbon variation by sector showed a greater variety of trophic sources being accessed by assemblies in different environments. For nitrogen we observed greater variation or amplitude of niche in the flood period of the post-dam period (Figure 2D) for the MR sector, this means assembly composition with both basal TL fish (primary sources consumers) and with higher TL (top chain predators). Already the AL sector has small amplitude as the variation of nitrogen, however, the assembly in AL is composed by fish with relatively higher TL than in the other sectors, as shown by the higher position of the ellipse in relation to nitrogen, indicating the colonization of this new sector by predatory fish, that is, with the highest TL (Figure 2B, D).

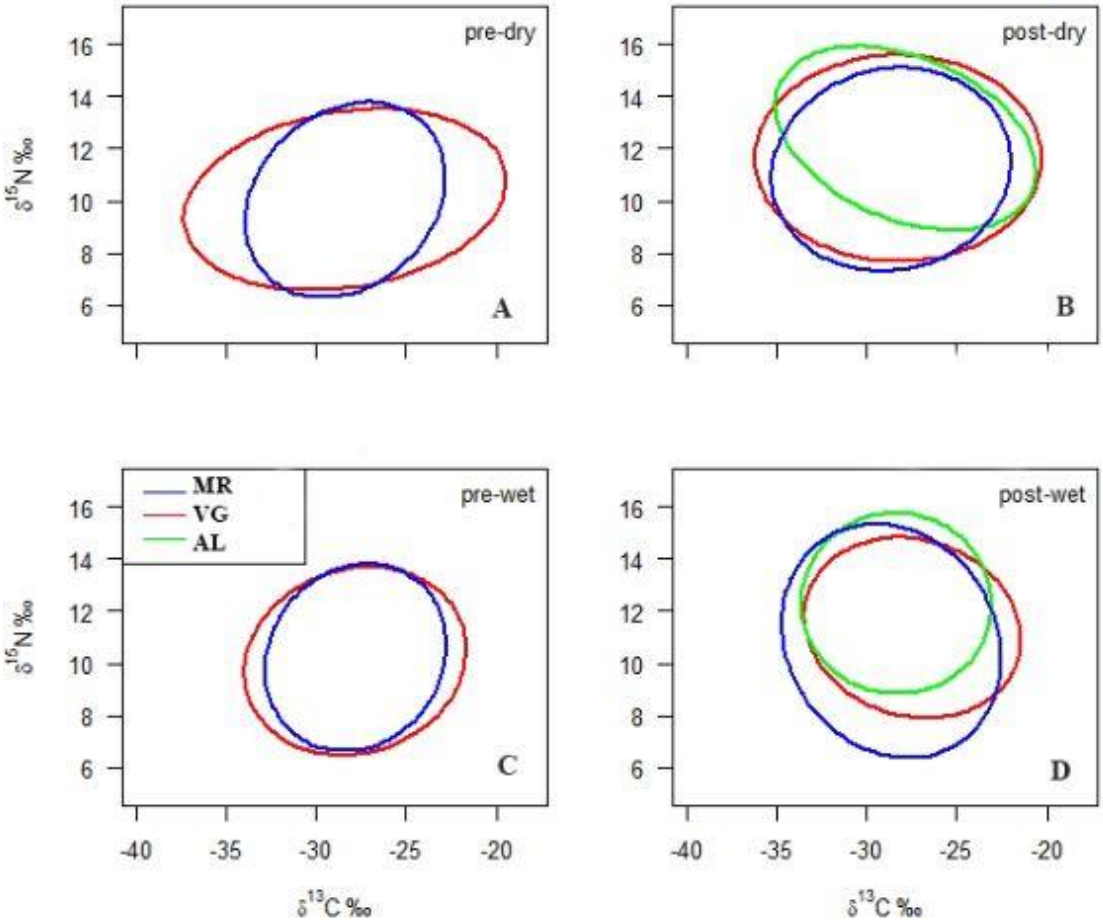

FIGURE 2: Analysis of trophic niche amplitude by species in each sector using δ^{13}C and δ^{15}N data in the dry and flood hydrological phases, pre- and post-dam, using the TA (total area) in the SIBER analysis, showing the ellipses. By sector, Volta Grande (VG), Main River (MR) and Artificial Lake (AL) according to each quadrant. Of which: (a) pre-dry, (b) post-dry, (c) pre-wet, (d) post-wet.

4.2. Trophic Diversity

Community-wide metrics use the stable isotope composition of the different component food networks to describe the trophic structure. Four of these metrics provided information on trophic diversity within the food chain by measuring the spacing of the different components in the δ^{13}C - δ^{15}N space: δ^{13}C range (CR), δ^{15}N range (NR), total area (TA) and average distance to centroid (CD). The trophic diversity of the sectors represented by the six metrics varied between hydrologic phases (pre and post-dam) and period (dry and wet). Analysis showed that had higher values for most metrics in the post-dam for the VG sector, except for the nitrogen variation (NR) which was higher for the MR in the period of pre-wet (Figure 3).

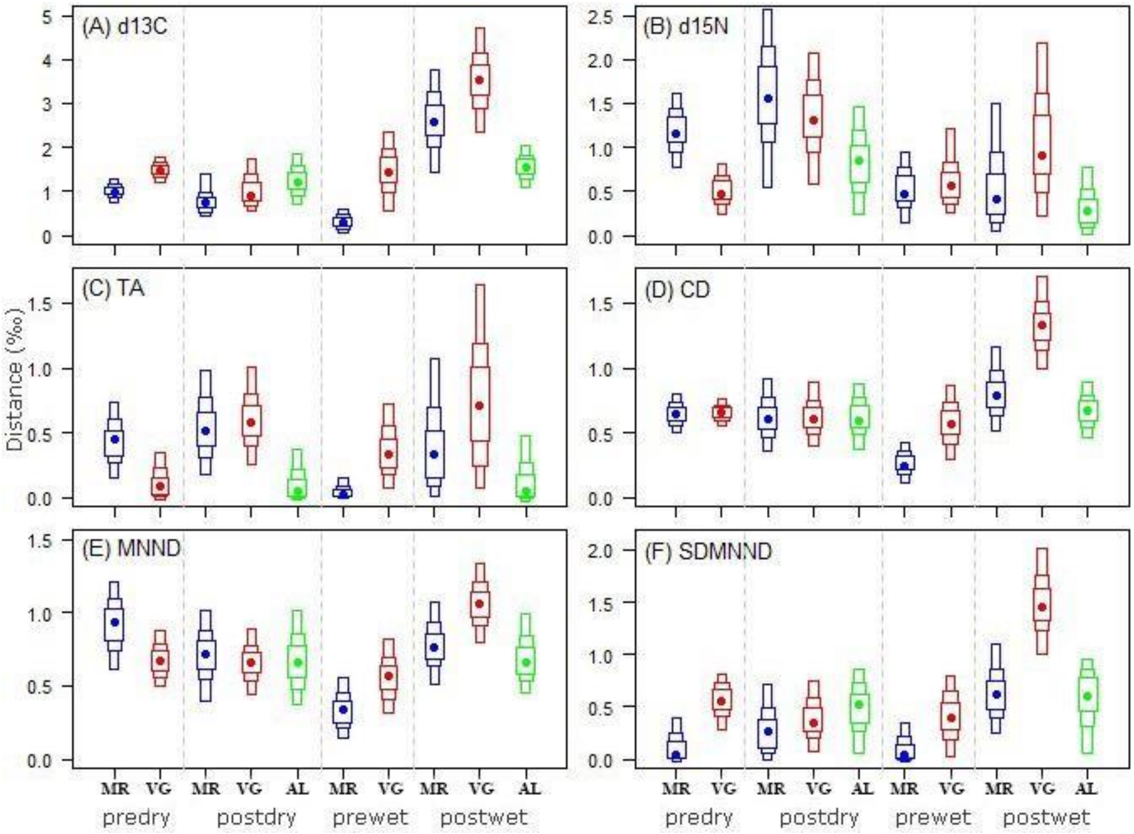

FIGURE 3: Graphic of Layman's metric, according to each dry and full hydrological phase, pre-post-dam in the three sectors of the Main River (MR), Artificial Lake (RI) and Volta Grande (VG).

The variation of the CR metric demonstrated a greater carbon range by sectors, which means greater availability of food sources between the periods of pre and post dam, and the trophic diversity of the VG sector was considered higher in the wet.

The Post-Dry samples had the highest trophic diversity (using the CD metric), with the exception of AL, but among sectors, VG was higher, suggesting, higher trophic diversity for VG in comparison to the other sectors and to the wet period.

MNND was also higher in VG suggesting greater trophic redundancy with assemblages composed by species more trophically similar to each other and then, a sector more trophically resilient to environment changes.

Low values of SDNND suggest great distribution of species in different trophic niches and the higher values were presented also by the VG sector in comparison to the remaining.

TABLE 2: Layman's metric values, according to each sector (pre- and post-dam), period (dry and wet) and hydrological phase. Main River (MR), Artificial Lake (RI) and Volta Grande (VG).

Metrics	**Pre-dry**		**Post-dry**		
	MR	**VG**	**AL**	**MR**	**VG**
NR	1.20	0.51	0.83	1.59	1.36
CR	1.28	1.92	1.23	0.69	1.08
CD	0.66	0.83	0.61	0.59	0.61
SDNND	0.44	0.17	0.57	0.29	0.40
	Pre-wet		**Post-wet**		
	MR	**VG**	**AL**	**MR**	**VG**
NR	0.52	0.90	0.16	1.61	1.12
CR	0.22	2.32	1.53	2.62	3.45
CD	0.25	0.66	0.64	1.00	1.30
SDNND	0.17	0.42	0.65	0.65	1.50

4.3. Trophic Level

Calculated species trophic levels values (TL ± SD) ranged in average from 0.4 for the *Pterygoplichthys pardalis* (Loricariidae), most basal consumer, in the post-wet period to 3.7 ± 0.1 for the *Pseudoplatystoasma punctifer* (Pimelodidae), a top predator species, in the post-dry period. Calculated TL per period (dry and wet, pre- and post-dam) did not have significant differences and ranged from 3.5 to 3.7 ± 0.1. Demonstrating that the post-dam species show highest TLs.

Comparing dry and wet conditions, the Kruskal-Wallis test, the TL of the assemblages were equal in the pre-dam period ($H = 0.067426$, $P = 0.7951$) and different in the post-dam period ($H = 17.571$; $P < 0.0001$), suggesting no changes in TL between seasons prior dam, while it was increased during the dry season of the post-dam. When comparing the hydrological phases before and after the dam, both had significant differences, both in dry ($H = 51.094$; $P < 0.0001$) and in wet ($H = 109.13$; $P < 0.0001$). That is, the trophic level being compared between the pre-dam periods was not different but compared to any post-dam period it was considered a significant increase of TL with higher TL in the post-dam dry period

5. DISCUSSION

The results of the present study elucidate trophic changes in the fish assemblages of the Xingu River as effects of the hydrological periods, and mainly under environmental changes promoted by the construction of Belo Monte Hydroelectric Complex. The seasonal variations naturally generate greater resources availability during flood period due to flooded forest, increasing the access to greater variability of trophic sources (Bayley, 1990).

The Volta Grande Region of Xingu is an environment with many bedrock rapids zones, during dry period. The construction of Belo Monte caused decrease of flooded forests downstream dam, resulting in lesser availability of food sources and shelter for many rapids-adapted species (Fitzgerald et al., 2016; Fitzgerald et al., 2017; Andrade et al., 2018). With a higher concentration of fish in the river channel, facilitating predation by top predator fishes, which promotes increase in the trophic level for many species (Bayley, 1990). This specifies how the trophic niche of this community works within the food web, that increases and decreases according with the availability of food sources that change consequently according to carbon and nitrogen cycle (Jardine et al., 2012; Abrantes et al., 2014).

Among the values compared between the pre-dam and post-dam, there was an increase in trophic diversity during wet season and its decrease during dry in the Main River and Volta Grande. Studies carried out show that hydrological periods can increase or decrease trophic diversity with consequently trophic redundancy increase. when comparing five different guild species that appear in all periods, we can more accurately observe that the dam had a negative effect on the niche amplitude, with the reduction of these metrics with the Belo Monte dam. It suggests greater diversity in the presented trophic niches, showing that seasonal changes can influence the composition of the trophic structure (Abrantes et al., 2014; Correa & Winemiller, 2014). The current lentic environment generated in the Main River sector by the dam permanently flooded historic terrestrial forest habitat and provided greate In compare just six than apper in all sectors (upstream, dowmstream, befor and after dam) can show with precision all change in tropic diversit.

r diversity of basal carbon sources that move through the food web. These results were most noticeable after the completion of the dam when the main river channel became a reservoir and the adjacent downstream habitat became greatly dewatered. Variations in carbon signatures range became more differentiated between flood and dry periods in these adjacent sectors. Variation in carbon signatures showed an increase in the wet period and a decrease in dry in both the pre and post-dam phases. The increased range in carbon signatures suggesting that basal carbon sources currently vary more between the wet and dry periods and as a result affect the trophic level of fish, and can change the composition and structure of communities (Pinnegar et al., 2002; Winemiller, 2012; Agostinho el al., 2008) .

Trophic levels of the Xingu River’s fishes were likely higher in the dry period due to reduced water level, mainly in the Volta Grande sector, but this can also be observed to the Reservoir (Figure 2). Some studies found that the changes due to flow modification below dams can modify the trophic structure of fish assemblages due to changes in physical habitats (Arantes et al., 2019). The Artificial Lake did not show changes between diversity of trophic niches between hydrological periods, likely due to the relative stability of the habitat compared to both the Main River and Volta Grande sectors. Given that variations of diversity and niche trophic structure are generally due to the availability and accessibility to food sources, it suggests that the food web of this new environment had a lower abundance of basal sources but the high concentration of top predators (Arantes et al., 2019; Hawes et al., 2015).

Among the three sectors, the highest proportion of higher trophic level fish was in the Artificial Lake, which is currently still in the process of colonization, a procedure that can take years to stabilize and varies according to the environment (Agostinho et al., 2015; Hawes et al., 2015). We observed that most fish species sampled in the Artificial Lake were opportunistic, but a large number of piscivorous fish were also collected. The low diversity of species in the Artificial Lake also functionally decreases the trophic niche space in the environment, however, some dam operations such as fluctuations in the level of lake due to the flood pulse or hydroelectric operations, may end up slowing the natural process of ecosystem stabilization (Agostinho et al., 2015; Layman et al., 2007).

6. CONCLUSION

In summary, the creation of the Belo Monte Hydroelectric Complex and the formation of the artificial lake led to changes in the trophic structure of the food webs throughout the area affected by dam. There were trophic community changes depending on the hydrological seasons, which were independent of dam. However, after construction of the dam, these changes were most apparent in the sectors upstream and downstream of the dam. In the artificial lake, opportunistic species appear to be exploiting available resources in the newly created habitat. In the other sectors, species at the same trophic level had reduced niche space. This can be attributed to differential responses of species based on the environments where they were confined. This may ultimately have negative consequences within these environments, such as increasing a single population, reducing or even extinction of species that can result in a trophic cascade. Many species have become vulnerable with the creation of the Belo Monte Hydroelectric Complex. One of the biggest concerns is the extinction of endemic species such as many of the rapid-adapted species as the Zebra pleco *Hypancistrus zebra*, and the Eaglebeak pacu *Ossubtus xinguense*, which are already listed as threatened species and are now in eminent risk.

The same thing that makes the hydroelectric potential of the Amazon basin is one of the reasons for the high ichthyologic diversity, flow diversity and resulting diversity in habitats, which is one characteristics affected by these anthropogenic alterations. The creation of new environments can take years to fully stabilize. We also note that the construction of the dam deeply affects the trophic structure of the fish assemblages, requiring solutions to mitigate impacts, restore biodiversity and all affected communities at all, be them a fish, plants, macroinvertebrates or humans, they need to integrating all ecological aspects. This knowledge is valuable in that it can be used to better manage altered ecosystems to conserve the diversity of fish.

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