UNIVERSIDADE FEDERAL DE SÃO CARLOS
CENTRO DE CIÊNCIAS BIOLÓGICAS E DA SAÚDE
PROGRAMA DE PÓS-GRADUAÇÃO EM ECOLOGIA E RECURSOS NATURAIS - PPGERN

Variação espacial e temporal do potamoplâncton ao longo do Rio Parnaíba (Piauí, Brasil): ferramentas ecológicas para o diagnóstico e monitoramento

São Carlos - SP
2022

Isabela de Lima Keppe

Variação espacial e temporal do potamoplâncton ao longo do Rio Parnaíba (Piauí, Brasil): ferramentas ecológicas para o diagnóstico e monitoramento

Dissertação apresentada ao Programa de Pós-Graduação em Ecologia e Recursos Naturais (PPGERN) da Universidade Federal de São Carlos (UFSCar), para obtenção do título de Mestra em Ecologia e Recursos Naturais.

Área de Concentração: Ecologia e Recursos Naturais.

Orientador: Professor Dr. Gilmar Perbiche Neves.

Coorientador: Professor Dr. Bruno Gabriel Nunes Pralon

São Carlos - SP
2022

UNIVERSIDADE FEDERAL DE SÃO CARLOS
CENTRO DE CIÊNCIAS BIOLÓGICAS E DA SAÚDE
PROGRAMA DE PÓS-GRADUAÇÃO EM ECOLOGIA E RECURSOS NATURAIS – PPGERN

Folha de Aprovação

Assinatura dos membros da comissão examinadora que avaliou e aprovou a Defesa de Mestrado do (a) canditado (a) Isabela de Lima Keppe, realizada em 10/11/2022:

____

Prof. Dr. Gilmar Perbiche Neves

UFSCar - Universidade Federal de São Carlos

____

Prof. Dr. Hugo Miguel Preto de Morais Sarmento

UFSCar – Universidade Federal de São Carlos

____

Prof. Dr. Fábio Amodêo Lansac Toha

UEM – Universidade Estadual de Maringá

AGRADECIMENTOS

À minha família: Beatriz, Gilcely e José Geraldo, por todos os sacrifícios feitos, por sempre me apoiarem e me darem o suporte necessário no caminhar da vida. Sem vocês eu não teria a oportunidade chegar onde eu cheguei.

À mim, por todo o esforço depositado na realização dessa dissertação.

À minha terapeuta, Simone, que me acompanhou desde o começo do projeto, me auxiliando nos momentos de dificuldade e, também, nos de felicidade. Obrigada por caminhar comigo na descoberta de quem eu verdadeiramente sou e ainda quero me tornar.

Ao meu querido orientador, professor Dr. Gilmar Perbiche Neves, que teve um papel fundamental na realização dessa dissertação, se esforçou ao máximo para transmitir seus conhecimentos, foi paciente e foi compreensível nos momentos de dificuldade; sempre me deu apoio e confiança, obrigada por tudo.

Às minhas companheiras de laboratório: Camila e Karime, por todo o apoio e pelos momentos de descontração ao longo do desenvolvimento do projeto.

Ao projeto de pesquisa proposto pelo professor Dr. Bruno Gabriel Nunes Pralon, Chamada Universal MCTI/CNPq nº 01/2016 e aos seus alunos pela ajuda na triagem das amostras.

Ao professor Dr. Francisco Diogo Rocha Sousa pela ajuda na identificação das espécies de cladóceros.

À CAPES (Coordenação de Aperfeiçoamento de Pessoal de Nível Superior), processo nº 88887.572679/2020-00, pelo financiamento da bolsa de pesquisa.

O Lótus floresce na dor, esse é o segredo da flor. O Lótus nasce na lama, Deus Pai faz sua eterna dança. O Lótus nasce no coração, se abrindo a cada oração.

(Me guia – Sandro Shankara)

Resumo

Aqui testamos se o Conceito de Descontinuidade Serial realmente prevê o efeito de represamento como uma quebra no gradiente no Conceito de Rio Contínuo. Microcrustáceos (Cladocera e Copepoda) foram coletados em seis pontos de amostragem ao longo de 815 km do canal principal em um grande rio tropical (Rio Parnaíba, Nordeste do Brasil) por 2 anos. Foi estudado a composição, a diversidade, a abundância e a dissimilaridade, bem como os efeitos de variáveis ambientais As hipóteses testadas foram: i) a presença de um único reservatório rompe a estrutura dos microcrustáceos, com maior riqueza nos pontos a jusante do reservatório devido à mistura de organismos lênticos e lóticos, bem como nos pontos no trecho mais a jusante do rio, como esperado no Conceito de Descontinuidade Serial, aumentando a diversidade e abundância do zooplâncton; ii) há perda de espécies em áreas próximas aos municípios como resultado do impacto de efluentes (menores valores de diversidade beta e efeito de aninhamento).Um total de 48 táxons (Cladocera = 37 espécies, Copepoda = 11 espécies) e 18 novos registros foram encontrados para o rio, refletindo os efeitos positivos em um amplo esforço espacial e temporal. As duas hipóteses foram aceitas, com o efeito de um reservatório causando uma quebra no gradiente longitudinal contínuo e a dissimilaridade aumentando em pontos de amostragem próximos a municípios. As variáveis ambientais apresentaram baixa variação entre os pontos amostrados, sendo a variação temporal no rio Parnaíba mais evidente. A presença de um único reservatório influencia no aumento da diversidade e abundância do zooplâncton, pois há um aumento de táxons no ambiente lótico a jusante, além da influência na vazão.

Palavras-chave: Ecologia, gradiente, rio Parnaíba, semiárido, zooplâncton.

Abstract

Here we test whether the Serial Discontinuity Concept actually predicts the damming effect as a gradient break in the Continuous River Concept. Microcrustaceans (Cladocera and Copepoda) were collected at six sampling points along 815 km of the main channel in a large tropical river (Rio Parnaíba, Northeast Brazil) for 2 years. The composition, diversity, abundance and dissimilarity were studied, as well as the effects of environmental variables. The hypotheses tested were: i) the presence of a single reservoir disrupts the structure of microcrustaceans, with greater richness at points downstream of the reservoir due to the mixture of lentic and lotic organisms, as well as at points in the downstream stretch of the river, as expected in the Serial Discontinuity Concept, increasing zooplankton diversity and abundance; ii) there is loss of species in areas close to the municipalities as a result of the impact of effluents (lower values of beta diversity and nesting effect). A total of 48 taxa (Cladocera = 37 species, Copepoda = 11 species) and 18 new records were found for the river, reflecting the positive effects on a wide spatial and temporal effort. Both hypotheses were accepted, with the effect of a reservoir causing a break in the continuous longitudinal gradient and the dissimilarity increasing at sampling points close to municipalities. The environmental variables showed low variation between the sampled points, with the temporal variation in the Parnaíba river being more evident. The presence of a single reservoir influences the increase in zooplankton diversity and abundance, as there is an increase in taxa in the downstream lotic environment, in addition to the influence on the flow

Keywords: Ecology, gradient, Parnaíba River, semi-arid, zooplankton.

SUMÁRIO

APRESENTAÇÃO

Esta dissertação de mestrado foi organizada na forma de um capítulo, o qual foi elaborado conforme as normas de formatação do periódico Hydrobiologia. Esse estudo tem como objetivo analisar a composição, a diversidade e a abundância de espécies zooplanctônicas (Cladocera e Copepoda) em relação aos fatores abióticos ao longo do canal central do rio Parnaíba, PI, Brasil, bem como analisar os padrões sazonais dessa comunidade sob a influência de uma barragem (Usina Hidrelétrica de Boa Esperança). A dissertação ainda contém uma contextualização que tem por objetivo introduzir os assuntos tratados ao longo do desenvolvimento da pesquisa.

Uma breve descrição do capítulo se encontra abaixo:

Capítulo 1: "Longitudinal gradients in one tropical river: the Serial Discontinuity Concept (SDC) applied on microcrustaceans (Cladocera and Copepoda)"

O capítulo abordou a Bacia Hidrográfica do Rio Parnaíba, a segunda mais importante do nordeste brasileiro. Essa bacia possui uma grande fragilidade ambiental e há poucos estudos relacionados à sua biota aquática. Este projeto estudou o plâncton lótico ao longo da calha principal do rio Parnaíba, considerada essencial para entendimento da diversidade desse rio, útil para o monitoramento da qualidade da água e ainda para o planejamento da conservação da bacia.

INTRODUÇÃO

A água é considerada um dos recursos naturais mais importantes encontrados na natureza, atuando em ciclos e processos ecológicos, essencial para a vida no planeta. Sua disponibilidade exerce influência direta e indireta nas atividades econômicas mundiais, uma vez que, caracteriza e condiciona o desenvolvimento econômico, social e ambiental das regiões (MMA, 2006). O desenvolvimento econômico em grande parte das regiões brasileiras tem sido estabelecido pela disponibilidade de energia e com isso a construção de barragens para geração de energia elétrica tem aumentado, causando diversos impactos ambientais em função desse processo (Straskraba & Tundisi, 1999).

Sabendo da importância desse recurso natural, em 8 de janeiro de 1997 foi criada a Lei nº 4.933 (Lei das Águas), a qual instituiu a Política Nacional de Recursos Hídricos (PNRH) e o Sistema Nacional de Gerenciamento de Recursos Hídricos (SINGREH). Foi apontado que o gerenciamento deve proporcionar usos múltiplos e sustentáveis com o objetivo de assegurar a disponibilidade de água de qualidade às gerações presentes e futuras (ANA, 2010). Uma divisão hidrográfica foi proposta em 2003 visando o aprimoramento da gestão de recursos hídricos no Brasil, sendo identificadas em doze bacias: Amazônica, Atlântico Leste, Atlântico Sudeste, Atlântico Nordeste Ocidental, Atlântico Nordeste Oriental, Tocantins-Araguaia, Parnaíba, São Francisco, Atlântico Sul, Paraguai, Paraná e Uruguai (CNRH, 2003).

A construção de uma usina hidrelétrica (UHE), além da geração de energia, traz desenvolvimento para a região a qual foi instalada. Contudo, dependendo do uso e ocupação da bacia, os impactos gerados podem ser mais negativos do que positivos, podendo comprometer a qualidade da água e até as próprias atividades econômicas e sociais relacionadas a ela (Tundisi, 1986). Por isso, o gerenciamento e monitoramento das bacias é de grande importância. Os reservatórios de uma UHE causam alteração do curso hídrico, variação de temperatura, ciclagem de nutrientes e alterações físico-químicas, fazendo com que as comunidades de fauna aquática se restabeleçam com o novo ambiente (Aoyagui et al., 2004).

A Bacia Hidrográfica do Parnaíba, uma das principais bacias da região Nordeste do Brasil, está situada em um cenário de evidente desigualdade econômica e social. A bacia em questão é marcada pela fragilidade dos processos de gestão dos recursos hídricos e retratada pela pouca implementação dos instrumentos sugeridos pela legislação. Ela estabelece fundamentos, objetivos, diretrizes e instrumentos, visando a gestão dos recursos hídricos no Brasil, contribuindo para o surgimento, permanência e expansão dos conflitos pelo uso da água na região (Melo, 2007).

Ambientalmente a Bacia Hidrográfica do Rio Parnaíba pode ser considerada como transição entre a região semi-árida e a amazônica, implicando em diferenças notáveis na sua fauna e flora. Em trabalhos biogeográficos de peixes e copépodes diaptomídeos, Albert & Reis (2011) e Perbiche-Neves et al. (2014) realizaram análises parcimônias de endemicidade que separaram essa bacia das demais, dando suporte para as suas peculiaridades. As nascentes dessa bacia estão localizadas na face oriental da Chapada do Jalapão, ou regionalmente conhecida como Chapada das Mangabeiras, cuja região de maior altitude (aproximadamente 800 metros) também possui nascentes que depois seguem para tributários dos rios Tocantins e São Francisco.

A região Nordeste é possui poucos estudos sobre o potamoplâncton, embora estudos com zooplâncton de ambientes lênticos sejam abundantes em lagos artificiais e rios intermitentes represados. Ainda sim, a falta de estudos sobre os processos ecológicos recorrentes dos biomas Caatinga e Cerrado acarreta em um conhecimento incerto sobre a biota aquática da região (Picapedra et al., 2017).

A comunidade planctônica é a fonte mais importante de carbono orgânico em conjunto com algas macrófitas e, consequentemente, para os peixes que se alimentam delas (Esteves, 2011). Picapedra et al. (2017) afirma que sem o conhecimento de como as enchentes e secas afetam a biota aquática, as estratégias de conservação dos rios semi-áridos do Brasil e sua biota não serão eficientes. Com isso, os estudos sobre a Bacia Hidrográfica do Rio Parnaíba são essenciais para um melhor entendimento da dinâmica e a diversidade de espécies locais, sendo uma possível ferramenta para conservação e monitoramento desse rio.

A bacia hidrográfica é uma área de captação natural da água da chuva, a qual converge os escoamentos para um único ponto de saída (exutório). Ela é composta por um conjunto de superfícies vertentes e de uma rede de drenagem formada pelos cursos d'água até chegar a um leito único no exutório. Ao longo do curso hídrico é possível observar um gradiente longitudinal de mudanças, tendo sido apresentado a primeira vez por Vannote et al. (1980), onde aponta que o conceito de equilíbrio dinâmico para comunidades biológicas é útil, uma vez que, sugere a estrutura e a função da comunidade se ajustem às mudanças em variáveis geomórficas, físicas e bióticas.

Na bacia hidrográfica é onde são realizados os balanços de entrada provenientes da precipitação chuva e saída de água (Tucci, 1997). As atividades humanas são desenvolvidas sobre o território das bacias hidrográficas se diferenciando na forma de ocupação e da utilização das águas que para ali convergem (Porto & Porto, 2008).

A Bacia Hidrográfica do Rio Parnaíba apresenta uma área de drenagem total de 325.834,80 km^2, drenando cerca de 98% da área do Estado do Piauí e ressaltando a influência desse rio para a gestão hídrica estadual. Por possuir uma extensão total de mais de 1.400 km, desde sua nascente (Chapada das Mangabeiras) até a sua foz (Delta do Parnaíba), ele é considerado o maior rio perene da região Nordeste do Brasil (SEMAR/PI, 2010).

Localizada em uma área de transição entre o nordeste brasileiro e o início da região amazônica, a bacia entra-se entre os biomas do Cerrado e Caatinga. Próximo às suas nascentes existe divisores de águas de tributários que seguem para os rios São Francisco e Tocantins. A região é caracterizada por um regime de chuvas bastante heterogêneo (Medeiros et al., 2011), resultando em três climas bem definidos, segundo a classificação de Köeppen: Aw' – tropical quente e úmido, com o período de chuvas entre janeiro e maio; Aw – tropical quente e úmido, com a estação das chuvas entre novembro e março; BShw – semi-árido, com um curto período chuvoso no verão, entre dezembro e abril (SEMAR/PI, 2010).

Desse modo a transição entre o clima semi-árido, parte oriental da Bacia do Parnaíba, e o clima úmido, característico da região amazônica, acaba gerando uma grande variedade de climas em função da meteorologia, da circulação atmosférica e do relevo local. Em virtude da transição de biomas, Rosa et al. (2003) sugere que o rio Parnaíba compartilha de espécies amazônicas, mas que ainda possui uma fauna peculiar; enquanto Paiva (1978) aponta que a bacia do Parnaíba é uma parte da região faunística da Amazônia. Já Perbiche-Neves et al. (2014), com análises biogeográficas separaram esse rio das bacias Amazônica e do São Francisco para copépodes, relevando a importância de ser mais estudado para esses organismos.

Os principais grupos de zooplanctôn encontrados em águas continentais possuem ciclo de vida curto e são bem adaptados a ambientes ricos em nutrientes, se tornando valiosos indicadores de mudanças ambientais nos ambientes aquáticos (Branco et al., 2000; Perbiche-Neves et al., 2016). Alguns organismos não só mostram relação com a pureza da água, mas também com a poluição ambiental (Sládecek, 1973).

DESENVOLVIMENTO

Longitudinal gradients in one tropical river: the Serial Discontinuity Concept (SDC) applied on microcrustaceans (Cladocera and Copepoda)

Isabela de Lima-Keppe[1*]; Bruno Gabriel Nunes Pralon[2] & Gilmar Perbiche-Neves[1]

[1] Programa de Pós-Graduação em Ecologia e Recursos Naturais, Departamento de Hidrobiologia, Universidade Federal de São Carlos - UFSCar, *Campus* São Carlos, CCBS, São Carlos, SP, Brasil. *isabeladlk@gmail.com

[2] Departamento de Biologia, Universidade Federal do Piauí – UFPI, *Campus* Ministro Petrônio Portella, Teresina, PI, Brasil.

ORCID: Isabela de Lima Keppe: 0000-0002-8744-9040.

Gilmar Perbiche Neves: 0000-0002-5025-2703.

Bruno Gabriel Nunes Pralon: 0000-0002-3733-3955.

Abstract

Here we tested if the Serial Discontinuity Concept really predicts the damming effect like a gradient breaking inside the River Continuum Concept. The microcrustaceans (Cladocera and Copepoda) were collected at six sampling sites of the main channel in a large tropical river (the Parnaíba River, Northeast Brazil). We studied the composition, diversity, abundance and dissimilarity, and also the effects of environmental variables for two years. A total of 48 taxa (Cladocera = 37 species, Copepoda = 11 species) and 18 new records were found for the river, reflecting the positive effects in a broad spatial and temporal effort. The two tested hypotheses were accepted, with the effect of the reservoir causing a break in the continuous longitudinal gradient and the dissimilarity increasing in sampling sites close to counties. The environmental variables showed low variation between the sampled points, with the temporal variation of the Parnaíba River being more evident. The presence of a single reservoir influences the increase in the diversity and abundance of zooplankton, as there is an increase in taxa from the environmental environment in the lotic, in addition to the influence of flows.

Keywords: Ecology, gradient, Parnaíba River, semi-arid, Zooplankton.

Introduction

The *River Continuum Concept* (RCC) proposed by Vannote et al. (1980) points out that lotic systems represent a gradient of ecological variables from the source to the mouth. Along the river there are changes in width, water volume, depth, temperature, quantity and type of suspended material transported. This dynamic makes communities organized on the longitudinal axis maximize the materials and energy transported by the gradient.

The *Serial Discontinuity Concept* (SDC) predicts that dams act as a disturbance agent within a RCC, going through changes along the continuum, depending upon biome, the longitudinal position of the dam and the mode of dam operation (Ward & Stanford, 1983). This concept also incorporates that issues related to hyporheic zones influence and change along a continuous or when an impoundment disrupts the gradients producing a longitudinal shift in the measured parameters (Stanford & Ward, 2001).

The construction of a hydropower reservoir, in addition to generating energy, brings development to the region in which it was installed (Tundisi & Matsumura-Tundisi, 2003). However, the reservoirs of a Hydroelectric Power Plant cause changes in the water course, temperature variation, nutrient cycling and physicochemical changes, causing the aquatic fauna communities to reestablish themselves with the new environment formed (Aoyagui et al., 2004).

Zooplankton consists of ecologically distinct groups with different niche requirements (Bonecker et al., 2009) and is appropriate for investigating the influence of regional factors on limnetic community structure. The transformation of a river into a reservoir causes major changes in zooplankton, mainly in the composition, abundance and spatial and temporal distribution of organisms (Serafim-Júnior et al., 2016). Regarding zooplankton, the sequence of medium and large reservoirs provides longitudinal gradients located in compartments that vary according to the water retention time, morphometry and nutrients (Nogueira et al., 2008).

The construction of reservoirs also decrease the flow velocity, prolongs the residence time of water and influences the structure of the aquatic ecosystem. The reservoir can affect zooplankton structure and spatial distribution through population density and biomass through changes in flows (Wang et al., 2016). After the reservoir, the lotic conditions tend to be restored as tributaries enter with it discharge, with a reduction in abundance and an increase in richness for a certain stretch (Portinho et al. 2016). The speed of the current seems to be crucial for the increase in the abundance of organisms in river-reservoir transition environments (Casanova & Henry, 2003).

The present study analyzed the microcrustaceans (Cladocera and Copepoda) from the Parnaíba River, the second largest and most important in the northeast region of Brazil. The transition between the semi-arid climate, in the eastern part of the Parnaíba Basin, and the humid climate, characteristic of the Amazon region, ends up generating a wide variety of climates depending on meteorology, atmospheric circulation and local relief with the absence of a lowland plain inundation. Perbiche-Neves et al. (2014), with parsimonic analyzes of endemicity, separated this river from the Amazon and São Francisco basins for some planktonic crustaceans, highlighting the importance of being further studied for these organisms.

The Parnaíba River is a geographic divider between two Brazilian states, and especially between the cities of Teresina-PI and Timon-MA. Both cities, since the beginning of their urbanization, were targets for the release of clandestine effluents; however, the high-water availability of the Parnaíba River provides a faster dilution of the effluents released (Marçal & Silva, 2019). The major concern with the Parnaíba River's water quality is mainly related to: sewage discharges without adequate treatment or no treatment, inadequate disposal of solid waste, agricultural and agricultural activities, deforestation and inadequate land use (ANA, 2012). Additionally, there is just one and large reservoir in the main channel of this river.

There are few studies carried out for zooplankton in the Parnaíba River Basin, all of which are recent (Lucena et al., 2016; Picapedra et al., 2017; Silva et al., 2020; Silva et al., 2021; Picapedra et al, 2022). Lucena et al. (2016) and Picapedra et al. (2017) found 132 (Rotifera, Cladocera and Copepoda) and 125 (Tecameba, Rotifera, Cladocera and Copepoda) zooplanktonic species, respectively. In both studies, more species were sampled during the river's wet season than during the dry season.

Aiming to test the SDC in this river, two hypotheses were tested: i) the presence of a single reservoir disrupts the structure of microcrustaceans, with greater richness at points downstream of the reservoir due to the mixture of lentic and lotic organisms, as well as at points in the downstream stretch of the river, as expected in the Serial Discontinuity Concept, increasing zooplankton diversity and abundance; ii) there is loss of species in areas close to the municipalities as a result of the impact of effluents (lower values of beta diversity and nesting effect).

Material and methods

Study area

The Parnaíba Hydrographic Basin is located in the Northeast of Brazil, between the states of Maranhão, Piauí and Ceará, it is a transition area between the semi-arid (BSh) and tropical (Aw) Amazon (SEMARH/PI, 2010) (Fig. 1), implying notable differences in its fauna and flora. The Parnaíba River is the largest river in the Northeast, it is 1,432 km long, extends between 2° to 10°S, and drains an area of approximately 344,112 km^2, in addition to containing a single reservoir. The Boa Esperança is a large hydroelectric plant with approximately 330 km^2 area and located close to the middle of the river, with a drainage area upstream of 87,500 km^2, 50 m maximum deep and a maximum flow of 12,000 m^3/s (CHESF, 1994). Most of the tributaries in the middle and lower parts are perennial (Gurgueia River, Balsas River, Canindé, Piauí, Poti and Uruçu-Preto) (CPRM, 2022), while the small streams in the upper region are intermittent (Lucena et al., 2016). The altitude of the studied stretch ranged from 190 to 16 meters and the temperature ranged from 24 to 38 °C.

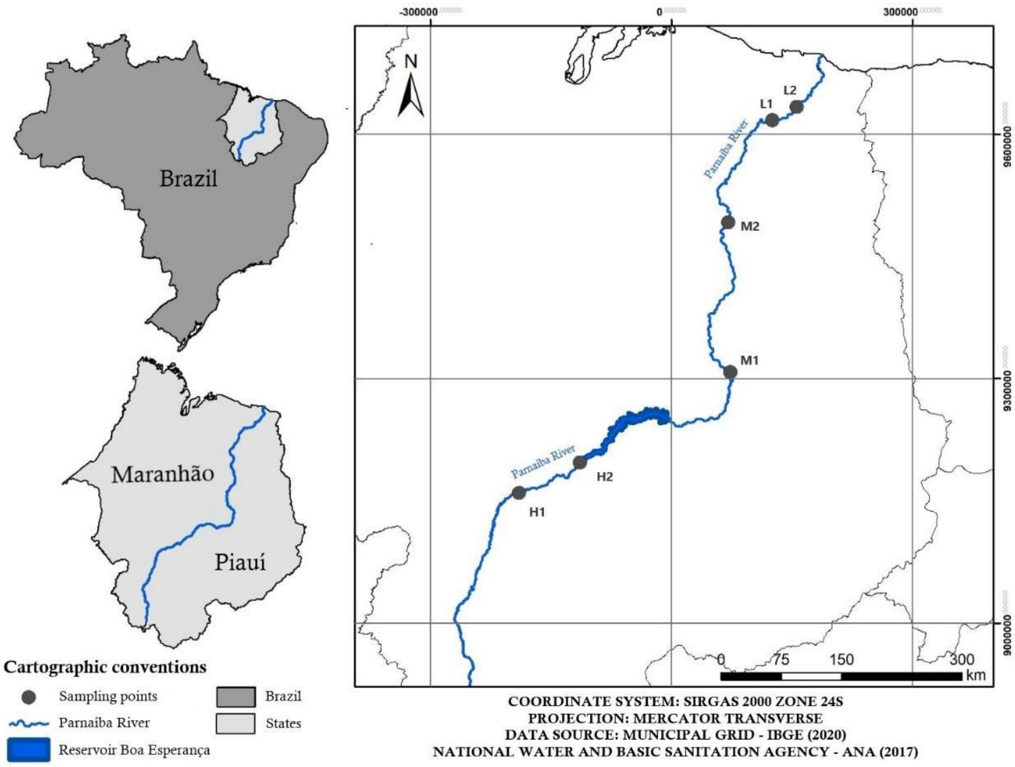

Fig. 1 Map of the study area and sampling sites along the Parnaíba River in the northeast Brazil

Sampling

The present study performed an extensive spatial and temporal sampling, which allowed to understand with detail the results here obtained. Zooplankton sampling was carried out bimonthly for two years (between 2018 and 2020) at 6 sampling sites along the main river channel (Table 1), with 2 sampling sites in each stretch (high, medium and low).

Table 1 Location of sampling sites with respective acronyms and geographic coordinates

Initials	Location (stretch)	City	Coordinates	Altitude (m.a.s.l.)
H1	High 1	Ribeiro Gonçalves	7°33’20.4’’S 45°14’37.0’’W	195
H2	High 2	Uruçuí	7°13’36.74’’S 44°33’23.37’’W	161
M1	Medium 1	Amarante	5°54’23.92’’S 42°30’30.20’’W	90
M2	Medium 2	União	4°35’6.04’’S 42°52’18.21’’W	42
L1	Low 1	Murici dos Portelas	3°18’39.90’’S 42°5’52.00’’W	19
L2	Low 2	Luzilândia	3°27’18.0’’S 42°22’17.4’’W	16

A volume of 1060 L was filtered for each sample, through horizontal hauls of 15 m using a conical plankton net with a mesh pore of 60 µm. The organisms were anesthetized with commercial gasified water and 0.5 g of sucrose was added in each sample (ANA, 2011), and following they were fixed with 4% formaldehyde. This procedure prevents some groups as cladocerans from losing eggs and minimizes carapace distortion. At the same time, we measured the values of water temperature, pH, conductivity and turbidity using a multiparameter probe meter Combo 5 (pH/Cond/TDS/Salt/Temp), and the dissolved oxygen using an Oxygen Meter Waterproof Pocket Dissolve – DO Eco (Version 1.00). Water transparency was determined using a Secchi disk. For the parameters total alkalinity, total hardness, ammonia and nitrite we used a portable kit for water analysis (ALFAKIT®). The rainfall data at each sampling point were obtained from INMET, and after month means were obtained. The lowest rainy period extends from June to October and the rainy season from November to May; so, the floods in the system generally occur in January and February (SEMARH/PI, 2010).

Laboratory analyzes

Qualitative and quantitative analyzes were performed in laboratory. Both samples were analyzed in their entirety in squared acrylic cuvettes and a Zeiss Stemi 300 stereoscope. When necessary, slides were mounted with the individuals and checked under a microscope. To taxa identification specialized bibliography was used such as Reid (1985), Matsumura-Tundisi

(1976/1986), Elmoor-Loureiro (1997), Sousa et al. (2015), Sousa et al. (2016), Smirnov & Matsumura-Tundisi (1984), Smirnov & Santos-Silva (1995), Sousa & Elmoor-Loureiro (2019), Perbiche-Neves et al. (2016) and the website “Cladocera do Brasil” (https://cladocerabrasil.wordpress.com/). Species of difficult identification were checked with specialists. For the quantitative samples, a minimum of 100 individuals were counted per sample or the totality when these were scarce, in the case of a lotic environment. Abundance was expressed in individuals per cubic meter (ind.m^{-3}).

Data analysis

The qualitative (binary data, presence and absence and species list) and quantitative (ind.m^{-3}) data were used to calculate ecological indices such as richness, Shannon-Wiener alpha diversity (H'), beta diversity with Sorensen index (using the betapart package of Baselga et al., 2022) and dissimilarity with Bray-Curtis index, aiming to understand the spatial and temporal variations of microcrustaceans. Permutation analysis of variance (PERMANOVA) (Vicente-Gonzalez & Vicente-Villardon, 2021) was performed to compare the microcrustacean composition between sampling sites and months, as well as the interaction between them, using the vegan package (Oksanen et al., 2022). A non-metric multidimensional scaling analysis (NMDS) with an abundance matrix was done using dissimilarity, and data homogeneity was observed with analysis of variance (ANOVA) (Fox & Weisberg, 2019) and betadisper (Anderson, 2006).

The abundance of species in the zooplankton community was correlated with environmental variables using a distance-based multivariate redundancy analysis (db-RDA). Some of these analyzed were putted in supplementary files. All of the above analyzes were done using the R 4.1.2 software (R Development Core Team, 2022). Rarefaction and extrapolation curves were made with the iNEXT package of the R software, directly on Chao's website (https://chao.shinyapps.io/iNEXTOnline/), using the abundance data of the microcrustacean species.

Results

A principal component analysis (PCA) explained 38% of the data variance considering the first two components (Fig. 2). In the first component it is possible to observe a separation of the rainy season (with rainfall, total dissolved solids, nitrite and electrical conductivity) and dry season (with transparency, pH, nitrite). Temperature, alkalinity, hardness and dissolved oxygen were mainly correlated with point L1. Spatially, the most upstream points (H1 and H2) are separated from the others on the right in the biplot, while the point downstream of the reservoir (M1) is the most heterogeneous and is dispersed in both components. The last stretches of the river (points M2, L1 and L2) suggest a more homogeneous distribution among themselves in relation to the limnological variables.

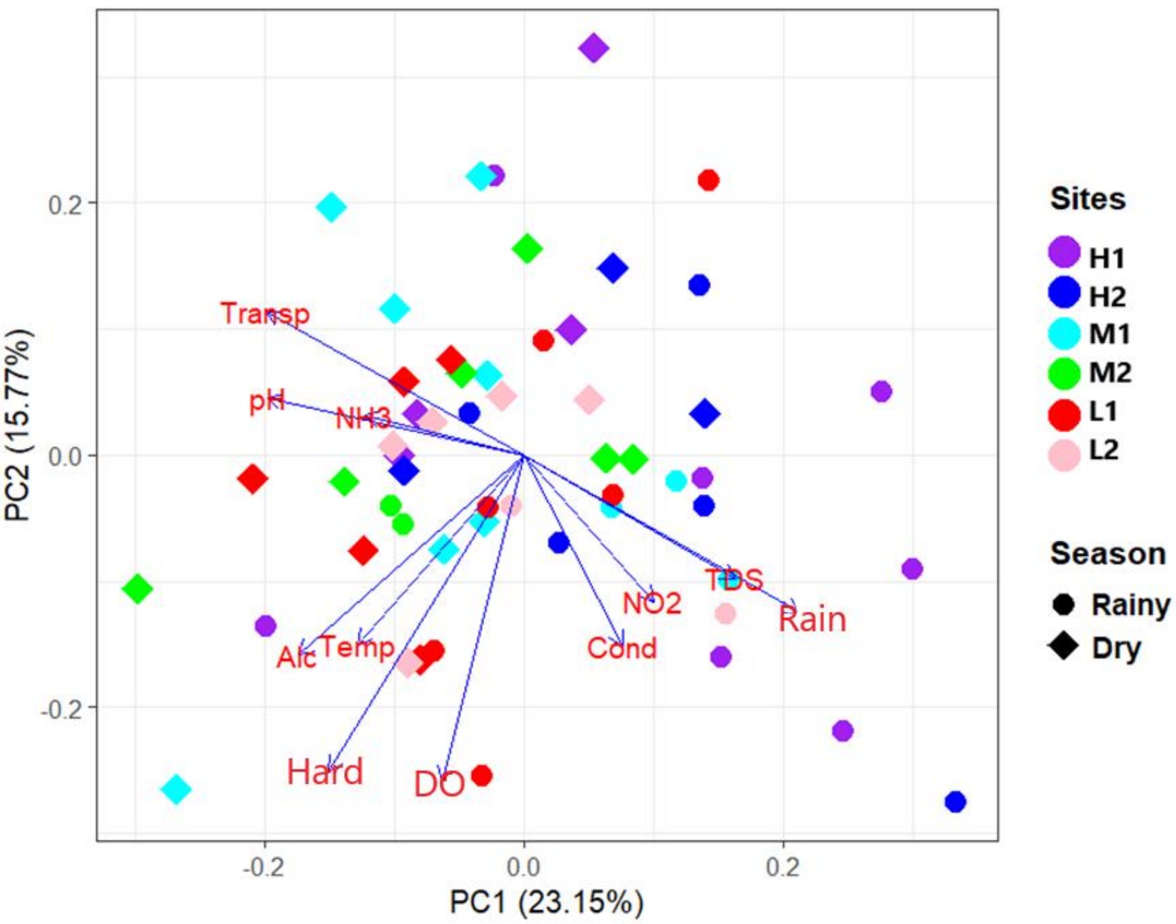

Fig. 2 PCA performed to temporally order the limnological variables (Rain: rainfall; NH3: ammonia; DO: dissolved oxygen; NO2: nitrite; Cond: conductivity; Hard: hardness; Transp: transparency; Alc: alkalinity; pH; Temp: temperature; TDS: total dissolved solids)

The results indicate that there was an increase in the number of species that occur after points H1 and H2, where the Boa Esperança Reservoir is located. The standard deviation was 269 individuals and the average of adult copepod organisms was 7 and 10 ind.m^{-3}, and after the dam they increased to 438, 164, 316 and 121 ind.m^{-3}, consecutively at each sampling point. For cladocerans, the average was 74 and 108 ind.m^{-3}, and after the dam they went to 64, 251, 676 and 574 ind.m^{-3}, respectively along the points.

A total of 48 species were found, with cladocerans being the dominant ones with 37 species and copepods with 11 species (Table 1 – Supplementary file, S1); cyclopoids and calanoids copepodites were recorded at all points. In comparison to the studies by Lucena et al. (2016) and Picapedra et al. (2017), 18 new records were made for both groups*: Ovalona glabra* (Sars 1901), *Leberis davidi* (Richard, 1895), *Alona* cf. *guttata* Sars 1862, *Bosmina* sp.*, *Ceriodaphnia laticaudata* Müller 1867, *Chydorus eurynotus* Sars 1901, *Coronatella* sp.*, *Ilyocryptus sarsi* Sars 1862, *Kurzia polyspina* Hudec 2000, *Latonopsis australis* Sars 1888, *Leydigia propinqua* Kurz 1875, *Leydigiopsis ornata* Daday 1905, *Macrothrix sioli* Smirnov 1982, *M. spinosa* King 1853, *Moina micrura* Kurz 1875, *M. reticulata* Daday 1905, *Nicsmirnovius incredibilis* (Smirnov, 1984), *Nicsmirnovius* sp., *Ectocyclops rubenscens* Brady 1904, *Mesocyclops meridianus* Kiefer 1926, *M. aspericornis* Daday, 1906, *Microcyclops finitimus* Dussart 1984, *Notodiaptomus cearensis* Wright 1936, *N. conifer* Sars 1901 and *N. henseni* Dahl 1894 (*Body anomaly).

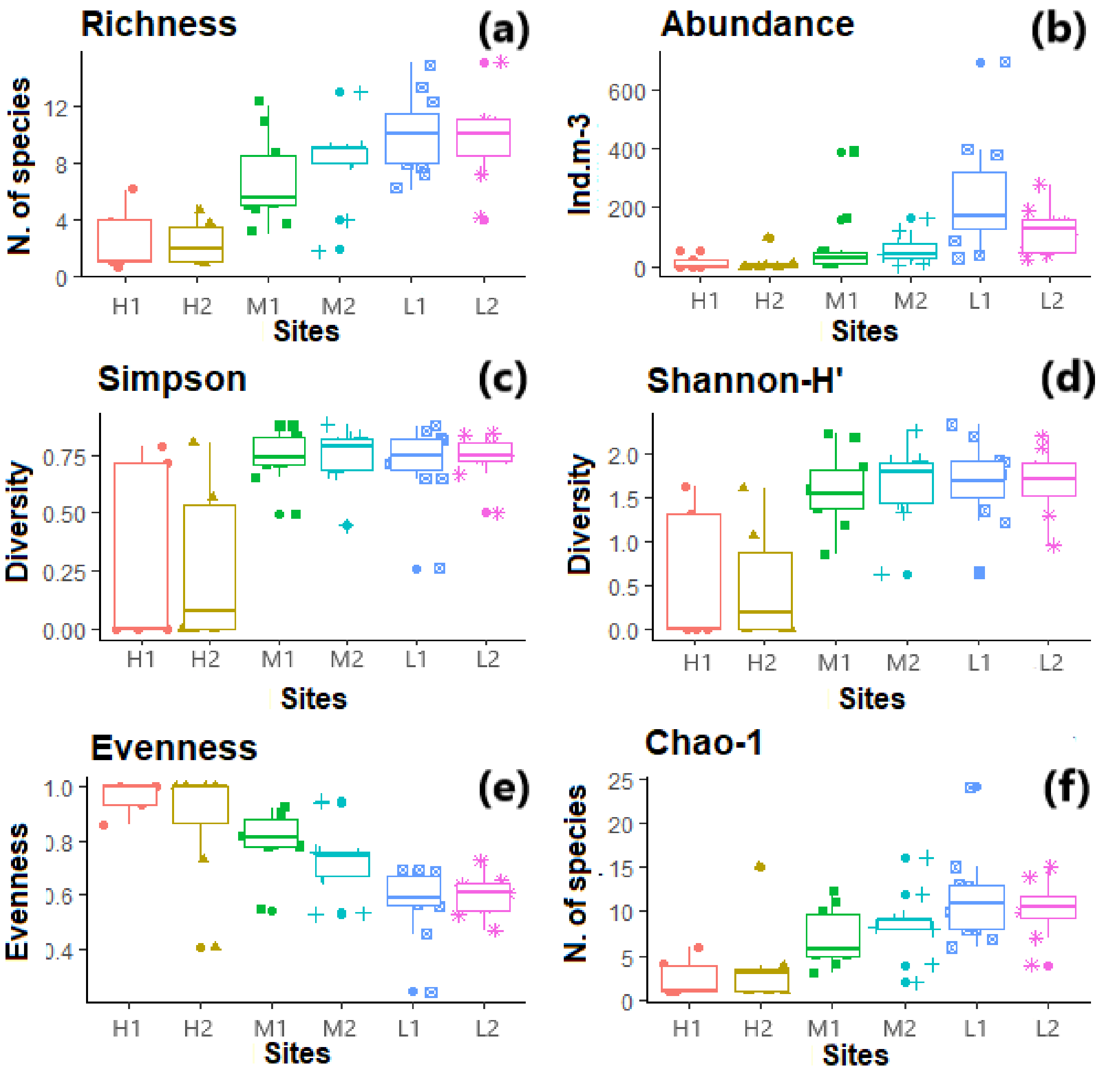

Fig. 3 Richness, abundance, Simpson, Shannon-H, Equitability and Chao-1 of microcrustaceans recorded monthly at points over the years

Species richness, abundance, Simpson's and Shannon-Wiener's alpha diversity indices and the richness estimated by the Chao-1 index showed an increase in an upstream and downstream direction, following the continuous river concept (Fig. 3). The Chao-1 index still estimated the double of species, especially in the last three sites. Evenness (H´/S) decreased downstream, indicating an increase in heterogeneity as the river gets larger.

PERMANOVA (Table 2 – Supplementary file, S1) indicated significance for both factors (spatial and temporal) as well as their interaction, indicating different temporal variations in the sampled sites. Data transformed into Bray-Curtis distance showed homogeneous distribution between points (betadisper F=1.21; p=0.32) and between periods (F: 3.61; p=0.06). The table of physical-chemical analysis (Table 3 - Supplementary file, S1) indicates that an increase of conductivity at the points H2, M1 and L2 increased.

The beta diversity (Fig. 4) calculated for the sampling sites and months indicate high values between points H1 and H2, with greater change in species composition at these sites, decreasing downstream. It is possible to observe the greatest change in the composition of the zooplankton community (higher values of beta diversity) between points H2 and M1, before and after the Boa Esperança dam, increasing richness and abundance. This increase is a reflection of the change in the physical-chemical characteristics of the water at point M1, which started to present lentic characteristics soon after the reservoir (Table 3 – Supplementary file, S1).

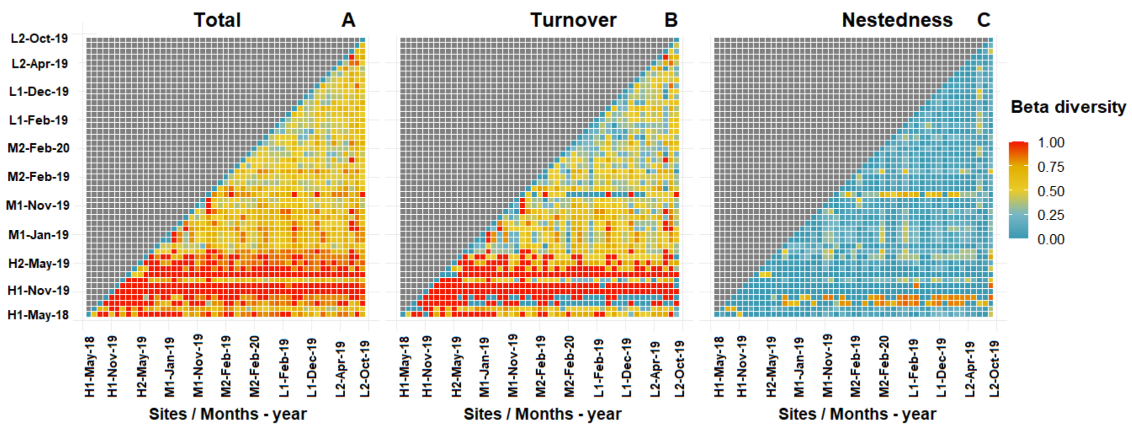

Fig. 4 Beta diversity of microcrustaceans decomposed in total beta-diversity (a), turnover (b) and nestedness (c)

The results of the NMDS analyzes (Fig. 1a, b – Supplementary file, S2) showed a distinction in the similarity between the sampling stations over time. The non-metric multidimensional scaling analysis showed a stress of 0.24 after 20 trials considering groupings by periods and sampling sites. Between periods, the microcrustacean assemblages were less dissimilar (Fig. 1a – Supplementary file, S2) than between the sites (Fig. 1b - Supplementary file, S2), with the rainy season practically included within the dry season. Among the sites, the NMDS indicates that there is greater dissimilarity between the sites H1, M1 and the others (M2-L2) that overlap, indicating separation of the upstream sites. Point M1 downstream of the reservoir indicates sharing similarity between the two groups.

The db-RDA (Fig. 5) indicated that the dissimilarity of copepods and cladocerans increases at sites under the direct effect of the reservoir, with the first upstream and the last downstream being more similar, that is, the effect of a single reservoir promotes the increase of dissimilarity, the opposite of when there is a sequence of reservoirs in cascade, with homogenization of the community. According to the analysis, the spatial difference explains 27% of the data, while the temporal difference explains 17%.

Throughout the study, it was possible to evidence the spatial-temporal variation of the microcrustaceans present along the Parnaíba River, relating it to the physical-chemical characteristics of the water and a seasonal variation between hydrological periods. The environmental variables (rainfall, ammonia, dissolved oxygen, nitrite, conductivity, hardness, transparency, alkalinity, pH, temperature and total dissolved solids) showed low variation between the sampled points, with the temporal variation of the Parnaíba River being more evident. The increase in the abundance of organisms that appeared after the Boa Esperança Reservoir, located between the Uruçuí (H2) and Amarante (M1) municipalities, may be related to the increase in conductivity at site M1.

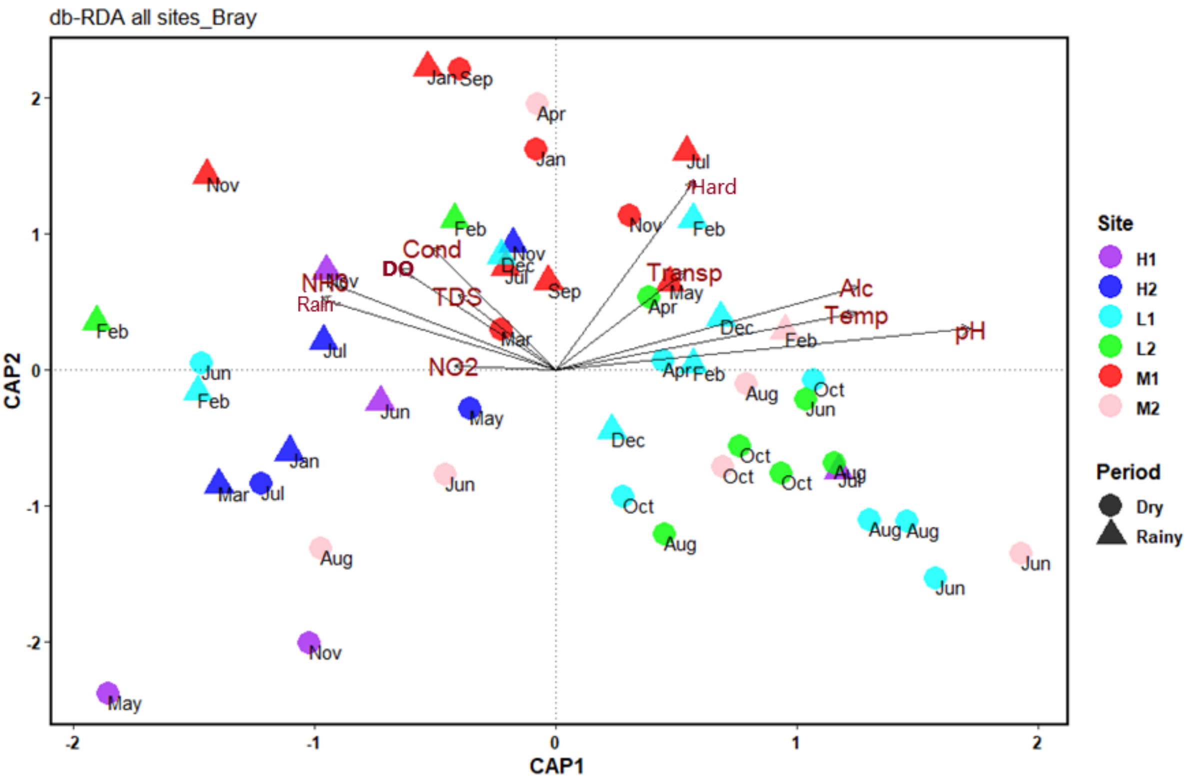

Fig. 5 Result of db-RDA analysis with dispersion of environmental variables and abundance of microcrustacean species during hydrological periods (Rain: rainfall; NH3: ammonia; DO: dissolved oxygen; NO2: nitrite; Cond: conductivity; Hard: hardness; Transp: transparency; Alc: alkalinity; pH; Temp: temperature)

The results of the rarefaction and extrapolation curves point to the stabilization of the number of individuals covered by the samples (Fig. 2a – Supplementary file, S2) and diversity according to the sample coverage and number of individuals for the H1 site, but for others still distant (Fig. 2b, c – Supplementary file, S2). This trend is especially relevant for sampling sites in the lower portion, between sites M1 and L2. In addition, the expected diversity occurs at the lowest sampling site.

Discussion

The two hypotheses tested were accepted, the effect of the reservoir had a direct impact on the dissimilarity. In fact, there was an increase in richness and abundance downstream, but the presence of the reservoir causes a break in the lotic structure of copepods and cladocerans according to the SDC, with greater values of richness and abundance downstream of the reservoir, persisting continuously downstream until the final stretch.

The presence of a single reservoir increases the diversity and abundance of microcrustaceans with a break in the gradient (Fig. 3). This shows that the appearance of zooplanktonic communities in some river stretches is highly influenced by the presence of dams, supporting our first and third hypothesis that the presence of a unique reservoir breaks in the structure of the microcrustaceans, with greater richness in points downstream of the reservoir by the mixture of points of lentic and lotic organisms, as well in the last sites downstream as what was expected in the Serial Discontinuity Concept.

According to Vannote et al. (1980), the upper stretch of the river is occupied by communities predominantly constituted by heterotrophic organisms, having larger body size. In the middle section, however, there is a predominance of autotrophs and filtering organisms; and, in the final stretch, heterotrophic organisms predominate again, but filtering small particles. A study carried out in the Parnaíba River Delta points out that the Trophic State Index was predominantly mesotrophic and eutrophic in the estuarine system (Filho et al., 2015). In a general context for floodplains,

Results show that the Chao-1 index estimated twice as many species in the last three points in our study and support our first and third hypothesis. Comparing with other studies in the Parnaiba River, Lucena et al. (2016) recorded 19 cladoceran and 7 copepod species. Picapedra et al. (2017) recorded 15 cladoceran species and 2 copepod species. In comparison with four previous studies, in the present study there was an increase in species richness: 37 of cladocerans and 11 of copepods; cyclopoids and calanoids copepodites were recorded at all points. Comparing with other rivers with longitudinal gradients, in La Plata River basin were estimated 46 copepod species for all basin with just two samplings (Perbiche-Neves et al., 2014). Souza et al (2021) recorded 55 cladoceran and 28 copepods in Amazonian river basin. Czerniawski & Domagala (2014) recorded 10 cladoceran and 6 copepods species in the Sitna stream (tributary of the Drawa River), in the buffer zone of the Drawieński National Park, NW Poland.

The construction of dams causes several ecological changes in a river, influencing the abundance of zooplankton in these places. Czerniawski & Domagala (2014) and Souza et al. (2021) recorded an increase in zooplankton density after the construction of a dam, indicating that zooplankton continued to develop with decreasing river flow. The greater stimulation of water from the dam creates a food base for the filtering organisms, favoring the development of planktonic ones.

There was a loss of species in areas close to counties, probably as a result of the impact of effluents reflected by the increase of electrical conductivity (causing lower values of beta diversity, nestedness effect – Fig. 4). We observed an increase of electrical conductivity in points close to counties, mainly before and after the dam (H2 and M1) and in the Parnaíba Delta (L2). These effects were especially observed on copepods, as pointed by other studies (e.g. Matsumura-Tundisi & Tundisi, 2005; Perbiche-Neves et al., 2016), but for both grups effects were found.

Copepods were mostly represented by Cyclopoida, and *Thermocyclops decipiens* Kiefer 1929, *Paracyclops chiltoni* Fischer 1853, and *N. cearensis* species stood out, being present in four or more points. However, only *T. decipiens* was present at all points. Perbiche-Neves et al. (2016) points out that this species is considered a bioindicator of oligotrophic or mesotrophic environments because it is able to maintain a high population density with the presence of algal blooms.

Among the cladocerans, some species stood out more, especially *Bosminopsis deitersi* in high abundances has been pointed as indicative of water with more primary productivity or impacts of human populations across the basins (Ghidini et al., 2009). The following species were identified at leastin 5 sites: *Alona* cf. *guttata*, *Bosmina freyi* (Müller, 1785), *Bosminopsis deitersi* Richard 1895, *Ilyocryptus spinifer* Herrick 1882, *Moina micrura* Kurtz 1874 and *Diaphanosoma spinulosum* Herbst 1967. *Bosmina hagmanni* Stingelin 1904 was the only specie recorded in all sites. Among the benthic cladocerans, *I. spinifer* is the most common species of neotropical Illyocryptidae, being recorded in several Brazilian states, having a wide variety of habitats (Kotov & Elmoor-Loureiro, 2008). *Bosmina freyi* is also a common species and is easily found in Amazonian environments and in limnetic regions (Previatteli et al., 2005).

The spatial difference is represented by the difference between the two most upstream sites (H1 and H2) and the two last downstream sites (L1 and L2), since at sites M1 and M2 the homogenization of the species occurs. The temporal difference was correlated between the sampling sites and the hydrological periods (dry and rainy) (Fig. 1 - Supplementary file, S2), where there was no substitution of species, but an exchange (Fig. 2 – Supplementary file, S2), and this exchange can be related to this variation of pluviosity.

The increase in the richness and abundance (Fig. 3) of microcrustaceans with the high number of new records can be correlated with the presence of the dam, which promotes diversity and many samplings in the rainy season (different from other studies), since in the dry periods the numbers decrease. The results about the species composition indicate that the Parnaíba River has characteristics similar to other rivers in the Brazilian semi-arid region and that different hydrological periods directly affect the river’s flow (Mescolotti et al., 2021). Souza et al. (2021) points out that the beta diversity varied between the rainy and dry periods, having higher averages during the flood and presenting greater environmental heterogeneity (species composition) after the dam.

Cascade reservoirs show a decrease in suspended solids and nutrients along their spatial sequence, as the upstream reservoir retains part of the sediment and pollutants, improving water quality down the cascade, increasing water transparency (Barbosa et al., 1999). Reservoirs provides a more stable environmental condition for the reproduction and development for zooplankton resulting in high abundances, however downstream these environments the abundance decreases and the richness can be high as the entrance of tributaries occurs (Portinho et al., 2016), that the presence of a single reservoir increases the diversity and abundance of zooplankton. Geomorphic studies have documented loss of lateral and vertical connectivity through degradation of the channel, due to substantial reduction in sediment load after regulation (Stanford & Ward, 2001).

Longitudinal changes occur in the water quality downstream of a reservoir because an increase of pollution downstream of the dam, with higher electrical conductivity, so the reservoir interrupts the river’s continuity for nutrients and physicochemical variables (Westhorpe et al., 2015), reinforcing the Serial Discontinuity Concept and gradient-breaking theories. Our results agreeing with other studies in Brazil, as Nogueira et al. (2008) which found similar trends in a cascade with eleven reservoirs.

Conclusions

Even with a solid base of studies related to the concepts of Continuous River and Serial Discontinuity Concept, there are still some gaps on how these concepts apply to the Parnaíba River considering its location, transition between Cerrado and Caatinga. The present study proposes the unprecedented spatial and temporal detailing with great sampling effort of the occurrence of zooplanktonic microcrustaceans, allowing to verify the effect of a single dam as a gradient break, in addition to the analysis of anthropic action and effluent discharge from cities close to the points of collect.

The study indicates that extensive sampling effort considerably increases richness and provides a better understanding of local and dynamic diversity. The reservoir modifies the lotic conditions downstream compared to the lotic point upstream without reservoirs or large sources of planktonic organisms, and thus favors the increase of zooplankton. A unique reservoir also contributes to the reduction of turbidity and water velocity, allowing greater development of phytoplankton and greater stimulation to consumers.

Acknowledgments To CAPES (Coordenação de Aperfeiçoamento de Pessoal de Nível Superior), process No. 88887.572679/2020-00, for funding the research; to Professor Dr. Francisco Diogo Rocha Sousa for his assistance in the identification of cladoceran species; to the research project proposed by Professor Dr. Bruno Gabriel Nunes Pralon, Universal Call MCTI/CNPq No. 01/2016 and to the students for their help in sorting the samples.

Availability of data and materials All data generated or analyzed during this study are included in this article.

Declarations

Conflict of interest The authors declare that they have no conflict of interest.

References

Anderson, M. J., 2006. Distance-based tests for homogeneity of multivariate dispersions. Biometrics 62, 245–253.

Aoyagui, A. S. & C. C. Bonecker, 2004. Rotifers in different environments of the Upper Paraná River floodplain (Brazil): richness, abundance and the relationship with connectivity. Hydrobiologia 522: 281-290.

Barbosa, F. A. R., J. Padisák, E. L. G. Espíndola, G. Borics & O. Rocha, 1999. The cascading reservoir continuum concept (CRCC) and its application to the river Tietê-basin, São Paulo State, Brazil.

Baselga, A., D. Orme, S. Villeger, J. de Bortoli, F. Leprieur, M. Lorgez, R. Henrique-Silva, S. Martnez-Santalla, R. Martn-Devassa, C. Gmez-Rodriguez & R. Crujeiras, 2022. Partitioning Beta Diversity into Turnover and Nestedness Components. CRAN.

Bonecker, C. C., A. S. M. Aoyagui, R. M. Santos, 2009. The impact of impoundment on the rotifer communities in two tropical floodplain environments: interannual pulse variations. Brazilian Journal of Biology [online] 69 (2): 529-537 https://doi.org/10.1590/S1519-69842009000300008

Brasil. Agência Nacional de Águas – ANA, 2012. Atlas Brasil: Abastecimento Urbano de Água. Panorama Nacional, volume 1. Agência Nacional de Água, Ministério do Meio Ambiente. Brasília, DF.

Casanova, S. M. C. & R. Henry, 2004. Longitudinal distribution of Copepoda populations in the transition zone of Paranapanema River and Jurumirim Reservoir (Sao Paulo, Brazil) and interchange with two lateral lakes. Brazilian Journal of Biology 64: 11–26

Cladocera do Brasil [online], 2022. Retrivied in 2022, July 5, from: https://cladoceradobrasil.wordpress.com/.

Companhia de Pesquisa de Recursos Minerais - CPRM. Serviço Geológico do Brasil - SACE –

Sistema de Alerta de Eventos Críticos, Bacia Hidrográfica do Parnaíba, 2022.

Companhia Hidro Elétrica do São Francisco - CHESF, Departamento de Meio Ambiente, 1994. Plano de manejo ambiental do Reservatório de Boa Esperança, outubro, 28p.

Elmoor-Loureiro, L. M. A., 1997. Manual de identificação de cladóceros límnicos do Brasil, v. 1. Brasília: Universa.

Filho, F. J. P., R. V. Martins & L. D. de Lacerda, 2015. Natural and anthropogenic emissions of N and P to the Parnaíba River Delta in NE Brazil. Estuarine, Coastal and Shelf Science 166: 34-44

Fox, J. & S. Weisberg, 2019. Na R Companion to Applied Pregression Third Edition, Sage. CRAN.

Instituto Brasileiro de Geografia e Estatística – IBGE, 2022.

Junk, W. J., P. B. Bayley & R. E. Sparks, 1989. The flood pulse concept in river-floodplain systems. Canadian Journal of Fisheries and Aquatic Sciences 106(1): 110-127

Kotov, A. A. & L. M. A. Elmoor-Loureiro, 2008. Revision of *Ilyocryptus* Sars, 1862 (Cladocera: Ilyocryptidae) of Brazil with description of two new subspecies. Zootaxa, 1962: 49-64

Lucena, L. C. A., T. X. D. Melo & E. S. F. Medeiros, 2016. Zooplankton community of Parnaíba River, Northeastern Brazil. Acta Limnologica Brasiliensia 27: 118-129

Marçal, D. A. & C. E. Silva, 2019. Avaliação do impacto do efluente da estação de tratamento de esgoto ETE-Pirajá sobre o Rio Parnaíba, Teresina (PI). Artigo Técnico, Engenharia Sanitária Ambiental 22 (4): 761-772

Matsumura-Tundisi, T. G., 1986. Latitudinal distribution of Calanoida copepods in freshwater aquatic systems of Brazil. Revista Brasileira de Biologia 46(3): 527-553

Matsumura-Tundisi, T. G. & J. G. Tundisi, 1976. Plankton studies in lacustrine environment. Oecologia 25(3): 265-270

Mascolotti, P. C., F. N. Pupim, F. S. B. Ladeira, A. O. Sawakuchi, A. S. Catharina & M. L. Assine, 2021. Fluvial aggradation and incision in the Brazilian tropical semi-arid: Climate-controlled landscape Evolution of the São Francisco River. Quaternary Science Reviews 263: 1069777

Nogueira, M G., P. C. R. Oliveira & Y. T. de Britto, 2008. Zooplankton assemblages (Copepoda and Cladocera) in a cascade of reserviors of a large tropical river (SE Brazil). Limnetica 27(1): 151-170

Oksanen, J., G. L Simpson, F. G. Balanchet, R. Kindt, P. Legendre, P. R. Minchin, R. B. O'Hara, P. Solymos, M. H. H. Steves, E. Szoecs, H. Wagner, M. Barbour, M. Bedward, B. Bolker, D. Bordcard, G. Carvalho, M. Chirico, M. de Cacesres, D. Durand, H. B. A. Evangelista, R. FitzJohn, M. Friendly, B. Furneaux, G. Hannigan, M. O. Hill, L. Lahti, D. McGlinn, M. H. Ouellette, E. R. Cunha, T. Smith, A. Sties, C. J. F. T. Braak & J. Weedon, 2022. Ordination methods, diversity analysis and other functions for community and vegetation ecologists. CRAN.

Paiva, M. P., 1978. A ictiofauna e as grandes represas brasileiras. Revista Dae 116: 49-57

Perbiche-Neves, G., C. Fileto, J. Laço-Portinho, A. Troguer & M. Serafim-Júnior, 2013. Relations among planktonic rotifers, cyclopoid copepods, and water quality in two Brazilian reservoirs. Latin American Journal of Aquatic Research 41(1): 138-149

Perbiche-Neves, G., D. Previattelli, M. R. Pie, A. Duran, E. Suárez-Morales, G. A. Boxshall, M. C. Nogueira & C. E. da Rocha, 2014. Historical biogeography of the neotropical Diaptomidae (Crustacea: Copepoda). 11(1): 36

Perbiche-Neves, G., V. S. Saito, D. Previatelli, C. E. da Rocha & M. G. Nogueira, 2016. Cyclopoid copepods as bioindicators of eutrophication in reservoirs: Do patterns hold for large spatial extents? Ecological Indicators 70: 340-347

Picapedra, P. H. S.; C. Fernandes, F. A. Lansac-Tôha, 2016. Zooplankton community in the Upper Parnaíba River (Northeastern, Brazil). Brazilian Journal of Biology 77(2)

Picapedra, P. H. S., C. Fernandes, G. Baumgartner & P. V. Sanches, 2022. Drivers of zooplankton spatial dynamics in a small neotropical river. Acta Limnologica Brasiliensia [online] 34
https://doi.org/10.1590/S2179-975X6421

Portinho, J. L., G. Perbiche-Neves, & M. G. Nogueira, 2016. Zooplankton community and tributary effects in free-flowing section downstream a large tropical reservoir. Hydrobiologia 101(1-2): 48-56

Previatelli, D.; E. N. Santos-Silva, & A. J. Darwich, 2005. Distribuição vertical do zooplâncton e sua relação com as variáveis ambientais. In: Santos-Silva, E. N.; Aprile, F. M.; Scudeller, V. V.; Melo, S. (eds). Biotupé: meio físico, diversidade biológica e sócio-cultural do baixo Rio Negro, Amazonas, Brasil. INPA, pp. 109-121.

R Development Core Team., 2022. A language and environment for statistical computing. Vienna, Austria, R Foundation for Statistical Computing ISBN 3-900051-07-0, URL. Retrieved 2022, May 17, from: http://www.R-project.org

Ramos, T. P. A., R. T. C. Ramos & S. A. Q. A. Ramos, 2014. Ichthyofauna of the Parnaíba river Basin, Northeastern Brazil. Biota Neotropica [online] 14
https://doi.org/10.1590/S1676-06020140039

Reid, J. W., 1985. Chave de identificação e lista de referências bibliográficas para as espécies continentais sulamericanas de vida livre da ordem Cyclopoida (Crustacea, Copepoda). Boletim de Zoologia 9(9): 17-143

Rosa, R. S., N. A. Menezes, H. A. Britski, W. J. E. M. Costa & F. Groth, 2003. Diversidade, padrões de distribuição e conservação dos peixes da Caatinga. In: Leal, I. R., Tabarelli, M. & Silva, J. M. C. Ecologia e Conservação da Caatinga. Recife: Editora Universitária da UFPE. p.135-162

Secretaria do Meio Ambiente e Recursos Hídricos do Piauí - SEMARH/PI., 2010. Plano Estadual de Recursos Hídricos do Estado do Piauí: Relatório Síntese. Piauí: 179 p.

Secretaria do Meio Ambiente e Recursos Hídricos do Piauí – SEMARH/PI., 2010. Secretaria de Recursos Hídricos do Ministério do Meio Ambiente Caderno Regional – Região Hidrográfica Parnaíba. Resumo Executivo. Piauí: 110 p.

Serafim-Junior, M.; F. A. Lansac-Tôha, R. M. Lopes, & G. Perbiche-Neves, 2016. Continuity effects on rotifers and microcrustaceans caused by the construction of a downstream reservoir in a cascade series (Iguaçu River, Brazil). Brazilian Journal of Biology 76(2): 279-29

Silva, N. J., F. M. Lansac-Tôha, F. A. Lansac-Tôha, P. C. L. Sales & J. R. S. Rocha, 2021. Beta diversity patterns in zooplankton assemblages from a semiarid river ecosystem. Hydrobiologia 106: 29-40

Silva, N. J., T. Mantovano, F. A. Lansac-Tôha, F. M. Lansac-Tôha, F. E. S. Sousa, C. G. Leal, P. C. L. Sales & J. R. S. Rocha, 2021. Spatio-temporal drivers of differente oomycete beta diversity components in Brazilian rivers. Hydrobiologia 848: 4695-4712 http://doi.org/10.1007/s10750-021-04659-x

Simões, N. R., J. D. Dias, C. M. Leal, L. S. M. Braghin, F. A. Lansac-Tôha & C. C. Bonecker, 2013. Floods control the influence of environmental gradients on the diversity of zooplankton communities in a neotropical floodplain. Aquatic Sciences 75(4): 607-617

Smirnov, N. N. & Santos-Silva. E. N., 1995. Some littoral anomopods (Crustacea) from Central Amazonia. Hydrobiologia 315: 227-230

Smirnov, N. N. & T. Matsumura-Tundisi, 1984. Description of *Alona broaensis* sp. nov. (Crustacea: Cladocera). Hydrobiologia 113: 327-329

Sousa, F. D. R., L. M. A. Elmoor-Loureiro & S. Santos, 2015b. Redescription of *Coronatella poppei* (Richard, 1897) (Crustacea, Branchiopoda, Chydoridae) and a revision of the genus in Brazil, with descriptions of new taxa. Zootaxa. 3955: 211-244

Sousa, F. D. R., L. M. A. Elmoor-Loureiro & S. Santos, 2016a. Position of the dentifera-group in the *Coronatella*-branch and its relocation to a new genus: *Magnospina* gen. n. (Crustacea, Chydoridae, Aloninae). ZooKeys 586: 95–119

Sousa, F. D. R. & L.M.A. Elmoor-Loureiro, 2019. Identification key for the Brazilian genera and species of Aloninae (Crustacea, Branchiopoda, Anomopoda, Chydoridae). Papéis Avulsos de Zoologia 59

Stanford, J. A., & J. V. Ward, 2001. "Revisiting the serial discontinuity concept." Regulated Rivers: Research & Management: An International Journal Devoted to River Research and Management 17.4-5: 303-310

Tundisi, J. G. & T. Matsumura-Tundisi, 2003. Integration of research and management in optimizing multiple uses of reservoirs: the experience in South America and Brazilian case studies. Aquatic Biodiversity. Springer, Dordrecht. 231-242

Vannote, R. L., G. W. Minshall, K. W. Cummins, J. R. Sedell, & C. E. Cushing, 1980. The river continuum concept. Canadian journal of fisheries and aquatic sciences 37: 130-137

Vicente-Gonzalez, L. & J. L. Vicente-Villadon, 2021. Multivariate Analysis of Variance Based on Distances and Permutations. CRAN.

Wang, L., Q. Chen, R. Han, B. Wang & X. Tang, 2016. Zooplankton community in Yangtze River Estuary and adjacent sea areas after the impoundment of the Three Gorges Reservior. Annales de Limnologie – Internacional Journal of Limnology 52: 273-284

Ward, J. V. & J. A. Stanford. 1983. The serial discontinuity concept of lotic ecosystems. In Dynamics of Lotic Ecosystems, Fontaine TD, Bartell S. M. (eds). Ann Arbor Scientific Publishers: Ann Arbor, MI; 29-42

Westhorpe, D. P., S. M. Mitrovic, I. O. Growns, W. L. Hadwen, & G. N. Rees, 2015. Disruption in water quality patterns along the river continuum by a large bottom release dam. Australasian Journal of Environmental Management 22(4): 400-416

CONCLUSÃO

Com o objetivo de testar o Conceito de Descontinuidade Serial no rio Parnaíba, as três hipóteses testadas foram aceitas, o efeito do reservatório teve impacto direto na dissimilaridade. Houve um aumento da riqueza e abundância a jusante, mas a presença do reservatório provoca uma quebra na estrutura lótica de copépodes e cladóceros, com maior riqueza e abundância a jusante do reservatório, persistindo a jusante.

O desenvolvimento econômico de regiões brasileiras, além da geração de energia, disponibilizado pela construção de barragens provoca diversas alterações ecológicas em um rio, influenciando a abundância de zooplacton nesses locais. Dependendo do uso e ocupação da bacia, os impactos gerados podem ser mais negativos do que positivos, podendo comprometer a qualidade da água e até as próprias atividades econômicas e sociais relacionadas a ela, por isso o gerenciamento e monitoramento constante das bacias é de grande importância.

Mesmo com uma base sólida de estudos relacionados aos conceitos de Rio Contínuo e Conceito de Descontinuidade Serial, ainda existem algumas lacunas sobre como esses conceitos se aplicam ao Rio Parnaíba considerando sua localização, transição entre Cerrado e Caatinga. O presente estudo propõe o inédito detalhamento espacial e temporal com grande esforço amostral da ocorrência de microcrustáceos zooplanctônicos, permitindo verificar o efeito de uma única barragem como quebra de gradiente, além da análise da ação antrópica e lançamento de efluentes de cidades próximas aos pontos de coleta.

O estudo indica que o esforço amostral extensivo aumenta consideravelmente a riqueza e proporciona uma melhor compreensão da diversidade local e dinâmica. O reservatório modifica as condições lóticas a jusante em relação ao ponto lótico a montante sem reservatórios ou grandes fontes de organismos planctônicos. A maior estimulação da água após a barragem cria uma base alimentar para os filtrados, favorecendo o desenvolvimento de organismos planctônicos, indicando que o zooplâncton continuou a se desenvolver com a diminuição do fluxo do rio.

.

REFERÊNCIAS

ALBERT, J. S. & REIS, R. (Eds.). **Historical biogeography of Neotropical freshwater fishes.** University of California Press. 2011.

ANA. Atlas Brasil: Abastecimento Urbano de Água. Panorama Nacional, volume 1. Agência Nacional de Água, Ministério do Meio Ambiente. Brasília, DF, 2010.

AOYAGUI, A. S., & BONECKER, C. C. Rotifers in different environments of the Upper Paraná River floodplain (Brazil): richness, abundance and the relationship with connectivity. **Hydrobiologia,** v. 522(1-3), p. 281-290. 2004.

BRANCO, C.W.C. et al. The zooplankton and other limnological features of a humic coastal lagoon (Lagoa Comprida, Macaé, RJ) in Brazil. **Hydrobiologia**, Dordrecht, v. 437, n.1-3, p. 71-81, 2000.

CNRH. Caderno da Região Hidrográfica do Parnaíba: Plano Nacional de Recursos Hídricos. Ministério do Meio Ambiente. Secretaria de Recursos Hídricos. Resolução n.32, de 14 de outubro de 2003.

ESTEVES, F. A. **Fundamentos de Limnologia**. 2Ed.: Rio de Janeiro: Interciência. 2011.

MEDEIROS, E.S.F. & ARTHINGTON, A.H. Allochthonous and autochthonous carbon sources for fish in floodplain lagoons of an Australian dryland river. **Environmental Biology of Fishes**. 90:1. 2011.

MELO, T. X.; LOURENÇO, L. J. S.; MEDEIROS, E. S. F. Checklist of zooplankton from the upper Ipanema River (Pernambuco), an intermittent river in semi-arid Brazil. **Check List**. 10(3), 524-528. 2014.

MMA. Ministério do Meio Ambiente. Caderno da Região Hidrográfica do Parnaíba: Plano Nacional de Recursos Hídricos.Ministério do Meio Ambiente.Secretaria de Recursos Hídricos. Brasília: 2006.

Ministério do Meio Ambiente. MMA. Caderno da Região Hidrográfica do Parnaíba. CNRH. Resolução n 32, de 14 de outubro de 2003.

PAIVA, M. P. 1978. A ictiofauna das Grandes Represas Brasileiras. **Revista DAE** 116: p. 49-57.

PERBICHE-NEVES, G. et al. Historical biogeography of the neotropical Diaptomidae (Crustacea: Copepoda). **Frontiers in zoology**, 11(1), 36. 2014.

PERBICHE-NEVES, G., V. S. SAITO, D. PREVIATELLI, C. E. DA ROCHA & M. G. NOGUEIRA, 2016. Cyclopoid copepods as bioindicators of eutrophication in reservoirs: Do patterns hold for large spatial extents? **Ecological Indicators,** 70: 340-347.

PICAPEDRA, P. H. S.; FERNANDES, C.; LANSC-TÔHA, F. A. Zooplankton community in the Upper Parnaíba River (Northeastern, Brazil). **Brazilian Journal of Biology.** vol.77 no.2 2016

PORTO, M. F. A. & PORTO, R. L. L. Gestão de bacias hidrográficas. Estud. av. vol.22, no.63. 2008.

ROSA, R. S.; MENEZES, N. A.; BRITSKI, H. A.; COSTA, W. J. E. M.; GROTH, F., 2003. Diversidade, padrões de distribuição e conservação dos peixes da Caatinga. In: I.R. LEAL, J.M.C. SILVA and M. TABARELLI, eds. Ecologia e conservação da caatinga. Recife: **Edufpe**, pp. 135-181.

SEMAR/PI. Plano Estadual de Recursos Hídricos do Estado do Piauí: Relatório Síntese. **Secretaria do Meio Ambiente e Recursos Hídricos.** Piauí: 2010, 179 p.

SLADECEK, A. System of Water Quality From the Biological Point of View. Archiv fur Hydrobiologie Beihefte. **Ergebnisse der Limnologie**, 218p. 1973.

STRASKRABA, M. & J. G. TUNDISI. **Gerenciamento da qualidade da água de represas**. Oficina de textos, Coleção diretrizes para o gerenciamento de lagos, São Paulo, v. 9. 3Ed. 2013

TUCCI, C. E. M. 1997. Hidrologia: ciência e aplicação. 2.ed. Porto Alegre:

ABRH/Editora da UFRGS, 1997. **Col. Associação Brasileira de Recursos Hídricos**, v.4

TUNDISI, J.G., (1986b). Ambiente, represas e barragens. **Ciência Hoje**, v.5; 49-54pp.

VANNOTE, R. L., G. W. MINSHALL, K. W. CUMMINS, J. R. SEDELL, AND C. E. CUSHING. 1980. The river continuum concept. **Canadian Journal of Fisheries and Aquatic Sciences.** 37: 130-137.

ANEXOS

Supplementary file – S1

Table 1. Frequency of occurrence of microcrustacean species along the sampling points

CLADOCERA	H1	H2	M1	M2	L1	L2
Bosminidae						
Bosmina						
Bosmina freyi (Müller, 1785)	17%	-	40%	67%	82%	63%
Bosmina hagmanni Stingelin, 1904	8%	13%	40%	44%	82%	63%
Bosmina sp.*	-	-	-	-	-	38%
Bosminopsis						
Bosminopsis deitersi Richard, 1895	8%	13%	-	22%	36%	38%
Chydoridae						
Subfamília Aloninae						
Alona						
Alona cf. *guttata* Sars, 1862	-	13%	10%	11%	9%	25%
Coronatella						
Coronatella sp.*	25%	-	-	-	-	-
Euryalona						
Euryalona cf. *brasilienses* Brehm & Thomsen, 1936	-	-	-	-	9%	-
Kurzia						
Kurzia polyspina Hudec, 2000	-	-	-	-	-	13%
Leberis						
Leberis davidi (Richard, 1895)	-	-	20%	10%	-	20%
Leydigia						
Leydigia propinqua Sars, 1903	-	-	-	11%	10%	13%
Leydigiopsis						
Leydigiopsis ornata Sars, 1901	-	-	-	11%	-	-
Magnospina						
Magnospina dentifera (Sars, 1901)	-	13%	-	-	18%	13%
Nicsmirnovius						
Nicsmirnovius incredibilis (Smirnov, 1984)	-	-	10%	10%	-	-
Nicsmirnovius sp.	25%	-	-	-	-	-
Ovalona						
Ovalona glabra (Sars, 1901)	-	-	-	11%	9%	-
Subfamília Chydorinae						
Chydoridae						
Chydorus eurynotus Sars, 1901	-	-	-	-	9%	13%
Chydorus sp.	-	13%	-	-	-	-
Daphniidae						
Ceriodaphnia						

Ceriodaphnia cornuta Sars, 1886	-	-	20%	67%	91%	63%
Ceriodaphnia laticaudata Müller, 1867	-	-	-	-	-	13%
Daphnia						
Daphnia gessneri Herbst, 1967	-	-	50%	-	-	1%
<u>Ilyocryptidae</u>						
Ilyocryptus						
Ilyocryptus sarsi Sars, 1862	-	-	-	-	-	13%
Ilyocryptus spinifer Herrick, 1882	-	13%	50%	44%	64%	75%
<u>Macrothricidae</u>						
Macrothrix						
Macrothrix elegans Sars, 1901	-	-	-	11%	-	-
Macrothrix laticornis Jurine, 1820	-	-	-	11%	18%	13%
Macrothrix sioli Smirnov, 1982	-	-	-	-	9%	38%
Macrothrix sp.	-	-	10%	-	-	-
Macrothrix spinosa King, 1853	-	25%	-	11%	-	13%
<u>Moinidae</u>						
Moina						
Moina micrura Kurz, 1874	-	13%	20%	33%	36%	38%
Moina minuta Hansen, 1899	-	-	20%	56%	82%	50%
Moina reticulata (Daday, 1905)	-	-	-	-	9%	-
Moina sp.	-	-	-	11%	-	25%
Moinodaphnia						
Moinodaphnia macleayi (King, 1853)	-	-	-	-	9%	-
<u>Sididae</u>						
Diaphanosoma						
Diaphanosoma brevireme Korinek, 1981	-	-	-	-	36%	-
Diaphanosoma spinulosum Herbst, 1967	-	13%	40%	67%	73%	38%
Latonopsis						
Latonopsis australis Sars,1888	-	-	-	-	9%	-
COPEPODA	**H1**	**H2**	**M1**	**M2**	**L1**	**L2**
<u>Cyclopoida</u>						
Ectocyclops						
Ectocyclops rubescens Brady, 1904	-	13%	-	-	-	-
Mesocyclops						
Mesocyclops aspericornis Daday, 1906	-	-	-	-	36%	-
Mesocyclops meridianus Kiefer, 1926	-	-	-	-	9%	-
Microcyclops						
Microcyclops finitimus Dussart, 1984	-	-	10%	-	18%	-
Thermocyclops						

Thermocyclops decipiens Kiefer, 1929	17%	13%	50%	67%	91%	88%
Thermocyclops minutus Lowndes, 1934	-	-	-	11%	45%	13%
Paracyclops						
Paracyclops chiltoni Fischer, 1853	-	-	60%	78%	9%	63%
Calanoida						
Notodiaptomus						
Notodiaptomus cearensis Wright, 1936	-	13%	60%	67%	73%	50%
Notodiaptomus conifer Sars, 1901	-	-	80%	11%	-	25%
Notodiaptomus henseni Dahl, 1894	-	-	80%	44%	9%	25%
Notodiaptomus iheringi Wright, 1935	-	-	-	-	-	13%

*Body anomaly

Table 2. PERMANOVA results comparing the abundance transformed into Bray-Curtis distance between sites, periods and sites interacting with periods. Significant differences in bold

	Df	**F.Model**	**R2**	**P**
Sites	5	20.782	0.20543	**0.000999**
Period	1	21.505	0.04252	**0.006993**
Sites * period	5	12.083	0.11943	0.110889

Table 3. Mean values ± standard deviation of physical-chemical variables in relation to the sampling site

Variable	High 1	High 2	Medium 1	Medium 2	Low 1	Low 2
Rainfall (mm)	55.13 ± 59.61	92.57 ± 105.60	51.89 ± 62.65	23.44 ± 34.36	16.64 ± 25.84	9.63 ± 19.23
Transparency (cm)	49.67 ± 33.71	26.33 ± 17.76	56.80 ± 35.94	44.78 ± 25.40	33.73 ± 27.37	37.50 ± 14.84
Temperature (°C)	29.37 ± 1.85	29,.53 ± 1.88	30.69 ± 1.30	31.56 ± 1.53	31.39 ± 1.98	31.74 ± 1.38
DO ($mg.L^{-1}$)	6.75 ± 3.02	7.43 ± 1.35	11.63 ± 15.75	7.41 ± 1.71	6.76 ± 2.65	7.58 ± 1.47
pH	7.77 ± 0.46	7.15 ± 0.65	8.11 ± 0.40	7.94 ± 0.67	7.94 ± 0.61	8.02 ± 0.71
Conductivity ($\mu S.cm^{-1}$)	31.58 ± 37.54	**97.92 ± 118.74**	**111.60 ± 103.48**	77.74 ± 23.51	78.15 ± 21.52	**129.25 ± 114.01**
TDS ($mg.L^{-1}$)	119.83 ± 168.86	89.20 ± 78.27	78.39 ± 85.98	48.76 ± 15.54	50.77 ± 17.27	65.41 ± 29.65
Alkalinity ($mg.L^{-1}$ of $CaCO3$)	16.67 ± 12.11	28.33 ± 30.61	32.00 ± 18.14	35.56 ± 15.09	34.55 ± 12.14	32.50 ± 14.88
Hardness (ppm)	21.67 ± 20.41	18.33 ± 9.38	30.00 ± 17.64	32.22 ± 16.41	26.36 ± 11.20	28.75 ± 14.58
NH3 ($\mu S.L^{-1}$)	0.16 ± 0.12	0.11 ± 0.11	0.25 ± 0.35	0.25 ± 0.16	0.23 ± 0.34	0.17 ± 0.08
NO2 ($\mu S.L^{-1}$)	0.03 ± 0.04	0.01 ± 0.03	0.01 ± 0.03	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00

Supplementary file – S2

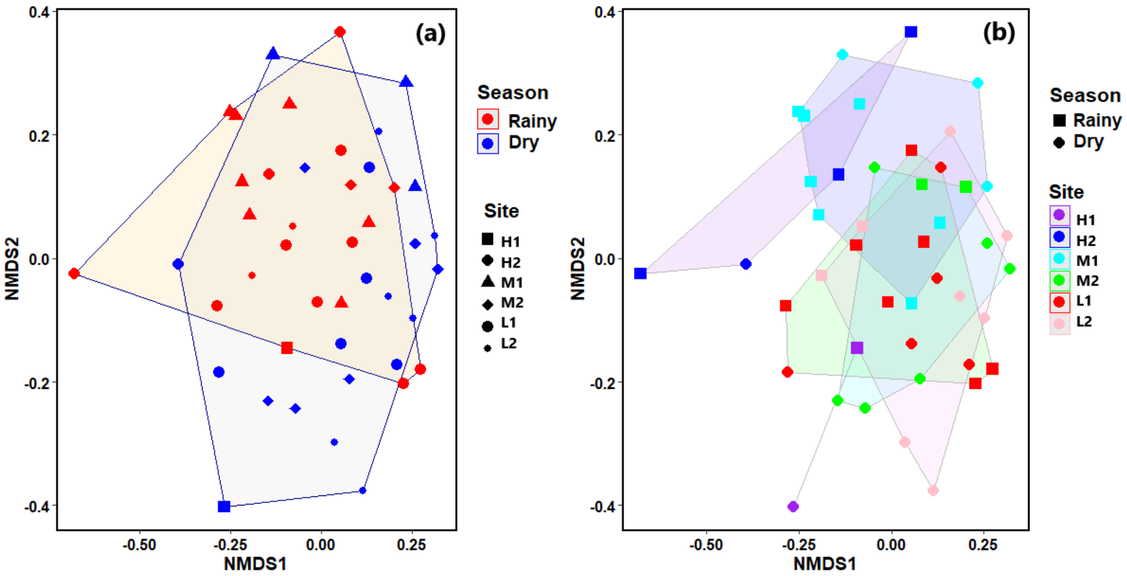

Fig. 1 NMDS analysis using Bray-Curtis dissimilarity transformed abundance for temporal (a) and spatial ordering (b) (stress = 0.24)

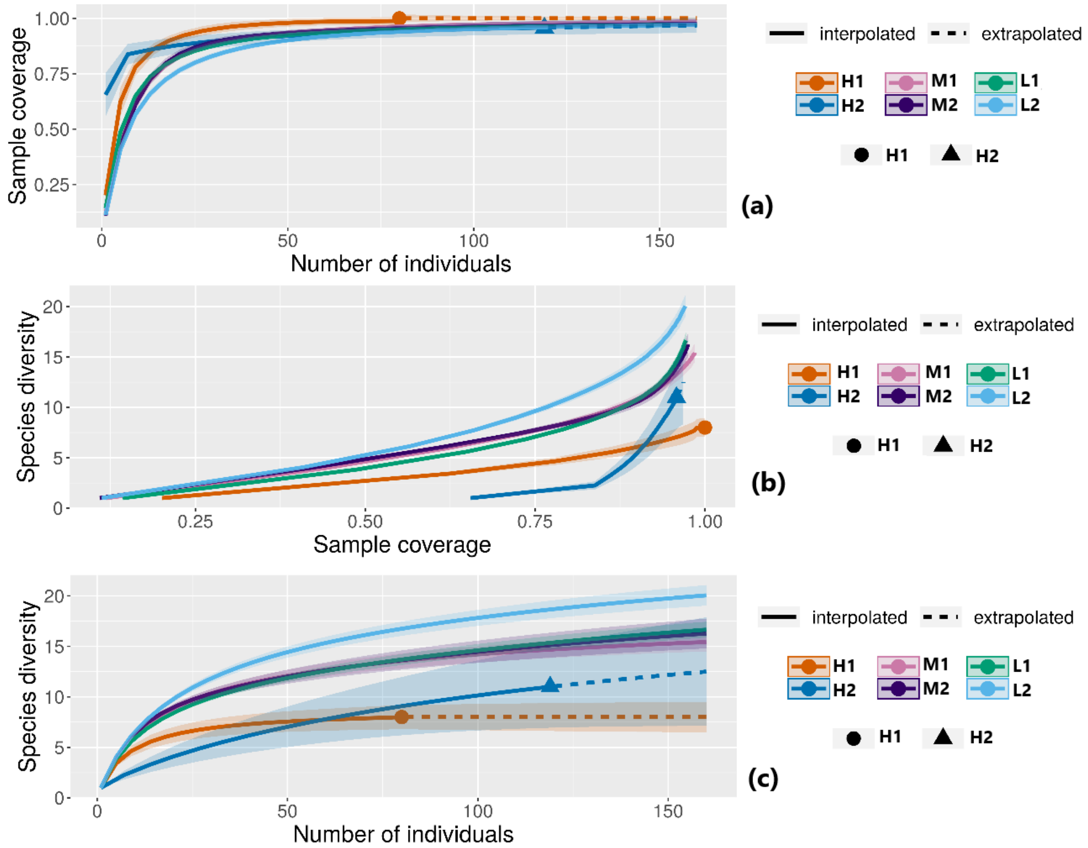

Fig. 2 Rarefaction and extrapolation curves of diversity of microcrustaceans among the sampling sites **(a)** Sample completeness curve **(b)** Coverage-based rarefaction and extrapolation sampling curve **(c)** Sample-size-based rarefaction and extrapolation sampling curve