



Universidade Federal do Rio Grande
Instituto de Ciências Biológicas
Pós-graduação em Biologia de
Ambientes Aquáticos Continentais



**Variáveis ambientais influenciam na diversidade
funcional e taxonômica de
microcrustáceos em lagos rasos da região
subtropical?**

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Orientador: Prof^a Dr^a Edélti Faria Albertoni

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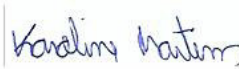
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“Dedico essa tese a minha mãe (Rosimari) e ao meu esposo (Leonardo), que me apoiaram incondicionalmente em todos os momentos. E ao meu Pai (in memoriam)”.

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RESUMO

Os lagos rasos têm sofrido com diversas mudanças nas variáveis ambientais, como por exemplo o incremento de nutrientes que leva a eutrofização e o aumento da turbidez. Uma importante comunidade presente nos lagos rasos, como os microcrustáceos, tem sofrido com estas alterações das variáveis ambientais, sendo assim esta tese tem como objetivo investigar como estas mudanças influenciaram a diversidade de microcrustáceos em um período de 14 anos. Para isso esta tese foi estruturada em dois capítulos, o primeiro com objetivo de avaliar a diversidade funcional de microcrustáceos frente as mudanças de estados alternativos, estado de águas claras com predomínio de macrófitas flutuantes, estado de águas claras com predomínio de macrófitas submersas e estado de águas túrbidas. Encontramos uma maior diversidade funcional em estados de águas claras com predomínio de macrófitas flutuantes em relação aos outros dois estados. A menor diversidade funcional encontrada nestes outros dois estados, pode estar associada a dominância dos traços funcionais encontrados no Ostracoda *Cypridopsis*, sendo este gênero abundante nestas amostras. Com isso, destacamos a importância da utilização da abordagem taxonômica juntamente com a funcional para melhor explicar os resultados. No segundo capítulo determinamos a diversidade taxonômica e funcional de Cladocera nos diferentes índices de estado trófico, oligotrófico, mesotrófico e eutrófico ao longo do tempo. Observamos uma diferença significativa na diversidade taxonômica entre os estados tróficos, com uma diminuição de espécies nos períodos de estado eutrófico. Já para diversidade funcional não observamos diferença significativa entre os estados tróficos, desta forma podemos observar que a perda de espécies não causou uma perda de características funcionais. Também observamos que em períodos eutrofizados encontramos espécies de maior tamanho corporal, o que está diretamente relacionado com a presença de espécies tolerantes a má qualidade de água. Desta forma, concluímos que as diferentes perturbações ambientais influenciam na comunidade de microcrustáceos, reduzindo sua diversidade taxonômica ou funcional, interferindo nas cadeias tróficas e no funcionamento dos lagos rasos.

Palavras-chave: Cladocera, Copepoda e Ostracoda, IET, diversidade funcional, estados alternativos, diversidade taxonômica.

ABSTRACT

Shallow lakes have suffered from several changes in environmental variables, such as the increase of nutrients that lead to eutrophication and increased turbidity. An important community present in shallow lakes, such as microcrustaceans, has suffered from these environmental changes, so this thesis aims to investigate how these changes influence the diversity of microcrustaceans over a period of 14 years. For this, this thesis was structured in two chapters, the first one aimed to evaluate the functional diversity of microcrustaceans against the changes of alternative states, state of clear water with a predominance of floating macrophytes, state of clear water with a predominance of submerged macrophytes and state of water turbid. We found greater functional diversity in clear water states with a predominance of floating macrophytes in relation to the other two states. This lower functional diversity found in these other two states may be associated with the dominance of the functional traits found in the Ostracoda *Cypridopsis*, as this genus is abundant in these samples. With that, we highlight the importance of using the taxonomic approach together with the functional one to better explain the results. In the second chapter we determined the taxonomic and functional diversity of Cladocera in the different indices of trophic, oligotrophic, mesotrophic, and eutrophic state. We observed a significant difference in taxonomic diversity between trophic states, with a decrease in species in eutrophic states. As for functional diversity, we did not observe a significant difference between trophic states, thus we can observe that the loss of species did not cause a loss of characteristics functional. We also observed that in eutrophic periods we found species with larger body size, which is directly related to the presence of species tolerant to poor water quality. In this way, we conclude that the different environmental disturbances influence the microcrustacean community, reducing its taxonomic or functional diversity, interfering in the trophic chains and in the functioning of shallow lakes.

Keywords: Cladocera, Copepoda and Ostracoda, TSI, functional diversity, alternative states, taxonomic diversity.

APRESENTAÇÃO

Esta tese é estruturada em uma introdução geral e dois capítulos. A introdução geral apresenta os principais conceitos sobre os temas abordados nos capítulos, é formatada de acordo com as normas da ABNT. O primeiro capítulo é composto com um artigo científico intitulado “Alternance of alternative stable states influence the functional diversity of microcrustaceans in a shallow subtropical lake” publicado na revista *Austral Ecology*, em 2022. Sua formatação segue de acordo com as normas da revista. Neste capítulo testamos a hipótese que as mudanças ao longo do tempo nos estados alternativos estáveis iriam influenciar na composição e na diversidade funcional de microcrustáceos em um lago raso subtropical.

O segundo capítulo foi submetido a revista *Hydrobiologia*, é intitulado “Taxonomic and functional diversity of Cladocera in two shallow subtropical lakes during 14 years” e foi formatado de acordo com as normas da revista. Neste capítulo testamos três hipóteses, a primeira de que encontraríamos uma menor diversidade funcional e taxonômica em períodos de estado eutrófico, a segunda que a diminuição da diversidade taxonômica seria acompanhada pela diminuição da diversidade funcional e a terceira que em períodos de estado eutrófico encontraríamos espécies de menor tamanho corporal e traços funcionais associados a tolerância a ambientes eutrofizados.

Finalizamos esta tese com considerações finais e perspectivas, onde apontamos as principais conclusões da tese.

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Table 1: Taxonomic indices of each trophic states. Average values of species richness, abundance, Shannon index, Equitability and Dominance index.

Table 2: Functional diversity index of each trophic state. Average values of functional richness, Rao's quadratic entropy and functional uniformity.

INTRODUÇÃO GERAL

1. Interações bióticas e principais características dos lagos rasos

Dentre os ecossistemas de águas doce, os lagos rasos são os mais abundantes e ocupam a maior parte da área lacustre do mundo (DOWNING, 2010). Estes lagos não ultrapassam três metros de profundidade e ocupam área menor que 100km² (SCHEFFER, 1998). A baixa profundidade permite que os ventos influenciem no movimento da água do lago (SCHEFFER, 1998), sendo assim diferentes dos lagos profundos que apresentam estratificação térmica no verão. Os lagos rasos apresentam um padrão de mistura polimítico, pois a água circula em toda a coluna d'água continuamente ou por longos períodos, não apresentando uma estratificação térmica duradoura (MEERHOFF; JEPPESEN, 2009). Outra característica dos lagos rasos é que a luz solar consegue penetrar em toda a coluna d'água, assim favorecendo o crescimento de macrófitas submersas em toda a extensão do lago, propiciando uma região litorânea mais extensa, do que em lagos profundos (SCHEFFER, 1998). Estes lagos também apresentam um contato próximo com o ambiente terrestre, gerando assim uma maior troca de matéria e organismos entre os ambientes aquático e terrestre (MEERHOFF; JEPPESEN, 2009).

As interações tróficas observadas nos lagos rasos podem sofrer um controle “bottom-up”, na qual a quantidade de luz e de nutrientes controla o fitoplâncton e o zooplâncton vai ser controlado pela quantidade de fitoplâncton. Este controle também pode ser “top-down” onde os peixes irão controlar o zooplâncton, que por sua vez irá controlar o fitoplâncton (SCHEFFER, 1998). O sucesso destas interações, zooplâncton pastando o fitoplâncton e a predação dos peixes sobre o zooplâncton depende de diversos fatores, como por exemplo o encontro mútuo entre eles (MEERHOFF; DE LOS ÁNGELES GONZÁLEZ-SAGRARIO, 2022). Na região pelágica dos lagos rasos com ausência de estruturas de refúgios, em condições de turbidez, algumas presas conseguem minimizar a predação, já em condições de águas claras estas presas precisam se deslocar para evitar a predação (MEERHOFF; DE LOS ÁNGELES GONZÁLEZ-SAGRARIO, 2022). Na presença de macrófitas aquáticas em regiões de clima temperado, estas podem atuar como abrigo para o zooplâncton, que por sua vez conseguem se esconder dos predadores, e consequentemente o zooplâncton irá exercer uma maior pressão de pastejo sobre o fitoplâncton (MEERHOFF et al., 2007). Já para as regiões subtropicais este refúgio nas macrófitas não é tão eficaz (MEERHOFF et al., 2006, 2007). Os peixes piscívoros também atuam nestas interações, uma vez que estes predam os

peixes planctônicos e assim diminuindo a pressão que estes exercem sobre o zooplâncton (SCHEFFER, 1998).

Os lagos rasos podem apresentar dois estados alternativos estáveis, um estado de águas claras com predomínio de macrófitas submersas, a um estado de águas túrbidas com predomínio do fitoplâncton (SCHEFFER et al., 1993). Uma série de fatores influenciam na mudança de estado alternativo, o principal deles é a carga de nutrientes, que em excesso estimula o crescimento do fitoplâncton. A ressuspensão do sedimento por exemplo, causa o carregamento interno de nutrientes, como por exemplo o fósforo (SØNDERGAARD; JENSEN; JEPPESEN, 1999), ocasionando um feedback positivo para o crescimento fitoplanctônico (SCHEFFER et al., 1993).

Para a região tropical e subtropical a carga de nutrientes, principalmente fósforo, favorece o crescimento de macrófitas flutuantes (MEERHOFF; JEPPESEN, 2009). Então, em um gradiente de concentração de fósforo, os lagos rasos podem apresentar três estados alternativos estáveis, estado de águas claras com dominância de macrófitas submersas, estado de águas claras com dominância de macrófitas flutuantes e estado de águas túrbidas com dominância do fitoplâncton (MEERHOFF; JEPPESEN, 2009) (Figura 1).

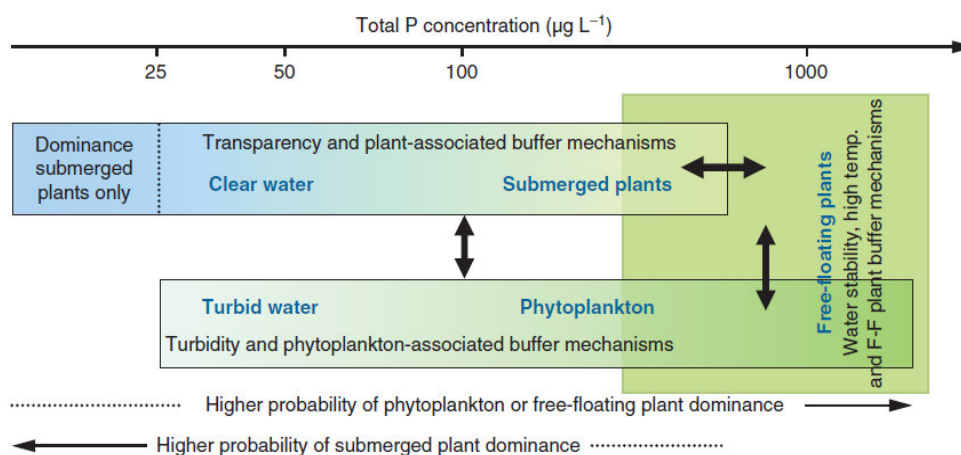


Figura 1: Estados alternativos estáveis em lagos rasos, em o gradiente de nutrientes (fósforo): dominado por fitoplâncton, dominado por plantas submersas e dominado por plantas flutuantes livres. Fonte: (MEERHOFF; JEPPESEN, 2009).

As macrófitas aquáticas são importantes na manutenção do estado de águas claras, pois podem atuar retirando nutrientes da água, e assim, suprimir o crescimento do fitoplâncton e reduzir as concentrações de clorofila- α (ALBERTONI et al., 2014). Além disso, o

sombreamento gerado pelas macrófitas flutuantes bloqueia a entrada de luz na água, assim impedindo o crescimento do fitoplâncton (MEERHOFF; JEPPESEN, 2009).

Muitos organismos possuem papel importante na alternância dos estados tróficos em lagos rasos tropicais e subtropicais, como os peixes bentônicos e muitos organismos construtores de tubos no sedimento, como oligoquetas e alguns insetos. Estes provocam a ressuspensão do sedimento em um processo conhecido como bioturbação, favorecendo o estabelecimento de um estado de águas turbidas, devido ao aporte de nutrientes para a coluna de água (MORMUL et al., 2012).

Para avaliar as mudanças nos estados tróficos de lagos rasos, são comumente utilizados os Índices de Estado Trófico (IET) (CUNHA; CALIJURI; LAMPARELLI, 2013). Estes índices levam em consideração principalmente a concentração de fósforo e clorofila- α , e permitem aferir as modificações causadas pelo processo de eutrofização nestes ambientes. Mais recentemente, as pressões antrópicas promovidas pelo aporte de nutrientes, aliadas as modificações causadas pelas mudanças climáticas estão causando mudanças na biota destes ecossistemas (ALLENDE et al., 2019; HILT et al., 2017). Estas mudanças alteram o funcionamento dos lagos rasos, causando mudanças nas cadeias tróficas e homogeneização da biota (ZHANG et al., 2019). Para os macroinvertebrados, se observou uma influência dos diferentes estados tróficos na comunidade, com o aumento de espécies tolerantes em ambientes eutrofizados (ZHANG et al., 2019). No zooplâncton, a eutrofização e consequentemente o aumento do fitoplâncton favoreceu algumas espécies, como Rotífera, pequenos Cladocera e Cyclopoida, mas por outro lado inibiu grandes Cladocera, como *Daphnia*, *Simocephalus* e *Leptodora* (LI et al., 2017).

2. Microcrustáceos

Dentre os invertebrados comumente encontrados em lagos rasos, os microcrustáceos constituem um grupo amplamente distribuído e abundante. Eles são representados principalmente por Cladocera, Copepoda e Ostracoda, mas também são constituídos por Anostraca e Conchostraca. Além disso diversas espécies de Cladocera e Copepoda compõem o zooplâncton de água doce (ESTEVES; BOZELLI; BRANCO, 2011; MARTINS; ALBERTONI, 2022). Os microcrustáceos são importantes elos tróficos nos ambientes aquáticos pois atuam como ligação entre os produtores primários (fitoplâncton) e consumidores secundários (peixes) (SODRÉ; BOZELLI, 2019). Desta forma, atuam na ciclagem de nutrientes e na transferência de energia (ESTEVES; BOZELLI; BRANCO, 2011).

Os Cladocera são pertencentes a Classe dos Branchiopoda, Subfilo Crustacea e Filo Arthropoda (RUPPERT; FOX; BARNES, 2005). No Brasil são frequentemente encontradas

as Famílias Sididae, Daphnidae, Bosminidae, Moinidae, Chydoridae, Macrothricidae e Ilyocryptidae, apresentam um tamanho que varia entre 0,2 e 3,0 mm (ELMOOR-LOUREIRO, 1997). Sua alimentação ocorre por filtração de partículas ou da coleta de partículas de sedimento ou plantas submersas (ELMOOR-LOUREIRO, 1997). Os Cladocera se reproduzem partenogeneticamente, onde as fêmeas produzem ovos diploides que ficam depositados na cavidade dorsal e resultam em indivíduos juvenis sem fase larval (DOLE-OLIVIER et al., 2000). Em períodos de condições ambientais desfavoráveis, como por exemplo, alterações na temperatura, no nível de água, no suprimento alimentar ou superpopulação, os Cladocera passam a se reproduzir sexualmente, pois surgem machos na população, assim ocorrendo a fecundação dos ovos e transformação da cavidade dorsal para formar um efípio, que pode conter de um a dois ovos (DOLE-OLIVIER et al., 2000). Estes ovos apresentam características que lhes confere resistência, podendo assim permanecer no sedimento por décadas (ESTEVES; BOZELLI; BRANCO, 2011).

Os Copépodes também são artrópodes do Subfilo Crustacea, pertencem a Classe Maxillopoda, Subclasse Copepoda (RUPPERT; FOX; BARNES, 2005). Apresentam 10 ordens, sendo Harpacticoida, Cyclopoida e Calanoida as mais importantes ecologicamente (RUPPERT; FOX; BARNES, 2005). Com tamanho corporal variando entre 0,2 a 5,0 mm, se alimentam por filtração ou através da captura de presas (DOLE-OLIVIER et al., 2000). Os Copepoda reproduzem-se de forma sexuada, com a produção de um a dois sacos ovíferos presos no abdômen da fêmea. Dos ovos eclodem náuplios (estágio larval) que até atingirem o estágio de copepodito, realizam seis mudas (DOLE-OLIVIER et al., 2000). Os copepoditos realizam mais seis mudas até se tornarem adultos (DOLE-OLIVIER et al., 2000). Devido ao processo de desenvolvimento dos Copepoda, estes exercem um importante papel no fluxo de energia dentro dos ambientes aquáticos (ESTEVES; BOZELLI; BRANCO, 2011).

Ostracoda constitui uma Classe de artrópodes igualmente pertencentes ao Subfilo Crustacea (RUPPERT; FOX; BARNES, 2005). Composto pelas Famílias Limnocytheridae, Darwinulidae, Candonidae, Cyprididae, Cypridopsidae, Ilyocyprididae e Notodromatidae, apresentam tamanho que varia de 0,4 a 3 mm (DOLE-OLIVIER et al., 2000). São organismos raspadores e comumente se reproduzem partenogeneticamente, podendo ter espécies com reprodução sexuada e partenogenética, a maioria é ovípara e depositam seus ovos nos substratos (DOLE-OLIVIER et al., 2000).

Nos ambientes aquáticos encontramos uma elevada riqueza microcrustáceos. Foram observados 41 gêneros de microcrustáceos em lagos rasos da região subtropical (MARTINS; ALBERTONI, 2022), em lagoas temporárias foram encontrados 35 táxons por DA SILVA

BANDEIRA et al. (2020) e 69 por MARTINS et al. (2019). Mudanças nas características ambientais são determinantes nas variações de biodiversidade em lagos rasos, incluindo os microcrustáceos (KRUK et al., 2009). O estado trófico pode atuar reduzindo a riqueza de espécies e levar a dominância de espécies mais tolerantes a maiores graus de trofia (GARCÍA-CHICOTE; ARMENGOL; ROJO, 2019). O aumento das concentrações de nitrogênio por exemplo, afetam negativamente a diversidade de microcrustáceos (YUN et al., 2021). Além da influência das variáveis fósforo, clorofila- α e transparência da água, diretamente relacionadas ao estado trófico, na composição de espécies de microcrustáceos (UMI et al., 2020).

3. Diversidade funcional

Além dos estudos taxonômicos, mais recentemente tem sido utilizada a abordagem funcional na avaliação das comunidades aquáticas, ou seja, traços funcionais. Estes, são definidos como qualquer característica mensurável a nível de indivíduo, que influencia na sua aptidão, através de consequências no seu crescimento, reprodução e sobrevivência (VIOLE et al., 2007). Os estudos com traços funcionais foram iniciados na década de 90, com as comunidades de plantas terrestres (TILMAN et al., 1997). Deste então, os traços funcionais têm sido utilizados em estudos com diferentes comunidades. Para as comunidades aquáticas, temos as classificações funcionais propostas por KRUK et al. (2011), PADISÁK; CROSSETTI; NASELLI-FLORES (2009) e REYNOLDS et al. (2002) para o fitoplâncton. Para o zooplâncton a primeira compilação de traços funcionais foi realizada por BARNETT; FINLAY; BEISNER (2007), seguida por BENEDETTI et al. (2018) e RIZO et al. (2017). A diversidade funcional pode ser mensurada através de grupos funcionais, que é o agrupamento de espécies com funções ecológicas semelhantes (PLA; CASANOVES; DI RIENZO, 2012), ou por meio de índices de diversidade funcional, que são valores mensurados pelos traços funcionais presentes nas espécies (SODRÉ; BOZELLI, 2019). Atualmente, temos diversos tipos de índices para calcular a diversidade funcional, como riqueza funcional, uniformidade funcional, divergência funcional, dispersão funcional, entropia quadrática de Rao, entre outros (LALIBERTÉ; LEGENDRE, 2010; LALIBERTÉ; LEGENDRE; SHIPLEY, 2014; MASON et al., 2005).

Os traços funcionais podem ser de resposta ou de efeito ou ambos, de resposta e efeito. Os traços de resposta são definidos como aqueles que variam em resposta a mudanças ambientais, já os de efeito são definidos como os efeitos que as espécies causam no ecossistema (HÉBERT; BEISNER; MARANGER, 2017). Para a comunidade zooplancônica

os traços de resposta são muito utilizados, ao contrário os traços de efeito que são raramente utilizados (HÉBERT; BEISNER; MARANGER, 2017). Os traços de resposta são divididos em quatro categorias: morfológicos, história de vida, comportamental e fisiológico e exercem diferentes funções ecológicas como alimentação, crescimento, reprodução e sobrevivência (LITCHMAN; OHMAN; KIØRBOE, 2013).

Os estudos com grupos funcionais dos microcrustáceos, abordam principalmente características como tipo de alimentação, grupo trófico, habitat e tamanho corporal (SODRÉ; BOZELLI, 2019). Para FINTELMAN-OLIVEIRA et al. (2023) habitat, tipo de alimentação e fuga contra predação foram os principais traços para definir os grupos tróficos funcionais de zooplâncton em reservatórios. Já para MARTINS; ALBERTONI (2022) os principais traços foram grupo trófico, tipo de alimentação e habitat, sendo estes os que melhor responderam as mudanças ambientais em lagos rasos.

O tamanho do corpo é um importante traço morfológico, pois ele responde a diversas mudanças ambientais e está diretamente associado a traços de categoria fisiológica (SODRÉ; BOZELLI, 2019). Em ambientes eutrofizados por exemplo, Cladocera de menor tamanho corporal podem ter melhor sucesso (UMI et al., 2020). Como por exemplo, a espécie *Chydorus sphaericus*, pois as cianobactérias são uma importante fonte de alimento, e esses organismos atuam como o principal elo trófico que transfere o carbono das cianobactérias para níveis tróficos superiores em ambientes eutróficos (TÖNNÖ et al., 2016). As pequenas espécies da família Bosminidae também podem ser favorecidas, pois são tolerantes a cianobactérias tóxicas em ambientes eutróficos (FIGUEROA SÁNCHEZ; SARMA; SARMA, 2014). As espécies de maior tamanho corporal, podem encontrar dificuldade para se alimentar em ambientes eutrofizados com presença de cianobactérias, devido à inibição química ou mecânica dos apêndices torácicos, pelas cianobactérias tóxicas e filamentosas (SUN et al., 2012).

O maior tamanho corporal pode ser favorecido nas interações tróficas entre os microcrustáceos e o fitoplâncton, pois os microcrustáceos de maior tamanho corporal são mais eficientes no pastejo de células fitoplanctônicas pequenas e grandes (GIANUCA; PANTEL; DE MEESTER, 2016). Traços relacionados com o tipo de alimentação e grupo trófico também são de grande relevância, pois estão relacionados a transferência de energia entre os grupos tróficos (GOMES et al., 2019). Desta forma, entender a relações trófica entre o fitoplâncton-microcrustáceos, através do uso de traços funcionais, nos permite entender o funcionamento dos ecossistemas aquáticos (JOSUÉ et al., 2019).

As informações ambientais são de grande importância para entender o significado e ecológico e evolutivo dos traços observados (MCGILL et al., 2006). A turbidez por exemplo, tem causado um impacto na diversidade de microcrustáceos (JOSUÉ et al., 2021). Mudanças no tipo de alimentação, expectativa de vida, tipo de reprodução e fuga de predadores foram observadas frente as variáveis turbidez e profundidade (BRAGHIN et al., 2020). As variáveis fósforo e clorofila- α , que são diretamente associadas a eutrofização, também mostraram influência na diversidade funcional (BARNETT; FINLAY; BEISNER, 2007; BRAGHIN et al., 2020). Assim como, a dominância de cianobactérias em lagos hipertróficos, leva a uma redução dispersão funcional do zooplâncton e selecionando características de espécies tolerantes (JOSUÉ et al., 2019).

A diversidade funcional é de grande relevância para entender o funcionamento dos ecossistemas aquáticos. Porém cabe destacar que os índices de diversidade funcional podem estar correlacionados com os índices de diversidade taxonômica. Por exemplo, a riqueza funcional pode ser altamente correlacionada com a riqueza de espécies (BRAGHIN et al., 2020), pois quanto maior for a riqueza de espécies, maior serão as chances de encontrar espécies raras e assim refletir em uma maior combinação de características funcionais (MOUCHET et al., 2010). Outros exemplos são a divergência funcional e uniformidade funcional, também dependem de índices taxonômicos, como riqueza de espécies (VILLÉGER; MASON; MOUILLOT, 2008). Sendo assim a utilização de uma abordagem funcional aliada a abordagem taxonômica podem melhor explicar o funcionamento dos ambientes aquáticos frente as mudanças ambientais (MARTINS; ALBERTONI, 2022; RIZO et al., 2017).

Considerando os aspectos acima expostos, esta tese tem como objetivo geral entender como a comunidade de microcrustáceos se estrutura taxonômica e funcionalmente frente a mudanças ambientais em lagos rasos subtropicais.

Objetivos específicos

- Avaliar a diversidade e composição funcional de microcrustáceos frente a mudanças dos estados alternativos estáveis em um lago raso.
- Determinar a diversidade taxonômica e funcional de Cladocera em dois lagos rasos, que sofreram mudanças em seu estado trófico ao longo de 14 anos.

- Verificar os efeitos da eutrofização sobre a diversidade taxonômica e funcional de Cladocera e se mudanças nos índices de diversidade taxonômica são refletidos nos índices de diversidade funcional.

Referencias

ALBERTONI, E. F. et al. Field evidence of the influence of aquatic macrophytes on water quality in a shallow eutrophic lake over a 13-year period. **Acta Limnol. Bras.**, v. 26, n. 2, p. 176–185, jun. 2014.

ALLENDE, L. et al. Phytoplankton functional group classifications as a tool for biomonitoring shallow lakes: a case study. **Knowledge & Management of Aquatic Ecosystems**, v. 420, p. 5, 1 jan. 2019.

BARNETT, A.; FINLAY, K.; BEISNER, B. Functional diversity of crustacean zooplankton communities: towards a trait-based classification. **Freshwater Biology**, v. 52, n. 5, p. 796–813, maio 2007.

BENEDETTI, F. et al. Do functional groups of planktonic copepods differ in their ecological niches? **Journal of Biogeography**, v. 45, n. 3, p. 604–616, 1 mar. 2018.

BRAGHIN, L. et al. Food availability, depth, and turbidity drive zooplankton functional diversity over time in a Neotropical floodplain. **Aquatic Sciences**, v. 83, p. 10, 6 nov. 2020.

CUNHA, D.; CALIJURI, M.; LAMPARELLI, M. A Trophic State Index for Tropical/subtropical Reservoirs (TSItsr). **Ecological Engineering**, v. 60, p. 126–134, 1 nov. 2013.

DA SILVA BANDEIRA, M. G. et al. Hydration time influences microcrustacean hatching in intermittent wetlands: in situ and ex situ approaches. **Hydrobiologia**, v. 847, n. 15, p. 3227–3245, 1 set. 2020.

DOLE-OLIVIER, M.-J. et al. The biology and ecology of lotic microcrustaceans. **Freshwater Biology**, v. 44, n. 1, p. 63–91, 1 maio 2000.

DOWNING, J. Emerging global role of small lakes and ponds: little things mean a lot. **Limnetica**, v. 29, n. 1, p. 9–24, jun. 2010.

ELMOOR-LOUREIRO, L. **Manual de Identificação de Cladóceros Límnicos do Brasil**. Brasília: Editora Universa - UCB, 1997.

ESTEVES, F.; BOZELLI, R. L.; BRANCO, C. Comunidade Zooplanctônica. Em: **Fundamentos de Limnologia**. 3ª ed. Rio de Janeiro: Interciência, 2011. p. 523–580.

FIGUEROA SÁNCHEZ, M.; SARMA, N.; SARMA, S. S. S. Zooplankton community structure in the presence of low levels of cyanotoxins: A case study in a high altitude tropical reservoir (Valle de Bravo, Mexico). **Journal of Limnology**, v. 73, 27 jan. 2014.

- FINTELMAN-OLIVEIRA, E. et al. Zooplankton functional groups in tropical reservoirs: discriminating traits and environmental drivers. **Hydrobiologia**, v. 850, n. 2, p. 365–384, 1 jan. 2023.
- GARCÍA-CHICOTE, J.; ARMENGOL, X.; ROJO, C. Zooplankton species as indicators of trophic state in reservoirs from Mediterranean river basins. **Inland Waters**, v. 9, n. 1, p. 113–123, 2 jan. 2019.
- GIANUCA, A. T.; PANTEL, J. H.; DE MEESTER, L. Disentangling the effect of body size and phylogenetic distances on zooplankton top-down control of algae. **Proceedings of the Royal Society B: Biological Sciences**, v. 283, n. 1828, p. 20160487, 13 abr. 2016.
- GOMES, L. F. et al. Zooplankton functional-approach studies in continental aquatic environments: a systematic review. **Aquatic Ecology**, v. 53, n. 2, p. 191–203, 1 jun. 2019.
- HÉBERT, M.-P.; BEISNER, B. E.; MARANGER, R. Linking zooplankton communities to ecosystem functioning: toward an effect-trait framework. **Journal of Plankton Research**, v. 39, n. 1, p. 3–12, 1 jan. 2017.
- HILT, S. et al. Translating Regime Shifts in Shallow Lakes into Changes in Ecosystem Functions and Services. **BioScience**, v. 67, n. 10, p. 928–936, 1 out. 2017.
- JOSUÉ, I. et al. Cyanobacteria dominance drives zooplankton functional dispersion. **Hydrobiologia**, v. 831, n. 1, p. 149–161, mar. 2019.
- JOSUÉ, I. I. P. et al. Zooplankton functional diversity as an indicator of a long-term aquatic restoration in an Amazonian lake. **Restoration Ecology**, v. 29, n. 5, p. e13365, 1 jul. 2021.
- KRUK, C. et al. Determinants of biodiversity in subtropical shallow lakes (Atlantic coast, Uruguay). **Freshwater Biology**, v. 54, n. 12, p. 2628–2641, 1 dez. 2009.
- KRUK, C. et al. Phytoplankton community composition can be predicted best in terms of morphological groups. **Limnology and Oceanography**, v. 56, n. 1, p. 110–118, 1 jan. 2011.
- LALIBERTÉ, E.; LEGENDRE, P. A distance-based framework for measuring functional diversity from multiple traits. **Ecology**, v. 91, n. 1, p. 299–305, 1 jan. 2010.
- LALIBERTÉ, E.; LEGENDRE, P.; SHIPLEY, B. FD: Measuring functional diversity from multiple traits, and other tools for functional ecology. **R package version**, v. 1, p. 0–12, 1 jan. 2014.
- LI, Y. et al. Effects of filter-feeding planktivorous fish and cyanobacteria on structuring the zooplankton community in the eastern plain lakes of China. **Ecological Engineering**, v. 99, p. 238–245, 1 fev. 2017.
- LITCHMAN, E.; OHMAN, M. D.; KIØRBOE, T. Trait-based approaches to zooplankton communities. **Journal of Plankton Research**, v. 35, n. 3, p. 473–484, 1 maio 2013.
- MARTINS, K. P. et al. Microcrustacean metacommunities in urban temporary ponds. **Aquatic Sciences**, v. 81, n. 4, p. 56, 18 jul. 2019.

MARTINS, K. P.; ALBERTONI, E. F. Alternance of alternative stable states influence the functional diversity of microcrustaceans in a shallow subtropical lake. **Austral Ecology**, v. 47, n. 5, p. 1016–1028, 1 ago. 2022.

MASON, N. W. H. et al. Functional richness, functional evenness and functional divergence: the primary components of functional diversity. **Oikos**, v. 111, n. 1, p. 112–118, 1 out. 2005.

MCGILL, B. et al. Rebuilding community ecology from functional traits. **Trends in Ecology & Evolution**, v. 21, n. 4, p. 178–185, abr. 2006.

MEERHOFF, M. et al. An experimental study of habitat choice by *Daphnia*: plants signal danger more than refuge in subtropical lakes. **Freshwater Biology**, v. 51, n. 7, p. 1320–1330, jul. 2006.

MEERHOFF, M. et al. Effects of habitat complexity on community structure and predator avoidance behaviour of littoral zooplankton in temperate versus subtropical shallow lakes. **Freshwater Biology**, v. 52, n. 6, p. 1009–1021, jun. 2007.

MEERHOFF, M.; DE LOS ÁNGELES GONZÁLEZ-SAGRARIO, M. Habitat complexity in shallow lakes and ponds: importance, threats, and potential for restoration. **Hydrobiologia**, v. 849, n. 17, p. 3737–3760, 1 out. 2022.

MEERHOFF, M.; JEPPESEN, E. Shallow Lakes and Ponds. Em: **Lake ecosystem ecology**. 2º ed. San Diego: Elsevier-Academic Press, 2009. p. 645–655.

MORMUL, R. P. et al. Migratory benthic fishes may induce regime shifts in a tropical floodplain pond. **Freshwater Biology**, v. 57, n. 8, p. 1592–1602, 1 ago. 2012.

MOUCHET, M. A. et al. Functional diversity measures: an overview of their redundancy and their ability to discriminate community assembly rules. **Functional Ecology**, v. 24, n. 4, p. 867–876, 1 ago. 2010.

PADISÁK, J.; CROSSETTI, L. O.; NASELLI-FLORES, L. Use and misuse in the application of the phytoplankton functional classification: a critical review with updates. **Hydrobiologia**, v. 621, n. 1, p. 1–19, 1 mar. 2009.

PLA, L.; CASANOVES, F.; DI RIENZO, J. Functional Groups. Em: PLA, L.; CASANOVES, F.; DI RIENZO, J. (Eds.). **Quantifying Functional Biodiversity**. Dordrecht: Springer Netherlands, 2012. p. 9–25.

REYNOLDS, C. S. et al. Towards a functional classification of the freshwater phytoplankton. **Journal of Plankton Research**, v. 24, n. 5, p. 417–428, 1 maio 2002.

RIZO, E. Z. C. et al. Identifying functional groups and ecological roles of tropical and subtropical freshwater Cladocera in Asia. **Hydrobiologia**, v. 799, n. 1, p. 83–99, 1 set. 2017.

RUPPERT, E. E.; FOX, R. S.; BARNES, R. D. **Zoologia dos invertebrados: uma abordagem funcional-evolutiva**. 7ª ed. São Paulo: Roca, 2005.

SCHEFFER, M. et al. Alternative equilibria in shallow lakes. **Trends in Ecology Evolution**, v. 8, p. 275–279, 1993.

SCHEFFER, M. **Ecology of shallow lakes**. London: Chapman and Hall, 1998.

SODRÉ, E. DE O.; BOZELLI, R. L. How planktonic microcrustaceans respond to environment and affect ecosystem: a functional trait perspective. **International Aquatic Research**, v. 11, n. 3, p. 207–223, 1 set. 2019.

SØNDERGAARD, M. et al. Water Framework Directive: ecological classification of Danish lakes. **Journal of Applied Ecology**, v. 42, n. 4, p. 616–629, 1 ago. 2005.

SØNDERGAARD, M.; JENSEN, J. P.; JEPPESEN, E. Internal phosphorus loading in shallow Danish lakes. **Hydrobiologia**, v. 408, n. 0, p. 145–152, 1 ago. 1999.

SUN, X. et al. Large-scale field evidence on the enhancement of small-sized cladocerans by Microcystis blooms in Lake Taihu, China. **Journal of Plankton Research**, v. 34, n. 10, p. 853–863, 1 out. 2012.

TILMAN, D. et al. The Influence of Functional Diversity and Composition on Ecosystem Processes. **Science**, v. 277, n. 5330, p. 1300–1302, 29 ago. 1997.

TÕNNO, I. et al. Algal Diet of Small-Bodied Crustacean Zooplankton in a Cyanobacteria-Dominated Eutrophic Lake. **PloS one**, v. 11, p. e0154526, 28 abr. 2016.

UMI, W. A. et al. Planktonic Microcrustacean Community Structure Varies with Trophic Status and Environmental Variables in Tropical Shallow Lakes in Malaysia. **Diversity**, v. 12, n. 9, 24 ago. 2020.

VALDERRAMA, J. C. The simultaneous analysis of total nitrogen and total phosphorus in natural waters. **Marine Chemistry**, v. 10, n. 2, p. 109–122, 1 jan. 1981.

VILLÉGER, S.; MASON, N.; MOUILLOT, D. New multidimensional functional diversity indices for a multifaced framework in functional ecology. **Ecology**, v. 89, p. 2290–2301, 1 set. 2008.

VIOLLE, C. et al. Let the concept of trait be functional! **Oikos**, v. 116, n. 5, p. 882–892, maio 2007.

YUN, L. et al. Eutrophication and predation mediate zooplankton diversity and network structure. **Limnology and Oceanography**, v. 67, p. S133–S145, 1 out. 2021.

ZHANG, Y. et al. Nutrient enrichment homogenizes taxonomic and functional diversity of benthic macroinvertebrate assemblages in shallow lakes. **Limnology and Oceanography**, v. 64, n. 3, p. 1047–1058, 1 maio 2019.

CAPÍTULO 1

Alternance of alternative stable states influence the functional diversity of microcrustaceans in a shallow subtropical lake

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Alternance of alternative stable states influence the functional diversity of microcrustaceans in a shallow subtropical lake

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Abstract

Shallow lakes in subtropical climate regions may have a clear water state with a predominance of submerged or floating macrophytes and a turbid water state with a predominance of phytoplankton. The relationship between microcrustaceans and these changes in alternative states is still incipient in the literature. And to better understand these relationships, the functional approach is an excellent tool. Thus, the present work seeks to test the hypothesis that changes in alternative stable states over time reflect the variability of composition and functional diversity of microcrustaceans. For this, samples of microcrustaceans collected in a subtropical shallow lake, which underwent alternate state changes in the period to 2000-2014, were used. Our results demonstrate a variation in composition and functional diversity among alternative states, thus supporting our hypothesis. In periods of clear water with a predominance of floating macrophytes we found a greater functional diversity and richness of genera. This result may be associated with several factors such as greater habitat heterogeneity and lower predation pressure. The lowest values of functional diversity found in periods of turbid waters with predominance of phytoplankton and periods of clear waters with submerged macrophytes are related to the dominance of functional traits such as scraper feeding type, herbivorous/omnivorous trophic group, littoral

habitat and asexual reproduction. These traits are functional features of most Ostracoda genera, a taxonomic group abundant in these two alternative states. The predominance of this group may be related to the environmental characteristics of these periods, such as the high vegetation cover and the availability of niches unoccupied by more sensitive species, since most Ostracoda have high environmental tolerance. We conclude that the functional traits approach combined with taxonomic groups respond to temporal variations of alternative stable states and are important tools to detect environmental changes.

Keywords: FD_Q, Spatial heterogeneity, Cladocera, Copepoda, Ostracoda

Introduction

Shallow lakes are widely distributed environments around the world, consisting mostly of continental water bodies (Downing 2010). In temperate environments, we can have two alternative stable states: a clear water state with predominance of submerged aquatic macrophytes, and a turbid water state with predominance of phytoplankton (Scheffer 1998). In these environments, the introduction of nutrients can quickly change their characteristics, resulting in the transition from a clear water state to a turbid water state, with a predominance of phytoplankton and absence of submerged aquatic macrophytes (Scheffer 1998). However, in tropical and subtropical climate regions, in a wide range of nutrients, especially phosphorus, floating macrophytes may grow (Meerhoff and Jeppesen 2009). Floating macrophytes maintain the state of clear water due to physical factors like shading to phytoplankton, and are also competitively more adept at removing some of the nutrients dissolved in the water column, resulting in an alternative third state in these regions, of clear waters with dominance of free-floating plants (Meerhoff and Jeppesen 2009). Numerous factors can cause an alternation between the alternative states of shallow lakes. An example of this is a state of clear water generated by the predominance of floating macrophytes that can change towards a clear water state with submerged macrophytes or a turbid water state with

phytoplankton by the influence of factors such as strong winds and/or rain, decrease in nutrients, decrease in water levels, etc. (de Tezanos Pinto and O'Farrell 2014).

Aquatic macrophytes are extremely important for maintaining the state of clear water because, in addition to aiding in the reduction of nutrient concentrations, chlorophyll-*a* and suspended material (Albertoni *et al.* 2014). Furthermore, in temperate regions, macrophytes play an important role as a refuge against predation by microcrustaceans (Meerhoff *et al.* 2007). However, in shallow lakes in Mediterranean, tropical and subtropical regions, macrophyte beds are places with greater risk of predation for microcrustaceans. (Meerhoff *et al.* 2006, 2007; Castro *et al.* 2007). In these environments we find a greater dominance and abundance of small fish and a greater association of these with aquatic plants, thus causing the loss of refuge for microcrustaceans (Jeppesen *et al.* 2007). In general, for the subtropical climate region, information about the structure of the microcrustacean community against the variation of alternative stable states in shallow lakes is still incipient. This is largely due to a majority of what has been described in relation to the functioning of shallow lakes already being postulated by studies in temperate climate regions. However, research demonstrates that there are clear differences in the functioning and structuring of this community between shallow subtropical and temperate lakes (Jeppesen *et al.* 2020).

In aquatic environments, the microcrustacean community aids in the transfer of energy and biomass between producers and consumers, and are important for monitoring water quality (Landa *et al.* 2007). The research approach using functional traits makes it possible to understand the interactions within food webs, their relationship with the environment, and to answer questions related to the functioning of the ecosystem (Diaz and Cabido 2001). These are defined as traits that involve the fitness of organisms, and are classified into morphological, life history, behavioral and physiological traits (Sodré and Bozelli 2019).

Thus, understanding the structure and functional diversity of microcrustaceans through functional traits, allows us to understand the functioning of aquatic environments (Amaral *et al.* 2021).

The relation of functional traits and the functioning of the aquatic ecosystem was observed in urbanized aquatic environments, where were found microcrustaceans of smaller body size and the absence of large filters in places with higher turbidity rates (Gianuca *et al.* 2018). In addition, this study reports that key microcrustacean species, such as large filter feeders, are associated with clear-water environments (Gianuca *et al.* 2018). Other example, was to decrease in submerged macrophyte beds cause a negative effect on the functional diversity of microcrustaceans, and this reduction has major effects on ecosystem functions, caused by the important role of microcrustaceans as a filter/scrapper in aquatic ecosystems (Bolduc *et al.* 2016). Although we have already found some implications in the aquatic environment related to variations in the functional traits of microcrustaceans. For this community, the functional traits approach is still recent, being the first data compilation carried out by Barnett *et al.* (2007). Studies with functional groups of microcrustaceans mainly address traits such as feeding type, trophic group, habitat, and body size (Sodré and Bozelli 2019). In addition to the individual's functional traits, information about the environment, where the trait was measured, is essential to understanding the ecological and evolutionary significance of the observed trait (McGill *et al.* 2006).

Metrics such as functional diversity have been an important tool for determining ecosystem processes (Diaz and Cabido 2001; Tilman 2001; Gomes *et al.* 2019). Energy transfer between trophic groups is an example of an ecosystem process that is related to functional traits such as feeding and diet strategies (Gomes *et al.* 2019). Furthermore, the trophic relationships between microcrustaceans and phytoplankton allow us to understand the

functioning of the aquatic ecosystem, as changes in phytoplankton availability can reduce the functional diversity values of microcrustaceans, resulting in the dominance of organisms with similar functional traits (Josué *et al.* 2019). Body size is also an important factor related to trophic interactions, as larger body sized microcrustaceans are more efficient in grazing on small and large phytoplankton cells (Gianuca *et al.* 2016).

Environmental variables, such as water turbidity, have shown a negative effect on the functional diversity of microcrustaceans, with the predominance of traits such as herbivorous trophic group, small filter-feeding Cladocera and asexual reproduction (Josué *et al.* 2021). Turbidity, combined with the depth of aquatic environments, has caused changes in the functional traits of microcrustaceans, mainly related to the feeding type, life span, reproduction mode, and escape from predators (Braghin *et al.* 2020). Higher values of functional diversity were observed in periods with clear water state with submerged macrophytes compared to periods with turbid water state and shaded state by floating macrophytes (Moi *et al.* 2022). A low number of functional traits, with persistence of a few species with a set of similar functional traits, was observed for periods of turbid water state and shaded state by floating macrophytes (Moi *et al.* 2022). For periods with clear water status with submerged macrophytes, a dominance of traits such as greater body size, filtering species and low predator escape capacity was observed (Moi *et al.* 2022). Thus, we can highlight that the functional approach is an excellent predictor for observing the relationship of the aquatic environment and the community, and to understand the functional structuring of the microcrustacean community facing the variations of alternative stable states in a shallow lake over time. Based on prior consideration of changes in community structure with alternance of states alternate in shallow lakes, we used the average of functional traits weighted by their relative abundances in the community, for tested the hypothesis that

changes in stable alternative states over time reflect the variability of microcrustacean functional traits composition and functional diversity.

Methods

Study Area

The study was carried out in a shallow lake (Biguás Lake) located in the city of Rio Grande, southern, Brazil (32° 04'43 "S, 52° 10'03" W) (Fig. 1). The lake is located in the coastal plain of Rio Grande do Sul State, a region with a humid subtropical climate, an average annual temperature from 17 °C to 19 °C, and precipitation ranging 1200 mm to 1500 mm, respectively (Alvares *et al.* 2013).

Biguás Lake has an area of approximately 1.5 ha and 2 m in depth, is heavily influenced by precipitation and wind, and incorporates a polymictic mixture pattern (Trindade *et al.* 2009). Two artificial islands are located in the center of the lake and serve as a shelter and resting place for a great abundance of birds. The presence of these birds results in an excessive supply of organic matter to the lake, causing a strong enrichment of nutrients which can accelerate the eutrophication process and the occurrence of frequent microalgae blooms (Trindade *et al.* 2009). As a result, over the years, Biguás Lake has undergone several variations in its trophic states, causing changes in the composition of macrophytes and phytoplankton biomass, generating changes in the water state over time, interspersing between moments of clear and turbid waters, and constant variation in chlorophyll-a and nutrient concentrations (Table 1)(Fig. 2)(Silva *et al.* 2015).

Date Collection

Twenty-seven samples (A1–A27) were collected from October 2000 to March 2014 from the environmental monitoring carried out by Limnology laboratory (ICB-FURG).

Sampling was conducted at three random points, forming a composite sample. Aquatic plants were removed using a cylindrical collector with an area of 0.07 m², then taken to the laboratory and washed over a 250 µm mesh net. Retained organisms were fixed in 80% alcohol, stained with bengal rose and stored in the collection of Subtropical Limnic Invertebrates (ICB-FURG). The microcrustaceans of the orders Cladocera, Copepoda, and Ostracoda were identified, originating from the association with aquatic macrophytes samples present in the lake. Organisms were identified to the taxonomic level of genus when possible, using specific bibliography (Reid 1985; Elmoor-Loureiro 1997; Buckup and Bond-Buckup 1999; Gazulha 2012; Sousa and Loureiro 2019).

The limnological variables of the water column were obtained along with the collection of organisms. The methods used to determine chlorophyll-*a* and total phosphorus were analyzed according to Baumgarten *et al.* (1996) and Valderrama (1981), with total nitrogen according to Mackereth *et al.* (1978). The pH, electrical conductivity, and dissolved oxygen variables were obtained using probes. The samples obtained from Biguás Lake were classified according to the alternative state of the lake and macrophytes predominance: clear waters with a predominance of floating macrophytes, clear waters with a predominance of submerged macrophytes, and turbid waters with a predominance of phytoplankton. To determine the state of the lake for each sample, we used data on the concentration of chlorophyll-*a* (we classify as turbid water state those samples with a concentration above 60 µg.L⁻¹) and the predominant aquatic macrophyte habit (floating or submerged). We have compiled data on aquatic macrophytes from the available literature on Biguás Lake (Albertoni *et al.* 2014; Silva *et al.* 2015).

The classification according to the alternative state of the lake and macrophytes predominance for each sample resulted in 11 samples classified as clear water state and

predominance of floating macrophytes, 9 samples classified as clear water state and predominance of submerged macrophytes, and 7 samples with turbid water state and predominance of phytoplankton.

Functional Traits

Functional diversity was calculated using five functional traits of microcrustaceans, body size (numeric variable), trophic group (categorical variable), feeding type (categorical variable), reproduction mode (categorical variable), and habitat (categorical variable). The functional traits used in this study were compiled at the genus level, as these do not vary between species belonging to the same genus. Body size was the only numeric trait used in this study and was measured during the identification process using a measuring eyepiece microscope. The average body size value was calculated for each genus. The other categorical features were compiled from literature. For trophic group, the following categories were established: herbivores, carnivores, omnivores, omnivores/ herbivores, omnivores/carnivores, and herbivores/carnivores. The feeding type for Cladocera was classified into categories related to the filtration mode of each family (Barnett *et al.* 2007). Daphnids and Moinids use limbs 3 and 4 to perform the filtration (D-filtration), Sidids use their first five limbs in filtering (S-filtration) Bosminids uses active swimming while filtering, with less developed thoracic limbs (B-filtration), Chydorids, Macrothricids and Ilyocryptids use their second limb to scrape food from the substrates (C- filtration) (Gutierrez *et al.* 2021). For Copepoda and Ostracoda, the feeding types were scraper, raptorial and suspension feeders. The reproduction mode was sexual or asexual, and habitat is littoral or pelagic (Appendix S1).

Data Analysis

To calculate the functional indices of microcrustaceans, the Gower dissimilarity method modified by Pavoine *et al.* (2009), as it accommodates mixed variables such as numeric,

binary, and ordinal variables. The functional diversity index measured by Rao's quadratic entropy (FD_Q; Botta-Dukát 2005) using the Distance-Based Functional Diversity Indices (dbFD) function of the FD package (Laliberté *et al.* 2014) in R program (R Core Team 2017). This index incorporates species abundance data and the functional differences between them, it is based on Simpson's diversity index and considers the mean functional distance between two random individuals (Botta-Dukát 2005). Due to the data not being homoscedastic, we performed a Kruskal-Wallis test in order to verify the differences in the FD_Q index between the three different alternative states and demonstrate this result through a boxplot. The proportion of microcrustacean groups (Cladocera, Copepoda, and Ostracoda) for each alternative state was presented in a bar graph and verified by Evenness analysis. To verify the composition of functional traits in each alternative state, we used the weighted mean values of the microcrustacean traits (CWM) through functcomp function (Lavorel *et al.* 2008) of the FD package (Laliberté *et al.* 2014). Posteriorly Analyse of non-metric multidimensional scaling (NMDS) with Bray-Curtis dissimilarity matrix and Permutational analysis of variance (PERMANOVA). With the data of CWM were realize a bar graph for each functional trait the alternative states.

Results

For the microcrustacean community, 41 genera were found, of which 10 were Ostracoda, 10 Copepoda, and 21 Cladocera. The greatest abundance of genera was found in the turbid states with an average of 850.86 individuals for sample and the greatest richness in clear water state with a predominance of floating with an average of 9.09 genera for sample (Table 2). For the clear water state with a predominance of floating and submerged macrophytes, we obtained a total of 39 and 19 genera, respectively. For the turbid water state with a predominance of phytoplankton we found a total of 20 genera. Among the states, the abundance of genera was better distributed among the three groups (Cladocera, Copepoda,

and Ostracoda) in environments with a clear water state and a predominance of floating macrophytes, evenness of 0.98 (Table 2). For the other two states, Ostracoda presented a dominance in the abundance of genera (Fig. 3).

The highest values FDQ were observed with in the clear water state, with a predominance of floating macrophytes with value an average of 0.18, followed by clear water state, with a predominance of submersed macrophytes with value an average of 0.12 and turbid waters with value an average of 0.08. (Table 2). We observed a significant difference between the alternative stable states (Kruskal-Wallis chi-squared =10.50; df = 2; p-value = 0.005) (Fig. 4).

The NMDS demonstrates a difference in the composition of the traits mainly between the clear water states with predominance of floating and submerged plants (Fig. 5). We can observe that some traits permeate all three periods of the lake and other traits are characteristic of some periods generating this separation between the groups, as shown by the PERMANOVA ($R^2= 0.16$; p-value=0.04). The weighted mean of the functional traits of community-level for each alternative state (CWM) demonstrated that samples with clear water state and a predominance of floating macrophytes had a more uniform distribution of trophic groups in the community compared to other alternative states (Fig. 6.A). Among the trophic groups that make up this sample, more than 50% were herbivores (Fig. 6.A). As for the samples collected in periods of a clear water state with a predominance of submerged macrophytes, we found that the herbivore/omnivore trophic group made up 60% of the sample, followed by the herbivore trophic group with 36%. As for the turbid water state, the herbivore/omnivorous trophic group made up 68% of the sample, followed by the omnivorous/carnivorous and herbivorous trophic group with 16% and 13%, respectively (Fig. 6.A). Regarding the habitat and the reproduction mode of organisms, the clear water state

with a predominance of submerged macrophytes showed a dominance of organisms with the littoral habit and asexual reproduction, with this dominance of certain traits possibly being reflected in the FD_Q index (Fig. 4, 6.B, and C). Overall, the percentage of sexual reproduction mode was lower than asexual reproduction in all alternative states (Fig. 6.C).

The clear water state with a predominance of floating macrophytes did not show a dominance of feeding types, the same was not observed for the clear water states with a predominance of submerged macrophytes and turbid water. For the states of clear water and predominance of floating macrophytes, C-filtration, D-filtration, scraper and raptorial feeding types were more representative. (Fig. 6.D). The feeding type, B-filtration, was the one that presented the smallest contribution in this alternative state. As for the clear water states with a predominance of submerged macrophytes and turbid water, the predominant feeding type was scraper with 59% and 67%, respectively. The predominance of the scraper feeding type together with the herbivorous/omnivorous trophic group (Fig. 6.A and D), is strongly related to the abundance of Ostracoda genera in these alternative water states. For clear water states with a predominance of submerged macrophytes we can also find the feeding type C-filtration and raptorial, and for the turbid water states the raptorial and D-filtration feeding type have a greater representation (Fig. 6.D). In relation to body size, we observed that only clear water with a predominance of floating macrophytes had an average size of the genus greater than 1 mm (Fig. 6.E). These values are directly related to the composition of genres, such as large Copepoda (*Macrocyclops*, *Mesocyclops*, and *Notoadiaptomus*) and Ostracoda (*Chlamidoteca* and *Strandesia*) (Appendix S2).

Discussion

In this study, we investigated the functional traits composition and functional diversity of microcrustaceans against the variation of alternative stable states over time in a shallow subtropical lake. We found differences in functional composition and diversity between the

three alternative states of the shallow lake studied. We also observed that in clear water periods we obtained a different faunal composition between periods with a predominance of floating macrophytes or submerged macrophytes. Thus, our hypothesis was corroborated, since we observed the variation of functional composition and diversity in the different alternative states. For the microcrustacean community, as well as for macroinvertebrates and fish, aquatic macrophytes, both floating and submerged, influence their trophic structure (Meerhoff *et al.* 2007).

Furthermore, we observed that the floating macrophyte habitat architecture presented greater microcrustacean genera richness, as well as greater functional diversity in relation to clear water periods with a predominance of submerged macrophytes and turbid waters with a predominance of phytoplankton. Greater species richness was observed in periods with a predominance of floating macrophytes and in studies with Cladocera. In which the authors found a significantly higher species richness in macrophytes with a floating habitat architecture (Debastiani Júnior *et al.* 2016). This result may be related to a variety of new habitats favorable to microcrustaceans generated by the increase in floating plants (Pinto-Coelho *et al.* 2005). For the zooplankton community, it was found that submerged macrophytes, together with environmental variables, influenced the abundance and structure of the community, as well as the functional diversity (Bolduc *et al.* 2016). As in our study, we addressed planktonic and non-planktonic microcrustaceans associated with the substrate, the more complex architecture of floating macrophytes may favor, in addition to greater functional diversity, also greater richness of genera associated with these plants. Thus, floating macrophytes have a high accumulation of matter organic (periphyton and debris), food for substrate-associated organisms (Debastiani Júnior *et al.* 2016).

For functional diversity, we found the lowest values in the clear water states with submerged macrophytes and turbid water states, which is directly related to the dominance in the abundance of Ostracoda in these periods. This result reflects the type of analysis used, as the functional diversity measured by the Rao's quadratic entropy takes into account the abundance of species (Botta-Dukát 2005). Indices such as functional richness are strongly correlated with species richness, while functional divergence and functional uniformity indices are independent of species richness (Villéger *et al.* 2008). The FD_Q is correlated with the functional richness index (Mouchet *et al.* 2010), thus, we believe that in our study both richness and abundance were reflected in the functional diversity index.

These results may also be related to the association of some small Ostracoda with plants of greater structural complexity (Matsuda *et al.* 2015), since periods of clear water and predominance of submerged macrophytes were observed a high coverage of aquatic macrophytes, ranging from 95-100% and a high plant biomass per m² (Albertoni *et al.* 2014). However, it should be noted that not all Ostracoda have this association with aquatic macrophytes, so other factors may be regulating the presence of Ostracoda in aquatic environments (Matsuda *et al.* 2015).

The concentration of dissolved oxygen would be one of these factors, *Cypridopsis vidua*, for example, a genus abundant in periods of turbid and clear water with submerged macrophytes, despite being a species with wide ecological tolerance, it does not tolerate poorly oxygenated waters (Kiss 2007). In addition, the wide ecological tolerance of *Cypridopsis* may be related to its high abundance in periods when the lake had turbid waters, since the limiting factor of this genus is the concentration of dissolved oxygen, and in this period the lake presented a high average of dissolved oxygen, thus favoring the predominance

of *Cypridopsis*, that can occupy vacant niches, remnants of species more sensitive to changes in environmental variables.

Another factor that may explain the presence of Ostracoda in periods of clear water with a predominance of submerged macrophytes is the association of *Cypridopsis* with the macrophyte *Chara*, found in this period. Roca *et al.* (1993) observed that *Cypridopsis vidua* prefers periphyton growing on *Chara* to other feeding substrates. In addition, the predation factor may also have influenced our results, since the study by Meerhoff *et al.* (2003) observed that the fish category may vary between plant types. Showing an association of planktivorous fish with submerged macrophytes and carnivorous fish in the roots of floating plants (Meerhoff *et al.* 2003). Thus, the predation exerted by planktivorous fish may be benefiting the Ostracoda species, which are benthic.

The floating macrophytes are considered as a place of refuge for microcrustaceans (Cazzanelli *et al.* 2008). On the other hand, classic experimental and field studies for the subtropical climate region have shown that macrophytes are fragile or rare refuges for microcrustaceans (Meerhoff *et al.* 2006, 2007; Iglesias *et al.* 2007). Furthermore, recent studies indicate that certain levels of predation can have positive effects on functional diversity, balancing species distribution and functional characteristics (Deosti *et al.* 2021). Since the predation factor was not measured in our study, the high genera richness and functional diversity observed in periods with floating macrophytes can be attributed both to the protection factor exerted by floating macrophytes, as well as to the predation factor.

Faunal composition was reflected in the CWM result for each microcrustacean traits in the three alternative states. The feeding type is an important trait when using functional approaches, being commonly used in environmental monitoring studies (Ferreira *et al.* 2017), because it is directly linked to the availability of food resources which is reflected in the

composition of the faunal environment (Conceição *et al.* 2020). In our study, we observed differences in the composition of microcrustacean traits in the three alternative states, mainly between the states with floating macrophytes and states with submerged macrophytes/turbid waters. The functional traits type of scraper feeding, which, together with the herbivore/omnivore trophic group, littoral habitat and asexual reproduction, were dominant periods with submerged macrophytes and turbid waters. These traits reflect the functional characteristics of most Ostracoda genera and are associated with the environmental characteristics found in these periods, such as vegetation cover and oxygen concentration. Furthermore, the genera in this group share the same functional traits and compete for the same resources, causing a reduction in the functional diversity index in these periods. However, this homogeneity in the functional traits of Ostracoda may be related to the low number of studies on these organisms in freshwater environments in Brazil, resulting in less knowledge of the functional traits of this group. The low number of studies is mainly related to the low number of specialists of Ostracoda (Silva and Perbiche-Neves 2017).

A greater variety of feeding types, higher values of the herbivorous trophic groups, and lower concentrations of chlorophyll-*a* in periods of clear water state with a predominance of floating macrophytes may be related to the grazing capacity of Cladocera and some Copepoda found in samples from this period. Studies show that species of the genus *Macrothrix* are good consumers of phytoplankton (Amorim *et al.* 2019), as well as the cladocerans of the genus *Ilyocryptus* and *Ceriodaphnia* abundant in these samples. The genus *Bosmina* may be associated with the control of filamentous cyanobacteria and suspended debris (ter Heerdt and Hootsmans 2007). In these periods, we observe the presence of Calanoid Copepoda *Notodiaptomus* and according to the literature, the species *Notodiaptomus iheringi* is more selective and chooses the type of algae it consumes (Leitão *et al.* 2018). Thus, the wide

variety of feeding types found in these periods, with a predominance of floating macrophytes, may reflect a greater grazing pressure on phytoplankton.

The predominance of genera with littoral habits may be associated with the general characteristics of shallow lakes. In these environments, light can penetrate the sediment, favoring the growth of macrophytes, as their depth is less than three meters (Søndergaard *et al.* 2005). In addition, the aquatic environment object of this study has a high vegetation cover, often covering the entire lake at different times, thus favoring the predominance of species associated with aquatic macrophytes. This preference for the littoral region was observed by Coelho and Henry (2021), with found higher values of organism abundance and functional diversity for the littoral region compared to the pelagic region in the shallow lake object of their study. The CWM result for the habitat functional traits showed a clear dominance of genera with a littoral habit in every alternative states. It should be noted that Ostracoda are preferably littoral. Likewise, some Cladocera genera that were abundant in these periods, such as *Chydorus*, *Macrothrix* and *Ilyocryptus*, are non-planktonic organisms that live associated with plants in littoral lake regions (Paina and Melão 2019).

The body size of microcrustaceans had a relatively small mean value in the three alternative states, around 1 mm. The small of body size of microcrustaceans found in this study was already expected, as in tropical and subtropical climate regions zooplankton have a smaller body size than in temperate aquatic environments (Meerhoff *et al.* 2007). We can even observe large Cladocerans in these regions, such as *Daphnia* species, but these organisms cannot sustain themselves for long in the aquatic environment, which may be related to the higher predation pressure in warmer lakes (Meerhoff *et al.* 2007). Since larger body size zooplankton can be eliminated by the fish population (Lacerot *et al.* 2013). In periods with a predominance of floating macrophytes the microcrustaceans had a mean body

size larger than in the other states. In our study, we found individuals of *Daphnia* in only one sample, in the period of clear water with floating macrophytes. Under these conditions, some genera of Copepoda (*Macrocyclus*, *Mesocyclops*, and *Notoadiaptomus*) and Ostracoda (*Chlamidoteca* and *Strandesia*) have a larger body size. Martins *et al.* (2019) observed an association of larger-bodied species in aquatic environments more impacted by urbanization, and this result may be directly related to the presence of complete trophic chains in these environments, favoring the predation of larger-bodied microcrustaceans by fish or macroinvertebrates. In addition, the use of this functional trait is important since body size involves several ecological functions of organisms, such as feeding, reproduction, growth and survival (Litchman *et al.* 2013). For example, for Cladocera, body size was an important factor in determining grazing force, as larger body size Cladocerans are more efficient in phytoplankton grazing (Gianuca *et al.* 2016). Thus, emphasizing the importance of measuring this trait in studies with a functional approach.

In general, the approach with functional traits allowed us to understand the structure of the community in the face of changing environmental conditions, implicit in changes in an alternative state. This type of tool becomes increasingly important in ecological studies (Gomes *et al.* 2019), as it allows us to understand trophic and environmental interactions (Diaz and Cabido 2001). Currently, the functional traits approach has been widely used in studies in shallow lakes for several taxonomic groups. For example, in the understanding of the ecological functions of floating macrophytes (Liu *et al.* 2021), on the effect of winter severity over time, on the composition of functional traits of phytoplankton communities (Özkundakci *et al.* 2016). In determining how nutrient enrichment influences the functional homogeneity of macroinvertebrate assemblages (Zhang *et al.* 2019), and on the effects of biomanipulation on the functional diversity of the zooplankton community through a temporal study in a shallow temperate lake (Setubal and Riccardi 2020).

Furthermore, the use of functional diversity indices has shown itself to be increasingly promising to observe ecological changes because it is more sensitive than species richness and can be used to detect environmental disturbances (Mao *et al.* 2021). Although this approach is growing in multiple taxonomic groups, there is still a lack of studies on the functional traits of microcrustaceans, especially for Ostracoda from freshwater environments. The vast majority of work tends to address only Cladocera and Copepoda, although for these groups the use of functional traits is still new, being the first compilation carried out by Barnett *et al.* (2007). Thus, the functional traits approach for the microcrustacean community is still an expanding field that, together with taxonomic diversity, allows us to understand various processes within the aquatic ecosystem.

Thus, we can conclude that the functional traits of microcrustaceans were sensitive to alternations of stable alternative states (Fig. 7). The functional traits such as feeding type, trophic group, and habitat best reflected the variations in alternative states. The richness as well as the abundance of microcrustaceans from the Cladocera, Copepoda, and Ostracoda groups over the 14 years in the shallow lake studied was influenced by stable alternative states. Likewise, the functional diversity of organisms responded to conditions of environmental variation, with probable effects on the structuring of food webs and ecosystem functioning. We highlight the importance of the functional traits of the microcrustacean community combined with the taxonomic groups as good indicators to detect temporal variations in stable alternative states. We recommend the use of this tool, combined with variation in the composition of microcrustacean communities, to monitor aquatic environments in the face of environmental changes.

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Conflict of interest

The authors do not have any conflict of interest to declare.

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Availability of data and materials

The authors declare that all data supporting the findings of this study are available within the article and its supplementary information files.

References

- Albertoni E. F., Palma-Silva C., Trindade C. R. T. & Furlanetto L. M. (2014) Field evidence of the influence of aquatic macrophytes on water quality in a shallow eutrophic lake over a 13-year period. *Acta Limnol Bras* **26**, 176–185.
- Alvares C., Stape J., Sentelhas P., Goncalves J. & Sparovek G. (2013) Koppen's climate classification map for Brazil. *Meteorol. Z.* **22**, 711–728.
- Amaral D., Dunck B., Braghin L. *et al.* (2021) Predation by an omnivorous fish and food availability alter zooplankton functional diversity: a microcosm approach. *An. Acad. Bras. Ciênc.* **93**, e20200778.

- Amorim C., Valenca C., de Moura-Falcao R. & Moura A. (2019) Seasonal variations of morpho-functional phytoplankton groups influence the top-down control of a cladoceran in a tropical hypereutrophic lake. *Aquat. Ecol.* **53**, 453–464.
- Barnett A., Finlay K. & Beisner B. (2007) Functional diversity of crustacean zooplankton communities: towards a trait-based classification. *Freshw. Biol.* **52**, 796–813.
- Baumgarten M., Rocha J. & Niencheski L. (1996) *Manual de análises em oceanografia química*. Editora da FURG, Rio Grande.
- Bolduc P., Bertolo A. & Pinel-Alloul B. (2016) Does submerged aquatic vegetation shape zooplankton community structure and functional diversity? A test with a shallow fluvial lake system. *Hydrobiologia* **778**, 151–165.
- Botta-Dukát Z. (2005) Rao's quadratic entropy as a measure of functional diversity based on multiple traits. *J. Veg. Sci.* **16**, 533–540.
- Braghin L., Dias J., Simoes N. & Bonecker C. (2020) Food availability, depth, and turbidity drive zooplankton functional diversity over time in a Neotropical floodplain. *Aquat. Sci.* **83**, 10.
- Buckup L. & Bond-Buckup G. (1999) *Os Crustáceos do Rio Grande do Sul*. Editora da Universidade/UFRGS, Porto Alegre.
- Castro B. B., Marques S. M. & Gonçalves F. (2007) Habitat selection and diel distribution of the crustacean zooplankton from a shallow Mediterranean lake during the turbid and clear water phases. *Freshw. Biol.* **52**, 421–433.

- Cazzanelli M., Warming Perlt T. & Christoffersen K. (2008) Emergent and floating-leaved macrophytes as refuge for zooplankton in a eutrophic temperate lake without submerged vegetation. *Hydrobiologia* **605**, 113–122.
- Coelho P. N. & Henry R. (2021) Functional groups of microcrustaceans along a horizontal gradient in a Neotropical lake colonized by macrophytes. *Aquat. Sci.* **83**, 3.
- Conceição A. A., Albertoni E. F., Milesi S. V. & Hepp L. U. (2020) Influence of Anthropic Impacts on the Functional Structure of Aquatic Invertebrates in Subtropical Wetlands. *Wetlands* **40**, 2287–2296.
- Debastiani Júnior J., Loureiro L. & Nogueira M. (2016) Habitat architecture influencing microcrustaceans composition: a case study on freshwater Cladocera (Crustacea Branchiopoda). *Braz. J. Biol.* **76**, 93–100.
- Deosti S., de Fátima Bomfim F., Lansac-Tôha F. M., Quirino B. A., Bonecker C. C. & Lansac-Tôha F. A. (2021) Zooplankton taxonomic and functional structure is determined by macrophytes and fish predation in a Neotropical river. *Hydrobiologia* **848**, 1475–1490.
- Diaz S. & Cabido M. (2001) Vive la difference: plant functional diversity matters to ecosystem processes. *Trends Ecol. Evol.* **16**, 646–655.
- Downing J. (2010) Emerging global role of small lakes and ponds: little things mean a lot. *Limnetica* **29**, 9–24.
- Elmoor-Loureiro L. (1997) *Manual de Identificação de Cladóceros Límnicos do Brasil*. Editora Universa - UCB, Brasília.

- Ferreira W. R., Hepp L. U., Ligeiro R. *et al.* (2017) Partitioning taxonomic diversity of aquatic insect assemblages and functional feeding groups in neotropical savanna headwater streams. *Ecol. Indic.* **72**, 365–373.
- Gazulha V. (2012) *Zooplâncton límnic: manual ilustrado*. 1ª. Technical Books, Rio de Janeiro.
- Gianuca A., Engelen J., Brans K. *et al.* (2018) Taxonomic, functional and phylogenetic metacommunity ecology of cladoceran zooplankton along urbanization gradients. *Ecography* **41**, 183–194.
- Gianuca A. T., Pantel J. H. & De Meester L. (2016) Disentangling the effect of body size and phylogenetic distances on zooplankton top-down control of algae. *Proc. R. Soc. B Biol. Sci.* **283**, 20160487.
- Gomes L. F., Pereira H. R., Gomes A. C. A. M. *et al.* (2019) Zooplankton functional-approach studies in continental aquatic environments: a systematic review. *Aquat. Ecol.* **53**, 191–203.
- Gutierrez M., Ale A., Andrade V. S., Bacchetta C., Rossi A. & Cazenave J. (2021) Metallic, metal oxide, and metalloid nanoparticles toxic effects on freshwater microcrustaceans: An update and basis for the use of new test species. *Water Environ. Res.* **93**, 2505–2506.
- Iglesias C., Goyenola G., Mazzeo N., Meerhoff M., Rodó E. & Jeppesen E. (2007) Horizontal dynamics of Zooplankton in subtropical Lake Bianca (Uruguay) hosting multiple Zooplankton predators and aquatic plant refuges. *Hydrobiologia* **584**, 179–189.

- Jeppesen E., Canfield D., Bachmann R. *et al.* (2020) Toward predicting climate change effects on lakes: a comparison of 1656 shallow lakes from Florida and Denmark reveals substantial differences in nutrient dynamics, metabolism, trophic structure, and top-down control. *Inland Waters* **10**, 197–211.
- Jeppesen E., Meerhoff M., Jacobsen B. *et al.* (2007) Restoration of shallow lakes by nutrient control and biomanipulation-the successful strategy varies with lake size and climate. *Hydrobiologia* **581**, 269–285.
- Josué I., Cardoso S., Miranda M. *et al.* (2019) Cyanobacteria dominance drives zooplankton functional dispersion. *Hydrobiologia* **831**, 149–161.
- Josué I. I. P., Sodré E. O., Setubal R. B. *et al.* (2021) Zooplankton functional diversity as an indicator of a long-term aquatic restoration in an Amazonian lake. *Restor. Ecol.* **29**, e13365.
- Kiss A. (2007) Factors affecting spatial and temporal distribution of Ostracoda assemblages in different macrophyte habitats of a shallow lake (Lake Fehér, Hungary). *Hydrobiologia* **585**, 89–98.
- Lacerot G., Kruk C., Lüring M. & Scheffer M. (2013) The role of subtropical zooplankton as grazers of phytoplankton under different predation levels. *Freshw. Biol.* **58**, 494–503.
- Laliberté E., Legendre P. & Shipley B. (2014) FD: Measuring functional diversity from multiple traits, and other tools for functional ecology. *R Package Version.* **1**, 0–12.
- Landa G., Barbosa F., Rietzler A. & Barbosa P. (2007) *Thermocyclops decipiens* (Kiefer, 1929) (Copepoda, Cyclopoida) as indicator of water quality in the State of Minas Gerais, Brazil. *Braz. Arch. Biol. Technol.* **50**, 695–705.

- Lavorel S., Grigulis K., McIntyre S. *et al.* (2008) Assessing functional diversity in the field – methodology matters! *Funct. Ecol.* **22**, 134–147.
- Leitão E., Ger K. A. & Panosso R. (2018) Selective Grazing by a Tropical Copepod (Notodiaptomus iheringi) Facilitates Microcystis Dominance. *Front. Microbiol.* **9**, 301.
- Litchman E., Ohman M. D. & Kiørboe T. (2013) Trait-based approaches to zooplankton communities. *J. Plankton Res.* **35**, 473–484.
- Liu H., Liu G. & Xing W. (2021) Functional traits of submerged macrophytes in eutrophic shallow lakes affect their ecological functions. *Sci. Total Environ.* **760**, 143332.
- Mackereth J., Heron J. & Talling J. F. (1978) *Water analysis: some revised methods for limnologists*. Freshwater Biological Association, Cumbria.
- Mao Z., Gu X., Cao Y. *et al.* (2021) How does fish functional diversity respond to environmental changes in two large shallow lakes? *Sci. Total Environ.* **753**, 142158.
- Martins K. P., Bandeira M. G. da S., Palma-Silva C. & Albertoni E. F. (2019) Microcrustacean metacommunities in urban temporary ponds. *Aquat. Sci.* **81**, 56.
- Matsuda J., Lansac-Tôha F., Martens K., Velho L., Mormul R. & Higuti J. (2015) Association of body size and behavior of freshwater ostracods (Crustacea, Ostracoda) with aquatic macrophytes. *Aquat. Ecol.* **49**, 321–331
- McGill B., Enquist B., Weiher E. & Westoby M. (2006) Rebuilding community ecology from functional traits. *Trends Ecol. Evol.* **21**, 178–185.

- Meerhoff M., Fosalba C., Bruzzone C., Mazzeo N., Noordoven W. & Jeppesen E. (2006) An experimental study of habitat choice by *Daphnia*: plants signal danger more than refuge in subtropical lakes. *Freshw. Biol.* **51**, 1320–1330.
- Meerhoff M., Iglesias C., De Mello F. *et al.* (2007) Effects of habitat complexity on community structure and predator avoidance behaviour of littoral zooplankton in temperate versus subtropical shallow lakes. *Freshw. Biol.* **52**, 1009–1021.
- Meerhoff M. & Jeppesen E. (2009) Shallow Lakes and Ponds. In: *Lake ecosystem ecology* pp. 645–655
- Meerhoff M., Mazzeo N., Moss B. & Rodríguez-Gallego L. (2003) The structuring role of free-floating versus submerged plants in a subtropical shallow lake. *Aquat. Ecol.* **37**, 377–391
- Moi D. A., Romero G. Q., Jeppesen E. *et al.* (2022) Regime shifts in a shallow lake over 12 years: Consequences for taxonomic and functional diversities, and ecosystem multifunctionality. *J. Anim. Ecol.* **91**, 551–565.
- Mouchet M. A., Villéger S., Mason N. W. H. & Mouillot D. (2010) Functional diversity measures: an overview of their redundancy and their ability to discriminate community assembly rules. *Funct. Ecol.* **24**, 867–876.
- Özkundakci D., Gsell A. S., Hintze T., Täuscher H. & Adrian R. (2016) Winter severity determines functional trait composition of phytoplankton in seasonally ice-covered lakes. *Glob. Change Biol.* **22**, 284–298.
- Paina K. & Melão M. (2019) Zooplankton community structure from tropical temporary ponds during a flood period. *Limnetica* **38**, 189–211.

- Pavoine S., Vallet J., Dufour A.-B., Gachet S. & Daniel H. (2009) On the challenge of treating various types of variables: Application for improving the measurement of functional diversity. *Oikos* **118**, 391–402.
- Pinto-Coelho R., Pinel-Alloul B., Méthot G. & Havens K. E. (2005) Crustacean zooplankton in lakes and reservoirs of temperate and tropical regions: variation with trophic status. *Can. J. Fish. Aquat. Sci.* **62**, 348–361.
- R Core Team (2017) *R: A language and environment for statistical computing*. R Foundation for Statistical Computing, Vienna.
- Reid J. (1985) Chave de identificação e lista de referências bibliográficas para as espécies continentais sulamericanas de vida livre da ordem Cyclopoida (Crustacea, Copepoda). *Bol. Zool.* **9**, 17.
- Roca J. R., Baltanas A. & Uiblein F. (1993) Adaptive responses in *Cypridopsis vidua* (Crustacea: Ostracoda) to food and shelter offered by a macrophyte (*Chara fragilis*). *Hydrobiologia* **262**, 127–131.
- Scheffer M. (1998) *Ecology of shallow lakes*. Chapman and Hall, London.
- Setubal R. B. & Riccardi N. (2020) Long-term effects of fish biomanipulation and macrophyte management on zooplankton functional diversity and production in a temperate shallow lake. *Limnology* **21**, 305–317.
- Silva J., Albertoni E. & Palma-Silva C. (2015) Temporal variation of phytophilous Chironomidae over a 11-year period in a shallow Neotropical lake in southern Brazil. *Hydrobiologia* **742**, 129–140.

- Silva W. & Perbiche-Neves G. (2017) Trends in freshwater microcrustaceans studies in Brazil between 1990 and 2014. *Braz. J. Biol.* **77**, 527–534.
- Sodré E. de O. & Bozelli R. L. (2019) How planktonic microcrustaceans respond to environment and affect ecosystem: a functional trait perspective. *Int. Aquat. Res.* **11**, 207–223.
- Søndergaard M., Jeppesen E., Peder Jensen J. & Lildal Amsinck S. (2005) Water Framework Directive: ecological classification of Danish lakes. *J. Appl. Ecol.* **42**, 616–629.
- Sousa F. D. & Loureiro L. (2019) Identification key for the Brazilian genera and species of Aloninae (Crustacea, Branchiopoda, Anomopoda, Chydoridae). *Papéis Avulsos Zool.* **59**, e20195924.
- ter Heerdt G. & Hootsmans M. (2007) Why biomanipulation can be effective in peaty lakes. *Hydrobiologia* **584**, 305–316.
- Tezanos Pinto P. & O’Farrell I. (2014) Regime shifts between free-floating plants and phytoplankton: a review. *Hydrobiologia* **740**, 13–24.
- Tilman D. (2001) Functional Diversity. In: *Encyclopedia of Biodiversity* pp. 109–120
- Trindade C., Furlanetto L. & Palma-Silva C. (2009) Nycthemeral cycles and seasonal variation of limnological factors of a subtropical shallow lake (Rio Grande, RS, Brazil). *Acta Limnol. Bras.* **21**, 35–44.
- Valderrama J. C. (1981) The simultaneous analysis of total nitrogen and total phosphorus in natural waters. *Mar. Chem.* **10**, 109–122.

- Villéger S., Mason N. & Mouillot D. (2008) New multidimensional functional diversity indices for a multifaced framework in functional ecology. *Ecology* **89**, 2290–2301.
- Zhang Y., Cheng L., Li K. *et al.* (2019) Nutrient enrichment homogenizes taxonomic and functional diversity of benthic macroinvertebrate assemblages in shallow lakes. *Limnol. Oceanogr.* **64**, 1047–1058.

Tables

Table 1: Chronological sequence of alternative states and predominant and cover of macrophytes in the Biguás Lake.

Year	Dominant macrophyte	Mean cover (%)	Alternative state/macrophyte habit
2000	<i>Nymphoides indica</i>	20	Clear water/floating
2001	<i>Nymphoides indica</i>	20	Clear water/floating
2002	<i>Nymphoides indica</i>	10	Clear water/floating - turbid water
2003	<i>Pistia stratiotes</i>	10-95	Turbid water - clear water/floating - turbid water
2004	<i>Nymphoides indica</i>	20	Turbid water
2005	<i>Pistia stratiotes</i> / <i>Nymphoides indica</i>	20	Turbid water
2006	-	-	Turbid water
2007	<i>Salvinia herzogii</i>	10	Turbid water
2008	<i>Nymphoides indica</i> / <i>Salvinia herzogii</i>	20	Turbid water - clear water/floating
2009	<i>Stuckenia pectinata</i> / <i>Chara zeylanica</i>	100	Turbid water - clear water/submersed
2010	<i>Stuckenia pectinata</i> / <i>Chara zeylanica</i>	100	Clear water/submersed
2011	<i>Stuckenia pectinata</i> / <i>Chara zeylanica</i>	100	Clear water/submersed
2012	<i>Stuckenia pectinata</i> / <i>Chara zeylanica</i>	100	Clear water/submersed
2013	<i>Salvinia herzogii</i>	95-100	Clear water/floating
2014	<i>Salvinia herzogii</i>	95	Clear water/floating

Table 2: Mean and standard deviation of limnological variables, richness, abundance, functional diversity (Rao's quadratic entropy-FD_Q) of alternative states.

	Clear water/ submersed	Turbid water	Clear water/ floating
Oxygen (mg.L ⁻¹)	6.39 ±2.24	9.81 ±2.47	6.31 ±2.37
pH	7.95 ±0.53	8.89 ±1.50	7.74 ±1.10
Conductivity (µs.cm ⁻²)	205.38 ±57.33	184.21 ±42.76	189.99 ±24.23
Chlorophyll-a (µg.L ⁻¹)	20.91 ±11.91	125.68 ±49.06	17.33 ±15.13
Phosphorus (mg.L ⁻¹)	0.07 ±0.038	0.514 ±0.18	0.254 ± 0.16
Nitrogen (mg.L ⁻¹)	0.94 ±0.46	2.95 ±1.15	0.86 ± 0.63
Richness (n)	7.44 ±2.50	6.86 ± 3.44	9.09 ±4.59
Abundance (n)	244.78 ±282.99	850.86 ±922.69	115.18 ±103.46
FD_Q	0.123 ± 0.06	0.083 ±0.07	0.187 ±0.03
Evenness-E	0.83	0.78	0.98

Figures:

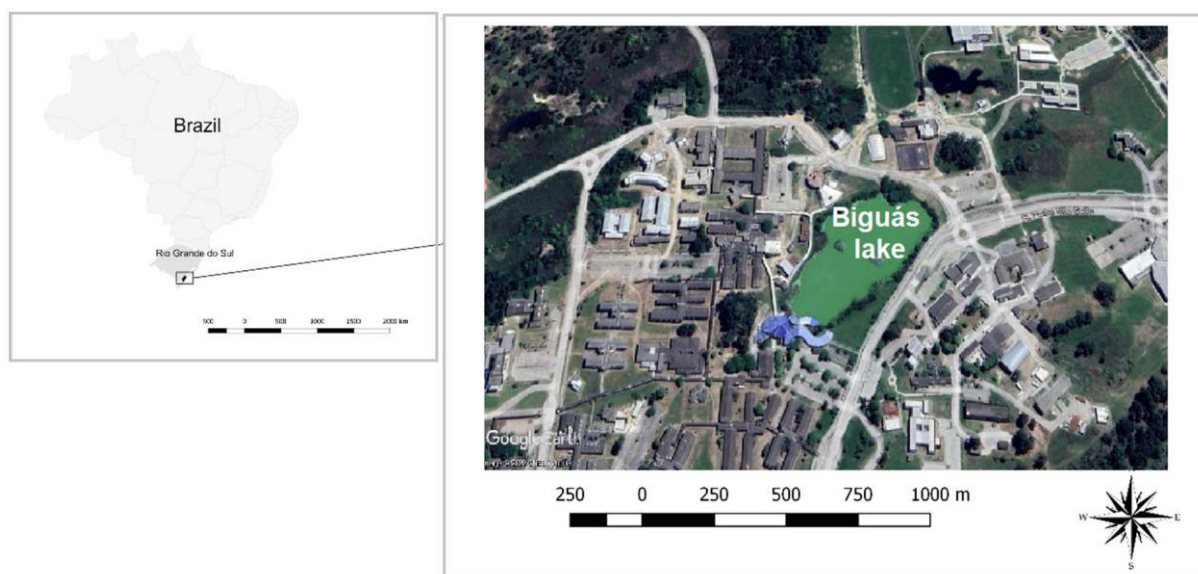


Fig. 1. Study area with the Biguás lake indication. Rio Grande. RS. Brazil. Satellite image obtained from Google Earth®.

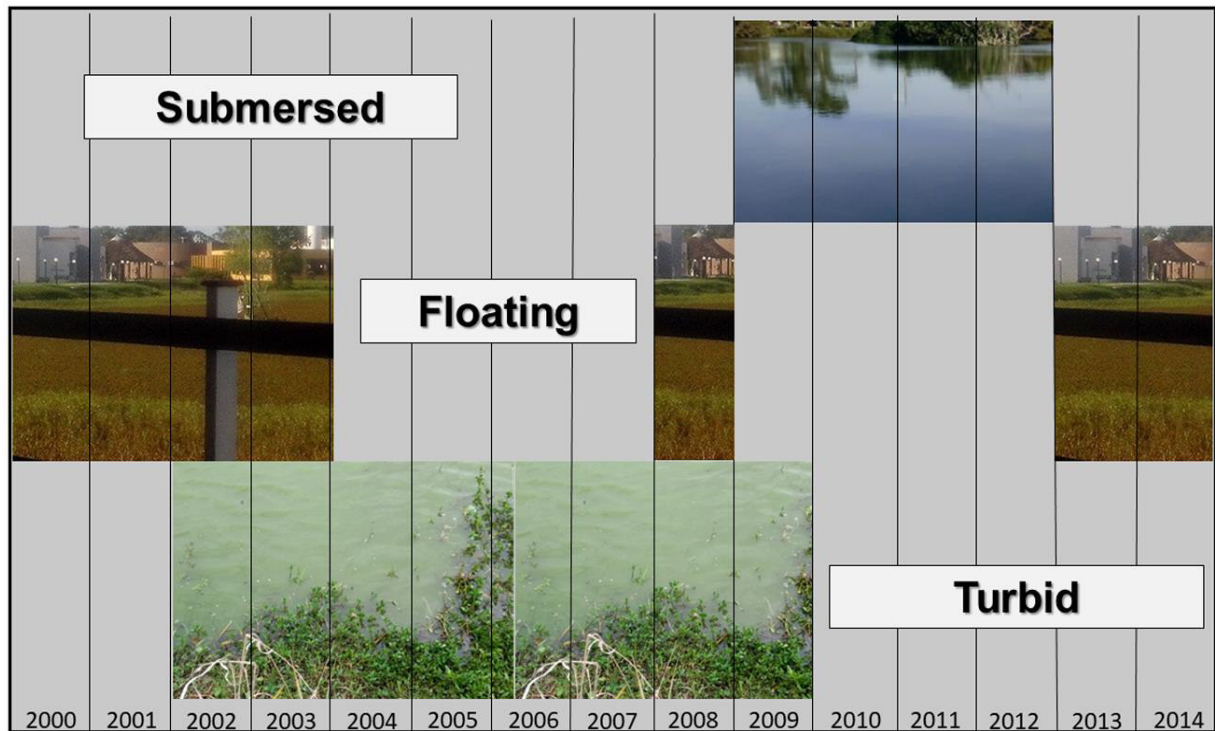


Fig. 2. Chronological changes of alternative stable states of Biguás Lake. States of clear water with a predominance of floating macrophytes and floating leaves (Floating), states of clear water with a predominance of submersed macrophytes (Submersed) and states of turbid water with a predominance of phytoplankton (Turbid), in the period of 2000 to 2014.

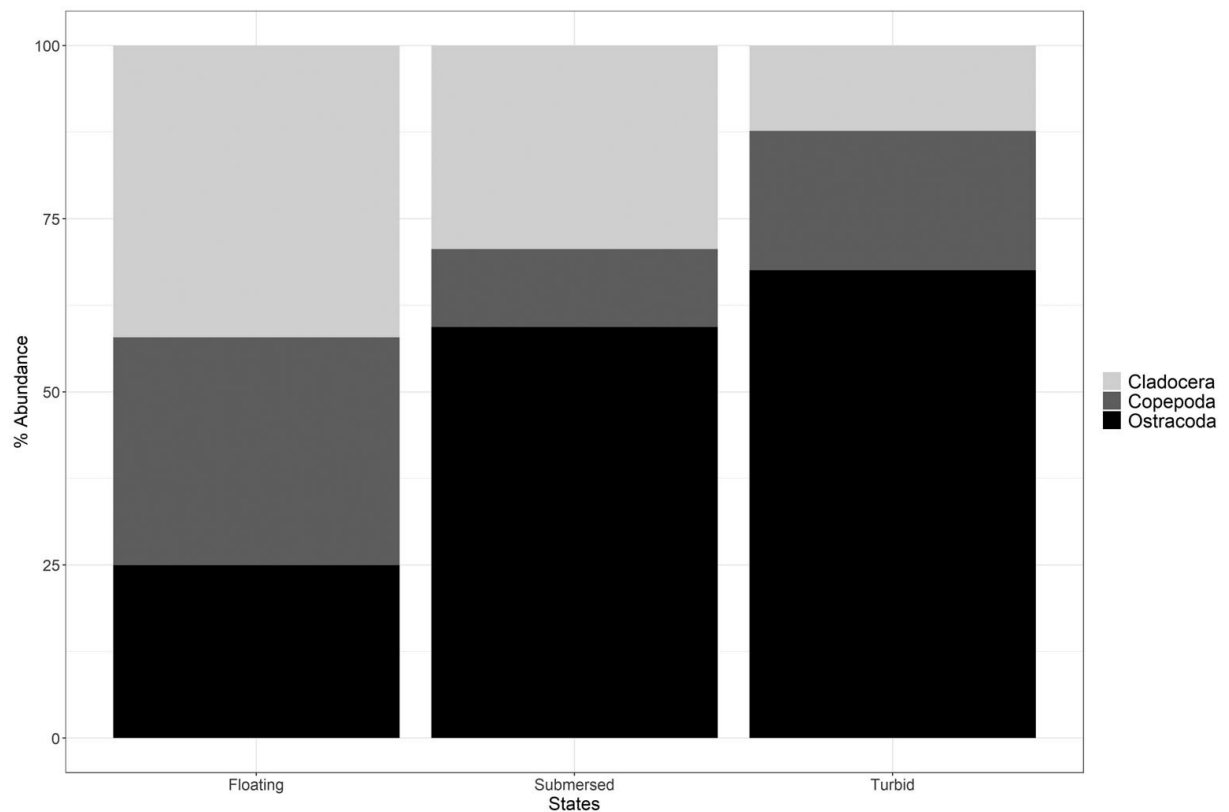


Fig. 3. Percentage of abundance for each group (Cladocera, Copepoda e Ostracoda) for alternative states, in one subtropical shallow lake (Biguás lake, Brazil) for samples collected between 2000 and 2014. States of clear water with a predominance of floating macrophytes and floating leaves (Floating), states of clear water with a predominance of submersed macrophytes (Submersed) and states of turbid water with a predominance of phytoplankton (Turbid).

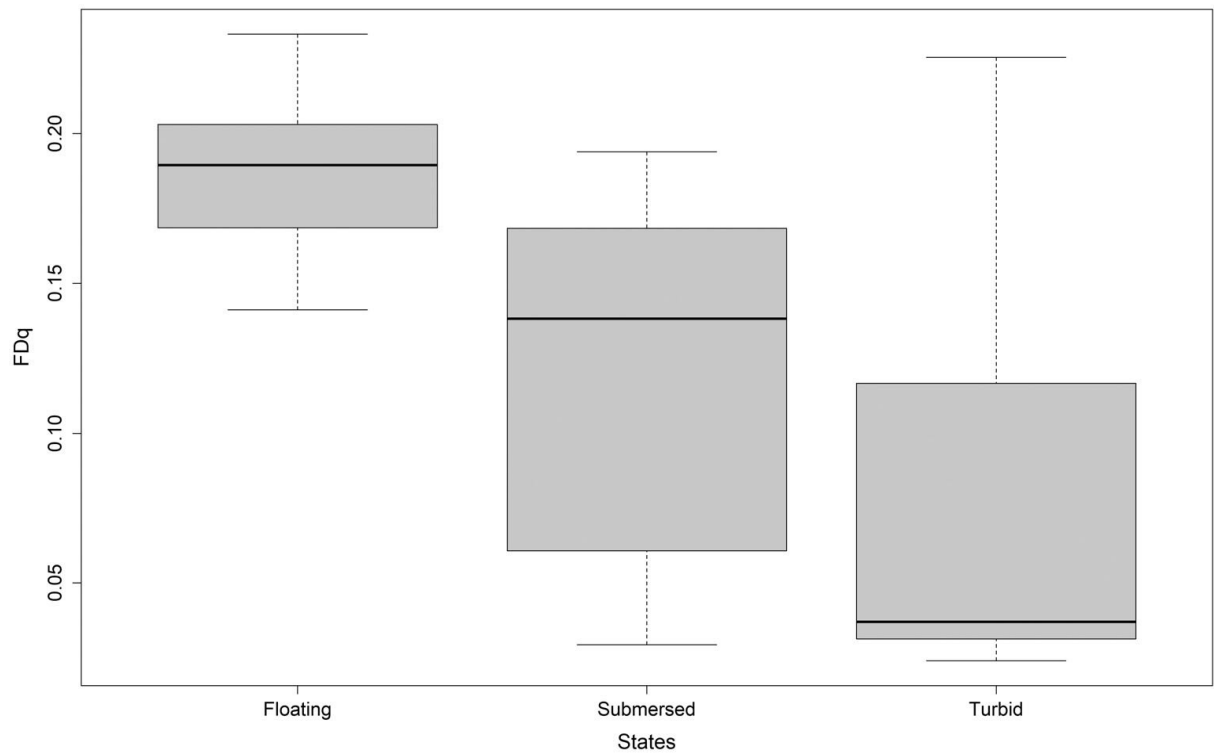


Fig. 4. Functional diversity (Rao's quadratic entropy- FD_Q) for with alternative states, in one subtropical shallow lake (Biguás lake, Brazil), for samples collected between 2000 and 2014 (Kruskal-Wallis chi-squared = 10.104; df = 2; p-value = 0.006). States of clear water with a predominance of floating macrophytes and floating leaves (Floating), states of clear water with a predominance of submersed macrophytes (Submersed) and states of turbid water with a predominance of phytoplankton (Turbid).

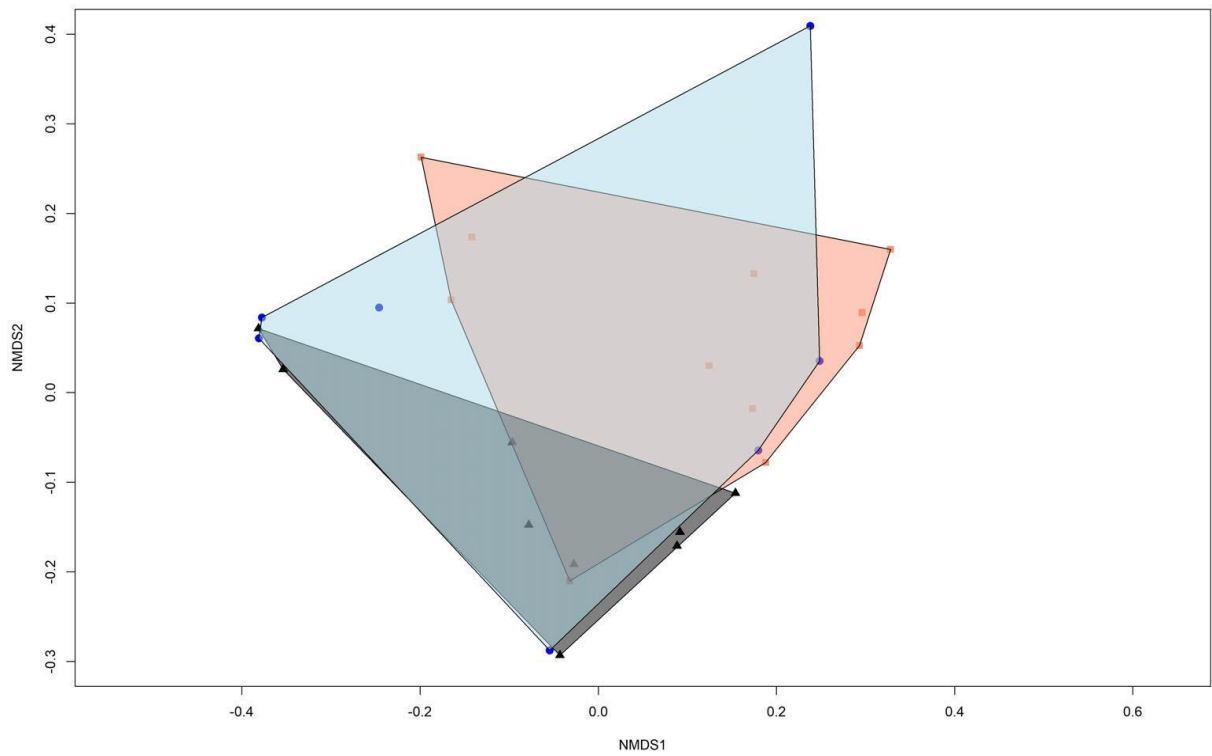


Fig. 5. Non-metric multidimensional scaling (NMDS), Bray-Curtis dissimilarity matrix. The square symbol was used for samples in clear water studies with a predominance of floating macrophytes, the triangle for samples in clear water studies with a predominance of submerged macrophytes and the circles for samples in periods of turbid water.

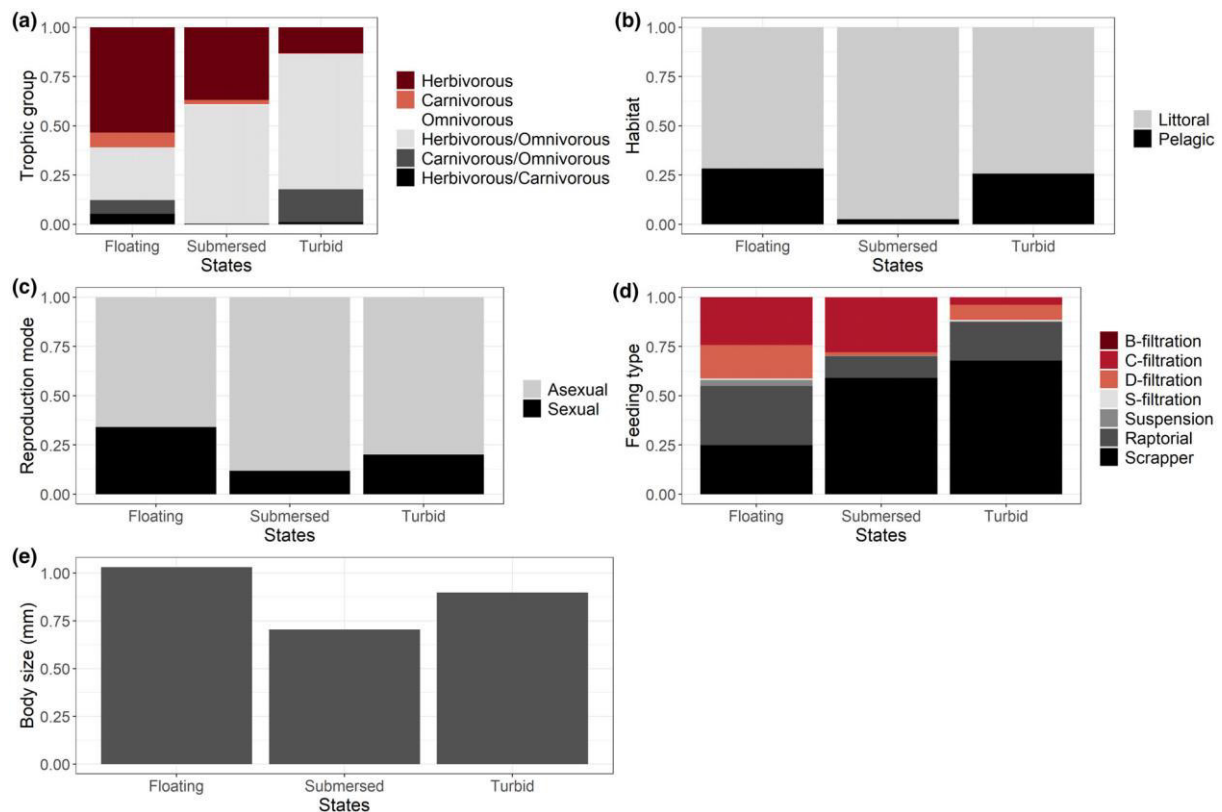


Fig. 6. Composition of functional trait in each alternative state in a shallow subtropical lake (Biguás lake, Brazil) for samples collected between 2000 and 2014. Using the weighted mean values of the Microcrustacean traits (CWM). (A) Trophic group (herbivores, carnivores, omnivores, omnivores/herbivores, omnivores/carnivores and herbivores/carnivores), (B) Habitat (littoral or pelagic), (C) Reproduction (sexual or asexual), (D) type of food (B-filtration, D-filtration, S-filtration, C-filtration, scraper, raptorial and suspensory, (E) body size (mm). States of clear water with a predominance of floating macrophytes and floating leaves (Floating), states of clear water with a predominance of submersed macrophytes (Submersed) and states of turbid water with a predominance of phytoplankton (Turbid).

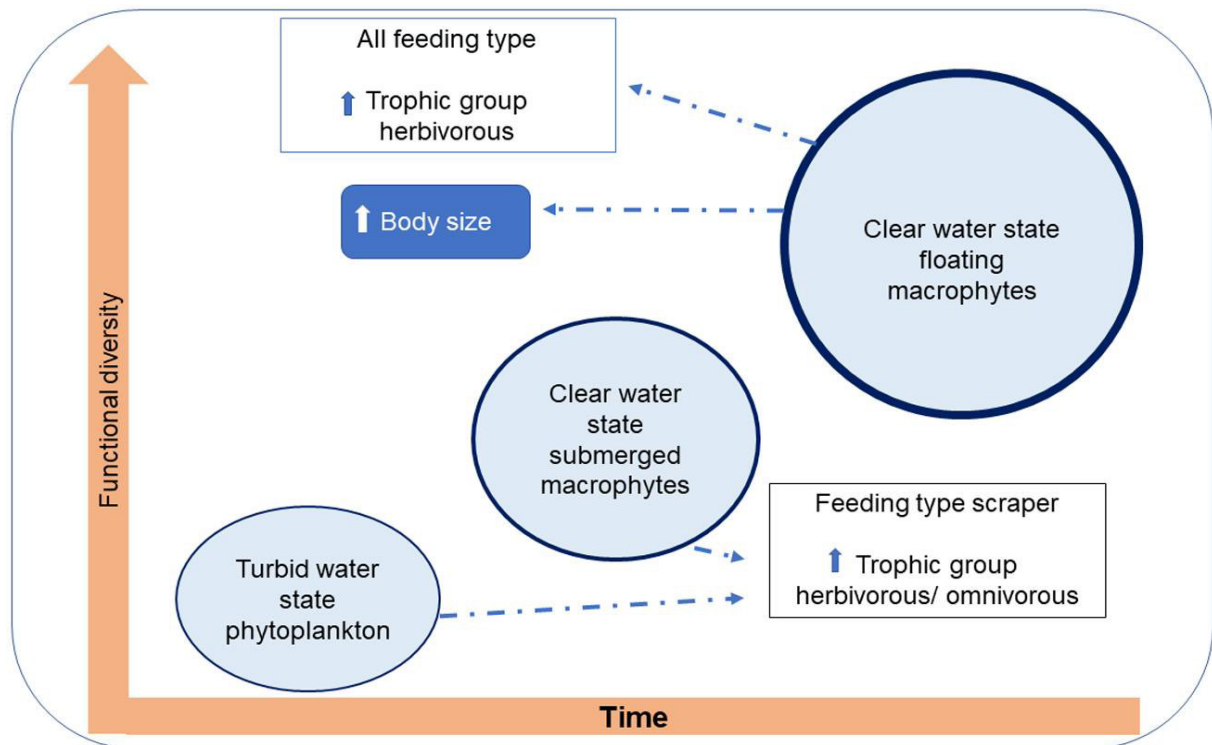


Fig. 7. Conclusion diagram of this study. The circles represented the value of functional diversity for the three alternative states. The squares represent the main results of functional traits observed for each.

Supplementary Information

Table S1: Functional traits of microcrustacean genera from a shallow subtropical lake (Biguás lake, Brazil). obtained from samples collected between 2000 and 2014.

Genera	Body size (mm)	Trophic group	Feeding type	Reproduction mode	Habitat
Cladocera					
<i>Bosmina</i>	0.34	Herbivore	B-filtration	asexual	Pelagic
<i>Alonella</i>	0.31	Herbivore	C-filtration	asexual	Littoral
<i>Alona</i>	0.35	Herbivore	C-filtration	asexual	Littoral
<i>Biapertura</i>	0.35	Herbivore	C-filtration	asexual	Littoral
<i>Celsinotum</i>	0.51	Herbivore	C-filtration	asexual	Littoral
<i>Chydorus</i>	0.41	Herbivore	C-filtration	asexual	Littoral
<i>Ephemeroporus</i>	0.3	Herbivore	C-filtration	asexual	Littoral
<i>Euryalona</i>	0.83	Herbivore	C-filtration	asexual	Littoral
<i>Leydigia</i>	0.72	Herbivore	C-filtration	asexual	Littoral
<i>Leydigiopsis</i>	0.71	Herbivore	C-filtration	asexual	Littoral
<i>Notoalona</i>	0.38	Herbivore	C-filtration	asexual	Littoral
<i>Ovalona</i>	0.36	Herbivore	C-filtration	asexual	Littoral
<i>Picripleuroxus</i>	0.33	Herbivore	C-filtration	asexual	Littoral
<i>Ceriodaphnia</i>	0.53	Herbivore	D-filtration	asexual	Pelagic
<i>Daphnia</i>	1.4	Herbivore	D-filtration	asexual	Pelagic
<i>Simocephalus</i>	1.39	Herbivore	D-filtration	asexual	Pelagic
<i>Ilyocryptus</i>	0.55	Herbivore	C-filtration	asexual	Littoral
<i>Macrothrix</i>	0.67	Herbivore	C-filtration	asexual	Littoral
<i>Moina</i>	0.6	Herbivore	D-filtration	asexual	Pelagic
<i>Diaphanosoma</i>	0.66	Herbivore	S-filtration	asexual	Pelagic
<i>Pseudosida</i>	1.4	Herbivore	S-filtration	asexual	Pelagic
Copepoda					
<i>Notodiaptomus</i>	1.27	Herbivore	Suspension	sexual	Pelagic
<i>Acanthocyclops</i>	1.63	Omnivorous	raptorial	sexual	Pelagic
<i>Ectocyclops</i>	1.3	Herbivore	raptorial	sexual	Littoral
<i>Eucyclops</i>	1.45	omnivorous/herbivore	raptorial	sexual	Littoral
<i>Macrocyclus</i>	1.75	Carnivore	raptorial	sexual	Littoral
<i>Mesocyclops</i>	1.92	omnivorous/carnivore	raptorial	sexual	Pelagic
<i>Metacyclops</i>	1.17	omnivorous/herbivore	raptorial	sexual	Pelagic
<i>Microcyclops</i>	1.13	Herbivore	raptorial	sexual	Littoral
<i>Paracyclops</i>	1.26	herbivore/carnivore	raptorial	sexual	Littoral
<i>Attheyella</i>	0.98	herbivore/carnivore	raptorial	sexual	Littoral
Ostracoda					
<i>Cardonopsis</i>	1.22	omnivorous/herbivore	scraper	sexual	Littoral
<i>Cypridopsis</i>	0.63	omnivorous/herbivore	scraper	asexual	Littoral
<i>Cyprinotus</i>	1.18	omnivorous/herbivore	scraper	asexual	Littoral
<i>Chlamidoteca</i>	2.01	omnivorous/herbivore	scraper	asexual	Littoral

<i>Cytheridella</i>	1.14	omnivorous/herbivore	scraper	sexual	Littoral
<i>Darwinula</i>	1.25	omnivorous/herbivore	scraper	asexual	Littoral
<i>Heterocypris</i>	1.07	omnivorous/herbivore	scraper	asexual	Littoral
<i>Isocypris</i>	1.05	omnivorous/herbivore	scraper	asexual	Littoral
<i>Strandesia</i>	2.05	omnivorous/herbivore	scraper	asexual	Littoral
<i>Pseudocandona</i>	1.56	omnivorous/herbivore	scraper	asexual	Littoral

Table S2: Abundance of microscutacean genera in a shallow subtropical lake (Biguás Lake, Brazil), for samples collected between 2000 and 2014. The alternative states are represented by (F) in periods of clear water state with a predominance or floating macrophytes, (S) in periods of clear water state with a predominance of submerged macrophytes and (T) turbid water state with a predominance of phytoplankton.

Genera	Samples																										
	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14	A15	A16	A17	A18	A19	A20	A21	A22	A23	A24	A25	A26	A27
Alternative states	F	F	F	F	F	F	F	T	T	T	T	T	T	F	T	S	S	S	S	S	S	S	S	S	F	F	F
<i>Bosmina</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	4	0
<i>Alonella</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	2
<i>Alona</i>	0	0	0	1	0	0	0	0	0	0	0	19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
<i>Biapertura</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0
<i>Celsinotum</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0
<i>Chydorus</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	1	0	2	107	10
<i>Ephemeroporus</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	10
<i>Euryalona</i>	0	0	0	1	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Leydigia</i>	1	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Leydigiopsis</i>	0	0	0	3	17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Notoalona</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5
<i>Ovalona</i>	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	3	8	2	0
<i>Picripleuroxus</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
<i>Ceriodaphnia</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	20	1	74
<i>Daphnia</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15	0	0
<i>Simocephalus</i>	28	0	0	3	7	0	0	2	0	7	212	1	0	2	0	24	1	5	0	0	0	1	0	3	0	6	0
<i>Ilyocryptus</i>	0	0	0	3	37	1	0	0	0	1	6	0	0	0	0	3	91	39	11	161	26	211	9	1	3	16	9
<i>Macrothrix</i>	0	0	0	0	5	0	0	16	20	0	38	0	128	0	0	0	0	2	2	1	3	47	0	0	14	9	4
<i>Moina</i>	0	27	1	0	0	0	0	0	0	0	0	74	0	0	159	0	0	0	0	0	0	0	0	0	14	17	0
<i>Diaphanosoma</i>	0	2	0	0	0	0	1	0	0	0	0	42	0	0	0	0	0	0	0	0	0	0	0	0	9	0	0
<i>Pseudosida</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0

<i>Notodiaptomus</i>	0	27	0	0	0	0	2	0	0	0	1	27	0	1	0	5	3	0	0	0	0	0	0	0	0	8	
<i>Acanthocyclops</i>	0	0	0	0	0	0	1	0	0	0	7	0	0	0	0	0	0	2	1	2	4	0	0	0	0	0	
<i>Ectocyclops</i>	0	0	1	0	0	0	0	2	0	0	8	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
<i>Eucyclops</i>	5	5	1	0	7	0	3	2	0	2	27	19	1	0	0	1	4	6	1	1	3	7	3	0	0	0	
<i>Macrocyclus</i>	0	0	0	14	78	3	0	1	0	0	16	0	0	0	0	0	0	2	2	1	0	43	0	0	0	1	
<i>Mesocyclops</i>	0	0	0	4	4	36	0	878	7	112	0	0	0	0	0	0	0	0	0	0	1	0	0	0	4	41	
<i>Metacyclops</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	
<i>Microcyclops</i>	0	0	0	0	50	0	0	16	0	0	1	5	0	1	0	1	0	0	1	1	19	125	5	0	7	31	15
<i>Paracyclops</i>	0	3	0	0	0	0	1	0	0	0	0	37	0	2	5	1	0	0	0	0	2	0	0	2	6	22	
<i>Attheyella</i>	0	0	0	0	17	0	0	0	0	0	20	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	
<i>Cardonopsis</i>	0	0	0	0	2	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
<i>Cypridopsis</i>	56	5	0	1	11	1	11	106	422	2571	910	8	7	0	0	720	493	9	7	0	40	16	0	0	4	55	3
<i>Cyprinotus</i>	0	0	0	0	13	43	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
<i>Chlamidoteca</i>	0	0	0	0	0	1	0	2	2	2	0	0	0	0	0	0	0	0	0	0	1	3	0	0	0	0	
<i>Cytheridella</i>	0	0	0	0	0	12	0	0	0	0	0	0	0	0	0	0	0	0	0	6	1	4	0	0	0	0	
<i>Darwinula</i>	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
<i>Heterocypris</i>	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
<i>Isocypris</i>	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
<i>Strandesia</i>	0	0	0	0	0	60	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
<i>Pseudocandona</i>	0	0	0	0	0	30	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	

CAPÍTULO 2

Taxonomic and functional diversity of Cladocera in two shallow subtropical lakes during a 14-year period

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Taxonomic and functional diversity of Cladocera in two shallow subtropical lakes during a 14-year period

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Abstract

Our aim was to determine the taxonomic and functional diversity of Cladocera in shallow lakes that underwent changes in their trophic states and how eutrophication influences these indices. For this, we used 62 samples of Cladocera from two subtropical shallow lakes that suffered several changes in their trophic states during a 14-year period. We calculated the trophic state index for each sample and classified them as oligotrophic, mesotrophic, and eutrophic. We also obtained taxonomic and functional diversity indices for each trophic state. In the eutrophic periods we found a lower taxonomic diversity in relation to the other trophic states, but we did not observe significant differences for functional diversity, so the changes in taxonomic diversity indices were not followed by functional diversity. We found species of smaller body size with low responses to predators in oligotrophic and mesotrophic environments, such as species of the families Chydoridae, Bosminidae and some Daphniidae. For the eutrophic periods, we observed larger body size and dominance of traits related to species of the Sididae family to be abundant in this period.

Keywords: FD_Q, Shannon diversity, Cladocera, TSI

Introduction

Aquatic ecosystems have increasingly suffered from anthropogenic pressures such as eutrophication (Hilt et al., 2017). Nutrient input has been identified as one of the main causes of the eutrophication process (Allende et al., 2019). Increased concentrations of phosphorus and nitrogen in aquatic environments lead to the growth of phytoplankton and cyanobacteria, which consequently leads to an increase in chlorophyll-*a* concentrations (Allende et al., 2019). Shallow lakes are directly impacted by the eutrophication process, mainly because these environments are characterized by low depth, thus allowing light to penetrate throughout the water column, which further favours the growth of both phytoplankton and aquatic macrophytes. Another important factor that contributes to this process is intense sediment-water interaction since this interaction causes the nutrients retained in the sediment to be released into the water, further increasing the nutrient load of the lakes (Scheffer, 1998).

In shallow lakes, Cladocera communities present great abundances. These organisms are characterized by sensitivity to changes in biotic and abiotic factors (Cardoso et al., 2008), mainly related to the trophic state, such as the variables phosphorus, nitrogen and chlorophyll-*a* (Umi et al., 2020). Increased nitrogen concentrations, for example, can be related to a decrease in zooplankton diversity (Yun et al., 2021). Trophic state is another factor that influences the species composition of Cladocera, and aquatic environments with higher trophic conditions are composed of few species generally adapted to stressful environments, resulting in lower taxonomic richness indices and greater dominance (García-Chicote et al., 2019). Umi et al., (2020) observed a dominance of the small-sized Cladocera *Ceriodaphnia cornuta* in eutrophic lakes where this species represented 74% of the sample collected, a typical dominance pattern found in these environments.

In addition to impacts on species richness, abundance and dominance, eutrophication has influenced the functional traits of zooplankton. The first compilation of functional traits of the

zooplankton community was carried out by Barnett et al. (2007), and this important tool was used to assess the functioning of aquatic ecosystems in studies in recent decades. Functional traits are of great importance since they are related to the performance of different ecological functions, such as reproduction, feeding, growth and survival (Litchman et al., 2013). Functional traits can be characterized as morphological, physiological, behavioural and life history and are directly related to the fitness of organisms (Sodré & Bozelli, 2019). Many of the traits usually used such as body size, feeding mode, motility and reproductive capacity may not be associated with fitness, but are key characteristics that affect several ecological processes (Rizo et al., 2017).

Body size is a feature that strongly influences ecological processes. Umi et al., (2020) provided an example of this, as they observed that a high eutrophication condition can select species of Cladocera with smaller body size. This is mainly due to the difficulty that larger-bodied cladocerans have to feeding on toxic filamentous cyanobacteria due to chemical or mechanical inhibition of the thoracic appendages (Sun et al., 2012). On the other hand, for smaller cladocerans, such as the species *Chydorus sphaericus*, cyanobacteria are an important food source, and these organisms can act as the main trophic link in eutrophic environments transferring carbon from cyanobacteria to higher trophic levels (Tönno et al., 2016). Besides this, Bosminids are also small cladocerans tolerant of toxic cyanobacteria and commonly found in eutrophic environments (Figuerola Sánchez et al., 2014).

Environmental variables associated with eutrophication such as phosphorus and chlorophyll-*a* have influenced functional diversity indices. Phosphorus concentrations showed negative correlation with functional diversity (Barnett et al., 2007), whereas functional uniformity (FEve) has shown a decline with increasing chlorophyll-*a* concentration (Braghin et al., 2020). The dominance of cyanobacteria in hypertrophic lakes has caused a reduction in

functional dispersion indices, as these environmental conditions only select traits of species tolerant to them (Josué et al., 2019).

Environmental changes can be better evaluated by analysing the taxonomic composition of communities combined with functional diversity indices (Martins & Albertoni, 2022). These two approaches allow us to understand different ecological processes in aquatic communities (Rizo et al., 2017). Functional richness, for example, is highly correlated with species richness (Braghin et al., 2020) since the increase in the number of species provides more chances of finding rare species, and these reflect a greater combination of different functional traits (Mouchet et al., 2010). Other functional indices such as functional divergence and functional uniformity also depend on taxonomic indices such as species richness (Villéger et al., 2008).

For aquatic environments in subtropical regions, studies on biodiversity and ecology are still scarce (Rizo et al., 2017). Consistent differences are observed in relation to the functioning of shallow lakes in temperate and subtropical regions, as the predation pressure is greater in subtropical region (Jeppesen et al., 2020). Thus, the functional traits of Cladocera in these environments are mainly related to survival, high predation rates and food availability (Rizo et al., 2017). Therefore, different patterns of taxonomic and functional diversity should be observed for the subtropical climate region. Thus, investigating how the Cladocera community is taxonomically and functionally structured in the face of trophic state changes in shallow lakes in the subtropical region fills a knowledge lacune.

The present work we studied the taxonomic and functional diversity of Cladocera in two shallow lakes that underwent changes in their trophic states over 14 years. We aim to evaluate how eutrophication influences the taxonomic and functional diversity of Cladocera and whether changes in taxonomic diversity are reflected in the functional diversity. Our first hypothesis was that we would find lower rates of taxonomic and functional diversity in eutrophic conditions. The second hypothesis was that the decrease in taxonomic diversity

would be accompanied by a decrease in functional diversity. Our third hypothesis was that in eutrophic environments we would have species with smaller body sizes and a predominance of functional traits related to species more tolerant to eutrophication.

Materials and Methods

Study Area

The study was conducted in two shallow lakes (Biguás and Polegar Lakes) located inside the campus of the Federal University of do Rio Grande – FURG (32° 04'43 "S, 52° 10'03" W) city of Rio Grande, RS, Brazil (Fig. 1). The region has a humid subtropical climate, with an average annual temperature from 17°C to 19°C and precipitation ranging from 1200 mm to 1500 mm (Alvares et al., 2013).

The campus has an urban area of about 250 ha, inserted in the Coastal Plain of Rio Grande do Sul State. Until the 1970s the area had a set of small water bodies, which were used as the city's water source. In 1978 the construction of the campus began and these environments were modified by anthropic action (Trindade et al., 2009). Currently, Biguás Lake has an area of 1.5 ha and a depth of 2 m and Polegar Lake has an area of 1 ha and a depth of 1.5 m. The Biguás lake has two artificial islands that serve as shelter and rest for several birds, but their presence leads to a high contribution of organic matter to the lake. In this way, it increases the nutrient load and favors the process of eutrophication and microalgae blooms (Trindade et al., 2009). In the period of this study (14 years) the lakes underwent several changes in their trophic states; Biguás Lake varied between oligotrophic, mesotrophic and eutrophic states, while Polegar Lake varied from oligotrophic to mesotrophic states (Marinho et al., 2009; Albertoni et al., 2014).

Date Collection

Sixty-two samples (36 Biguás Lake and 26 Polegar Lake) were collected from October 2000 to March 2014 through environmental monitoring carried out by the Limnology Laboratory (ICB-FURG). Sampling was conducted at three random points, forming a composite sample. Aquatic plants were removed using a cylindrical collector with an area of 0.07 m², taken to the laboratory and washed over a 250 µm mesh net. Retained organisms were fixed in 80% alcohol, stained with Bengal rose and stored in the collection of Subtropical Limnic Invertebrates (ICB-FURG). The Cladocera were identified to the species level when possible using specific sources (Elmoor-Loureiro, 1997; Gazulha, 2012; Sousa & Loureiro, 2019).

The limnological variables are also from the monitoring carried out by the Limnology laboratory (ICB-FURG). The methods of Baumgarten et al. (1996) and Valderrama (1981) were used for chlorophyll-*a* and total phosphorus, and the method from Mackereth et al. (1978) was used for total nitrogen. The water temperature, pH, electrical conductivity, and dissolved oxygen variables were obtained using probes. The trophic state index (TSI) was calculated according to (Cunha et al., 2013) using the following equations:

$$TSI = \frac{TSI(TP) + TSI(Chla)}{2} \quad \text{where} \quad TSI(TP) = 10 \left[6 - \frac{(-0.27637 \ln TP + 1.329766)}{\ln 2} \right] \quad \text{and}$$

$$TSI(Chla) = 10 \left[6 - \left(\frac{0.2512 \ln Chla + 0.842257}{\ln 2} \right) \right].$$

To determine the trophic index, we considered oligotrophic those with TSI less than 53.1 to be oligotrophic, greater than 53.2 and less than 55.7 to be mesotrophic and greater than 55.8 to be eutrophic (Table S1).

Functional Traits

To calculate functional diversity, nine functional traits were used, one was a numerical trait (body size) and eight were categorical traits (feeding type, trophic group, habitat, presence of ocelli, carapace colour, presence of helmet, escape response to predators and number of eggs).

Body size was measured at the time of species identification using a microscope with a measuring eyepiece. Feeding type was classified into categories related to the filtration mode of each family (Barnett et al., 2007). Daphnids and Moinids were classified as D-filtration as they use limbs three and four to perform the filtration, Sidids were classified as S-filtration, as they use their first five limbs in filtration, Bosminids were classified as B-filtration as they use active swimming while filtering with less developed thorax limbs, Chydorids, Macrothricids were classified as C-filtration, as they use their second limb to scrape food from substrates and Ilyocriptids were classified as I-filtration, as its members are designed to collect and filter algae and debris (Rizo et al., 2017). Trophic groups were classified as herbivore or herbivore-detritivore. Habitats were classified as littoral or pelagic, and some morphological features evaluated such as with or without ocellus, transparent or with colour and with or without a helmet. The escape responses to predators were classified as (1) pausing and jumping, (2) rapid swimming and (3) not moving. The number of eggs was used as a reproductive trait as all Cladocera under normal conditions reproduce parthenogenetically (Table S2).

Data Analysis

The calculated taxonomic diversity indices were Shannon-H, Pielou Equability, Dominance, richness, and abundance. These indices were tested to verify the differences between the trophic states (oligotrophic, mesotrophic, and eutrophic) using a one-way analysis of variance (ANOVA) with verification of assumptions and subsequent Tukey test and demonstrate this result through a boxplot. The compositions of species in trophic states

were verified by non-metric multidimensional scaling (NMDS) analyses using the Euclidean distance matrix.

To calculate functional diversity indices for Cladocera, we used the Gower dissimilarity method modified by (Pavoine et al., 2009), as it accommodates mixed variables, such as numeric, binary and ordinal variables. We used functional richness, functional uniformity and the functional diversity index measured by Rao's quadratic entropy (FDQ; (Botta-Dukát, 2005) using the Distance-Based Functional Diversity Indices (dbFD) function of the FD package (Laliberté et al., 2014) in the R program (R Core Team, 2017). The FDQ indices were based on the Simpson's diversity index because incorporates species' abundances and the functional differences between them and weights the mean functional distance between two random individuals (Botta-Dukát, 2005). The functional indices, as they did not meet the assumptions of the analysis of variance, were tested for the differences between the trophic states through Kruskal-Wallis analyses. To verify the compositions of functional traits in each trophic state index (TSI), we obtained the weighted mean values of the microcrustacean traits (CWM) through the funtcomp function (Lavorel et al., 2008) of the FD package (Laliberté et al., 2014). With the CWM data we performed the non-metric multidimensional scaling (NMDS) analysis using the Euclidean distance matrix. Finally, the groupings were tested with permutational analyses of variance (PERMANOVA) and results of each functional trait for the trophic states (oligotrophic, mesotrophic, and eutrophic) were presented with bar graphs.

Results

Over time, the shallow lakes studied have undergone several changes in environmental variables. In the Polegar Lake the water temperature varied between 19°C and 29 °C, dissolved oxygen varied from 2.70 to 14.00 mg.L⁻¹, pH from 6.25 to 10.37, electrical conductivity from 41.50 to 180.0 µS, chlorophyll-*a* from 0.63 to 26.30 ug/L⁻¹, total

phosphorus from 0.01 to 0.06 mg.L⁻¹ and total nitrogen from 0.18 to 1.97 mg.L⁻¹. The trophic state index (TSI) ranged from 47.75 to 53.87, thus we obtained 23 samples classified as oligotrophic state and three samples as mesotrophic state. For Biguás Lake, water temperature ranged from 19°C to 31°C, dissolved oxygen ranged from 1.70 to 12.84 mg.L⁻¹, pH from 5.54 to 10.77, electrical conductivity from 128.50 to 334.0 µS, chlorophyll-*a* 4.13 to 206.59 µg/L⁻¹, total phosphorus from 0.02 to 0.79 mg.L⁻¹ and total nitrogen from 0.11 to 5.24 mg.L⁻¹. The trophic state index ranged from 51.41 to 59.75, resulting in 5 samples classified as oligotrophic, 16 mesotrophic and 15 eutrophic (Table S1).

We found 41 species of Cladocera in the 62 samples from Biguás and Polegar lakes over a 14-year period, with a total of 20 species found in the Polegar lake samples and 22 species in the Biguás lake samples (Table S3). In the samples collected from oligotrophic and mesotrophic states, we found high species richness, with 33 and 29 species of Cladocera, and low abundances with a total of 2,596 and 2,229 individuals, respectively (Table 1). We also observed high equitability and low dominance in the samples from these two states. Conversely, to the eutrophic state, there were 15 species of Cladocera, a high abundance, totalling 14,491 individuals, low equitability and high dominance. The results further showed significant differences between oligotrophic and eutrophic states regarding the Shannon-H diversity index ($F=4.391$, $p=0.018$), and for this index the Tukey test showed a difference between samples. For species richness we also observed a significant difference ($F=5.34$, $p=0.007$), with the Tukey test showing differences between oligotrophic and eutrophic states, as well as mesotrophic and eutrophic (Fig. 2). The NMDS showed that the trophic states differ in their compositions of species, with significant clusters ($R^2=0.07$; $p\text{-value}=0.0002$) (Fig. 3). The eutrophic environments occupy a smaller space in the ordering when compared to the other trophic states.

The functional diversity indices did not show significant differences between trophic states, but we observed higher values of FDQ, FRic and FEve for samples collected in oligotrophic states, followed by mesotrophic and lower values for eutrophic states (Table 2). The NMDS showed that with significant clusters ($R^2=0.09$; $p\text{-value}=0.002$) we can observe that the oligotrophic and mesotrophic states occupy a greater amplitude in the ordering, however some characteristics overlap between the three trophic states (Fig. 4). The eutrophic, oligotrophic and mesotrophic environments presented traits that permeated each other and small differences of trait compositions between them. The weighted means of the functional traits of the community-level (CWM) for each trophic state showed that eutrophic states have Cladocera of large body size (Fig. 5a), but the differences of body sizes between states were too small.

The oligotrophic and mesotrophic states showed a more uniform distribution of the number of eggs per clutch than the eutrophic state; species with 12 eggs per clutch represented 82% of the samples from the eutrophic state (Fig. 5b). This trait is related to species of the Macrothricidae and Sididae families, which are abundant in this state. For the mesotrophic state, we observed a greater representation of species that lay two eggs per clutch (47%), a characteristic trait of species of the Chydoridae family, followed by 11 eggs per clutch (26%), a trait of *Ilyocryptus spinifer*. As for the oligotrophic state samples, 15 (35%) and 10 (32%) eggs per clutch were more abundant, which is related to species of the Bosminidae and Moinidae families, respectively.

The predator escape response was clearly distinct between the eutrophic state and the oligotrophic and mesotrophic states, as pause and jump responses were 80% for the eutrophic environments and no move was 63% for the oligotrophic and 87% for mesotrophic environments (Fig. 5c). The dominant trophic group in the mesotrophic state samples was herbivores/detritivores and herbivores for the other trophic states (Fig. 5d).

The helmet structure was not found in the species comprising the eutrophic states, although the oligotrophic and mesotrophic states were composed of the species *Ceriodaphnia cornuta* and *Daphnia laevis*, which have helmet structures (Fig. 6a). The presence of an ocellus was predominant in samples from the mesotrophic state with 91% (Fig. 6b). The feeding types were better distributed in the samples of the oligotrophic and mesotrophic states, with greater contribution of C-filtration and I-filtration for mesotrophic and B-filtration and D-filtration for oligotrophic (Fig. 6c). As for the eutrophic state, we observed a dominance of the C-filtration feeding type. We observed that the eutrophic and oligotrophic samples presented a greater number of transparent species, while for the mesotrophic samples we obtained a distribution almost in the same proportion for transparent and coloured species (Fig. 6d). The same pattern was observed for the habitats of the species, with almost equal distributions of pelagic and littoral species in the mesotrophic state sample (Fig. 6e). For oligotrophic and eutrophic, we observed a dominance of pelagic species with 80% and 93%, respectively.

Discussion

We found lower taxonomic diversities of Cladocera and high dominance in samples collected in periods of eutrophic states. This decrease in taxonomic diversity and increase of dominance was expected and this relationship has been reported in the literature, such as studies of (García-Chicote et al., 2019; Yun et al., 2021). As for the functional diversity indices, contrary to expectations, they did not present significant differences between the trophic states. The relationship between functional diversity and the trophic state of environments has been demonstrated in several studies, where the functional diversity indices showed a decrease in eutrophic environments (Josué et al., 2019; Braghin et al., 2020). However, in our study, we did not observe this relationship, thus leading us to partially accept our first hypothesis.

The decrease in taxonomic diversity in eutrophic state environments was not accompanied by a decrease in functional diversity, so we rejected our second hypothesis. This loss of species not being accompanied by a loss of functional diversity may be related to the presence of species that perform similar functions in the lakes, where a local extinction of species does not generate a loss of characteristics (Mayfield et al., 2010). In addition, environmental gradient are important to determine this relationship between taxonomic and functional diversity (Cadotte et al., 2011).

Contrasting responses between functional and taxonomic diversity indices were observed in a study of phytoplankton and zooplankton across an environmental gradient and human impacts (Stamenkovic et al., 2022). Contrary to what was observed in our study, changes observed in the functional characteristics of zooplankton, without impacting the taxonomic diversity indices, prolonged exposure to cyanobacterial bloom (Krztoń et al., 2019). In agreement with (Stamenkovic et al., 2022), we also suggest the use of taxonomic and functional diversity metrics to evaluate aquatic environments in the face of environmental changes, since the diversity indices of functional diversity provide additional information to the classic measures of taxonomic diversity (Krztoń et al., 2019).

In relation to the functional characteristics, we observed species with larger body sizes in samples of eutrophic states and smaller body size in oligotrophic and mesotrophic periods, thus partially refuting our third hypothesis, unlike what was found in a recent study where eutrophic lakes had smaller species (Umi et al., 2020). Our result may be related to factors such as the presence of macrophytes. Studies report the association of smaller species with aquatic macrophytes, mainly due to greater availability and variety of food (Deosti et al., 2021). High concentrations of phosphorus, as observed in eutrophic periods, are negatively correlated with aquatic macrophytes (Gianuca et al., 2017). Thus, species of smaller body

size, such as the Chydoridae family, which scrape the leaves of aquatic macrophytes to obtain food, will be absent in periods of eutrophic state, with high concentrations of phosphorus and an absence of aquatic macrophytes (Gianuca et al., 2017). The presence of smaller species in oligotrophic and mesotrophic environments can be explained by the presence of macrophytes; our results show a great contribution of the C-filtration feeding type in mesotrophic environments, a trait of the Chydoridae family.

Cladoceran body size can also be regulated by pressure from predators (Wang et al., 2007). The presence of fish is also related to the occurrence of smaller species in periods of oligotrophic and mesotrophic state since in subtropical lakes the permanence of larger species is associated with the absence of predation by fish (Iglesias et al., 2011). Martins et al. (2019) found an association of smaller species, such as the Cladocera of the family Chydoridae, with more preserved environments. The authors suggest that more structured communities occur in these environments, with greater diversity of aquatic macrophytes and the presence of predators such as invertebrates and fish (Martins et al., 2019).

In periods of eutrophic state, we found a high abundance of species of the Sididae family. The abundances of these species are directly related to the predominance of functional traits: greater body size, S-filtration feeding type, herbivore trophic group, pelagic habit, absence of ocellus, transparent colour, absence of helmet, twelve eggs per clutch and pausing and jumping due to predators. The species of this family are associated with environments with poor water quality, such as high values of turbidity and trophic state index (Martins et al., 2019). The *Diaphanossoma spinulosum* observed in these samples, for example, may be related to the great tolerance capacity that these organisms have to different trophic states. According Rizo et al. (2017) the genus *Diaphanossoma* has a high capacity to tolerate

eutrophic environments in subtropical climate regions, and still has an important role in the top-down control of algae.

For oligotrophic and mesotrophic environments, we observed a wide distribution of traits, mainly in oligotrophic periods, we found a wide distribution of feeding types, which may be associated with the great availability of food for aquatic macrophytes present in this period (Deosti et al., 2021). For periods of mesotrophic state, we observed a greater contribution of the C-filtration and I-filtration feeding types, which is related to the presence of species from the Chydoridae, Macrothricidae and Ilyocryptidae families, organisms that characteristically consume the detritus present in the leaves of aquatic macrophytes or in the sediment (Rizo et al., 2017). Other relevant traits observed for the mesotrophic state are, for example, two eggs per clutch, herbivore-detritivore trophic group, non-moving response to predators and the presence of ocellus, characteristic traits of the Chydoridae family. We also observed an equal contribution from the pelagic and the littoral habitats, as this family has species that inhabit both types of habitats.

In lakes of subtropical regions, high rates of predation are observed (Jeppesen et al., 2020). Therefore, an important trait to be evaluated is the escape response of Cladocera to predation. We observed a low escape response to predation in periods of oligotrophic and mesotrophic states, thus reflecting a greater exposure to predators, contrary to what was observed in eutrophic periods, in which organisms responded to predation by pausing and jumping. Although organisms did not have an escape response to predators, in mesotrophic periods they have structures to protect themselves from predation, such as the presence of an ocellus, presence of a helmet and a transparent body. As for oligotrophic periods, we observed species that have a greater investment in egg production to compensate for their greater chance of predation (Rizo et al., 2017).

Conclusion

We conclude that eutrophication has a negative impact on Cladocera taxonomic diversity and species richness. As for functional diversity, we did not observe an influence on the trophic state indices. We observed that the variation in taxonomic diversity indices is not directly correlated to the variation in functional diversity indices. The NMDS analysis makes it clear that we have a species distinction between the trophic states, but an overlap of functional traits between these states. In environments with a eutrophic state, we found individuals with larger body size, dominance of the S-filter feeding type, twelve eggs per clutch, absence of an ocellus, pelagic habits and transparent colour. These characteristics are directly related to the high abundance of the *Diaphanosoma spinulosum* species found in this period. In the mesotrophic and oligotrophic environments, however, we found individuals of smaller body size, with the presence of macrophytes and predators being one of the main causes of the smaller body size. In these states, we also observed a low response to predator escape, but these organisms compensate for this low response through other functional traits, such as the presence of an ocellus, transparent colour, presence of a helmet and a greater number of eggs per clutch. We emphasize that the functional traits that were most relevant in the distinction between trophic conditions were feeding-types, eggs per clutch and escape from predation. We conclude by emphasizing the importance of using the two diversity indices (functional and taxonomic), as these indices often respond differently to environmental disturbances.

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Availability of data and materials

The authors declare that all data supporting the findings of this study are available within the article and its supplementary information files.

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Declaration

Conflict of interest

The authors do not have any conflict of interest to declare.

References

- Albertoni, E. F., C. Palma-Silva, C. R. T. Trindade, & L. M. Furlanetto, 2014. Field evidence of the influence of aquatic macrophytes on water quality in a shallow eutrophic lake over a 13-year period. *Acta Limnologica Brasiliensia*. 26: 176–185.
- Allende, L., M. Fontanarrosa, A. Murno, & R. Sinistro, 2019. Phytoplankton functional group classifications as a tool for biomonitoring shallow lakes: a case study. *Knowledge & Management of Aquatic Ecosystems* 420: 5.
- Alvares, C., J. Stape, P. Sentelhas, J. Goncalves, & G. Sparovek, 2013. Koppen's climate classification map for Brazil. *Meteorologische Zeitschrift* 22: 711–728.
- Barnett, A., K. Finlay, & B. Beisner, 2007. Functional diversity of crustacean zooplankton communities: towards a trait-based classification. *Freshwater Biology* 52: 796–813.

Baumgarten, M., J. Rocha, & L. Niencheski, 1996. Manual de análises em oceanografia química. Editora da FURG, Rio Grande.

Botta-Dukát, Z., 2005. Rao's quadratic entropy as a measure of functional diversity based on multiple traits. *Journal of Vegetation Science* 16: 533–540.

Braghin, L., J. Dias, N. Simoes, & C. Bonecker, 2020. Food availability, depth, and turbidity drive zooplankton functional diversity over time in a Neotropical floodplain. *Aquatic Sciences* 83: 10.

Cadotte, M. W., K. Carscadden, & N. Mirotchnick, 2011. Beyond species: functional diversity and the maintenance of ecological processes and services. *Journal of Applied Ecology* 48: 1079–1087.

Cardoso, L. S., J. D. Ramos, & H. O. de O. Mello, 2008. Composition, density and abundance of populations of cladocera, copepoda and rotífera of area of permanent protection of Uberabinha river. *Em Extensão* 7: 95–106.

Cunha, D., M. Calijuri, & M. Lamparelli, 2013. A Trophic State Index for Tropical/subtropical Reservoirs (TSI_{tsr}). *Ecological Engineering* 60: 126–134.

Deosti, S., F. de Fátima Bomfim, F. M. Lansac-Tôha, B. A. Quirino, C. C. Bonecker, & F. A. Lansac-Tôha, 2021. Zooplankton taxonomic and functional structure is determined by macrophytes and fish predation in a Neotropical river. *Hydrobiologia* 848: 1475–1490.

Elmoor-Loureiro, L., 1997. Manual de Identificação de Cladóceros Límnicos do Brasil. Editora Universa - UCB, Brasília.

Figuerola Sánchez, M., N. Sarma, & S. s. s Sarma, 2014. Zooplankton community structure in the presence of low levels of cyanotoxins: A case study in a high altitude tropical reservoir (Valle de Bravo, Mexico). *Journal of Limnology* 73: 157–166.

García-Chicote, J., X. Armengol, & C. Rojo, 2019. Zooplankton species as indicators of trophic state in reservoirs from Mediterranean river basins. *Inland Waters Taylor & Francis* 9: 113–123.

Gazulha, V., 2012. Zooplâncton límico: manual ilustrado. Technical Books, Rio de Janeiro.

Gianuca, A., J. Engelen, K. Brans, F. Hanashiro, M. Vanhamel, E. van den Berg, C. Souffreau, & L. De Meester, 2017. Taxonomic, functional and phylogenetic metacommunity ecology of cladoceran zooplankton along urbanization gradients. *Ecography* 40:183–194.

Hilt, S., S. Brothers, E. Jeppesen, A. J. Veraart, & S. Kosten, 2017. Translating Regime Shifts in Shallow Lakes into Changes in Ecosystem Functions and Services. *BioScience* 67: 928–936.

Iglesias, C., N. Mazzeo, M. Meerhoff, G. Lacerot, J. M. Clemente, F. Scasso, C. Kruk, G. Goyenola, J. García-Alonso, S. L. Amsinck, J. C. Paggi, S. José de Paggi, & E. Jeppesen, 2011. High predation is of key importance for dominance of small-bodied zooplankton in warm shallow lakes: evidence from lakes, fish exclosures and surface sediments. *Hydrobiologia* 667: 133–147.

Jeppesen, E., D. Canfield, R. Bachmann, M. Sondergaard, K. Havens, L. Johansson, T. Lauridsen, S. Tserenpil, R. Rutter, G. Warren, G. Ji, & M. Hoyer, 2020. Toward predicting climate change effects on lakes: a comparison of 1656 shallow lakes from Florida and Denmark reveals substantial differences in nutrient dynamics, metabolism, trophic structure, and top-down control. *Inland Waters* 10: 197–211.

- Josué, I., S. Cardoso, M. Miranda, M. Mucci, K. Ger, F. Roland, & M. Marinho, 2019. Cyanobacteria dominance drives zooplankton functional dispersion. *Hydrobiologia* 831: 149–161.
- Krztoń, W., J. Kosiba, A. Pocięcha, & E. Wilk-Wozniak, 2019. The effect of cyanobacterial blooms on bio- and functional diversity of zooplankton communities. *Biodiversity and Conservation* 28: 1815–1835.
- Laliberté, E., P. Legendre, & B. Shipley, 2014. FD: Measuring functional diversity from multiple traits, and other tools for functional ecology. R package version 1: 0–12.
- Lavorel, S., K. Grigulis, S. McIntyre, N. S. G. Williams, D. Garden, J. Dorrough, S. Berman, F. Quétier, A. Thébault, & A. Bonis, 2008. Assessing functional diversity in the field – methodology matters! *Functional Ecology* 22: 134–147.
- Litchman, E., M. D. Ohman, & T. Kiørboe, 2013. Trait-based approaches to zooplankton communities. *Journal of Plankton Research* 35: 473–484.
- Mackereth, J., J. Heron, & J. F. Talling, 1978. Water analysis: some revised methods for limnologists. Freshwater Biological Association, Cumbria.
- Marinho, C., C. Palma-Silva, E. Albertoni, C. Trindade, & F. Esteves, 2009. Seasonal dynamics of methane in the water column of two subtropical lakes differing in trophic status. *Brazilian journal of biology* 69: 281–287.
- Martins, K. P., & E. F. Albertoni, 2022. Alternance of alternative stable states influence the functional diversity of microcrustaceans in a shallow subtropical lake. *Austral Ecology* 47: 1016–1028.

- Martins, K. P., M. G. da S. Bandeira, C. Palma-Silva, & E. F. Albertoni, 2019. Microcrustacean metacommunities in urban temporary ponds. *Aquatic Sciences* 81: 56.
- Mayfield, M. M., S. P. Bonser, J. W. Morgan, I. Aubin, S. McNamara, & P. A. Vesk, 2010. What does species richness tell us about functional trait diversity? Predictions and evidence for responses of species and functional trait diversity to land-use change. *Global Ecology and Biogeography* 19: 423–431.
- Mouchet, M. A., S. Villéger, N. W. H. Mason, & D. Mouillot, 2010. Functional diversity measures: an overview of their redundancy and their ability to discriminate community assembly rules. *Functional Ecology* 24: 867–876.
- Pavoine, S., J. Vallet, A.-B. Dufour, S. Gachet, & H. Daniel, 2009. On the challenge of treating various types of variables: Application for improving the measurement of functional diversity. *Oikos* 118: 391–402.
- R Core Team, 2017. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna.
- Rizo, E. Z. C., Y. Gu, R. D. S. Papa, H. J. Dumont, & B.-P. Han, 2017. Identifying functional groups and ecological roles of tropical and subtropical freshwater Cladocera in Asia. *Hydrobiologia* 799: 83–99.
- Scheffer, M., 1998. Ecology of shallow lakes. Chapman and Hall, London.
- Sodré, E. de O., & R. L. Bozelli, 2019. How planktonic microcrustaceans respond to environment and affect ecosystem: a functional trait perspective. *International Aquatic Research* 11: 207–223.

Sousa, F. D., & L. Loureiro, 2019. Identification key for the Brazilian genera and species of Aloninae (Crustacea, Branchiopoda, Anomopoda, Chydoridae). *Papéis Avulsos de Zoologia* 59: e20195924.

Stamenkovic, O., M. Piperac, D. Cerba, D. Milosevic, A. Ostojic, N. Dordevic, S. Simic, D. Cvijanovic, & O. Buzhdygan, 2022. Taxonomic and functional aspects of diversity and composition of plankton communities in shallow lentic ecosystems along the human impact and environmental gradients. *Aquatic Sciences* 84: 57.

Sun, X., M. Tao, B. Qin, M. Qi, Y. Niu, J. Zhang, Z. Ma, & P. Xie, 2012. Large-scale field evidence on the enhancement of small-sized cladocerans by *Microcystis* blooms in Lake Taihu, China. *Journal of Plankton Research* 34: 853–863.

Tönno, I., H. Agasild, T. Kõiv, R. Freiberg, P. Nõges, & T. Nøges, 2016. Algal Diet of Small-Bodied Crustacean Zooplankton in a Cyanobacteria-Dominated Eutrophic Lake. *PloS one* 11: e0154526.

Trindade, C., L. Furlanetto, & C. Palma-Silva, 2009. Nycthemeral cycles and seasonal variation of limnological factors of a subtropical shallow lake (Rio Grande, RS, Brazil). *Acta Limnologica Brasiliensia* 21: 35–44.

Umi, W. A., F. M. Yusoff, A. Z. Aris, Z. Sharip, & A. Y. Sinev, 2020. Planktonic Microcrustacean Community Structure Varies with Trophic Status and Environmental Variables in Tropical Shallow Lakes in Malaysia. *Diversity* 12: 322.

Valderrama, J. C., 1981. The simultaneous analysis of total nitrogen and total phosphorus in natural waters. *Marine Chemistry* 10: 109–122.

Villéger, S., N. Mason, & D. Mouillot, 2008. New multidimensional functional diversity indices for a multifaced framework in functional ecology. *Ecology* 89: 2290–2301.

Wang, S., P. Xie, S. Wu, & H. Wang, 2007. Crustacean zooplankton size structure in aquaculture lakes: Is larger size structure always associated with higher grazing pressure?. *Hydrobiologia* 575: 203–209.

Yun, L., R. Wang, S. Haojie, J. Wang, P. Xie, & F. Chen, 2021. Eutrophication and predation mediate zooplankton diversity and network structure. *Limnology and Oceanography* 67: S133–S145.

Tables

Table 1: Taxonomic indices of each trophic states. Average values of species richness, abundance, Shannon index, Equitability and Dominance index.

Trophic state	Richness (N species)	Abundance	Shannon-H	Equitability-J	Dominance-D
Eutrophic	15	14497	0.79	0.29	0.71
Mesotrophic	29	2229	2.29	0.67	0.32
Oligotrophic	33	2596	1.99	0.57	0.43

Table 2: Functional diversity index of each trophic state. Average values of functional richness, Rao's quadratic entropy and functional uniformity.

Trophic state	Fric	FDQ	FEve
Eutrophic	0.71	0.86	2.39
Mesotrophic	1.14	1.59	7.05
Oligotrophic	2.75	2.69	11.39

Figures

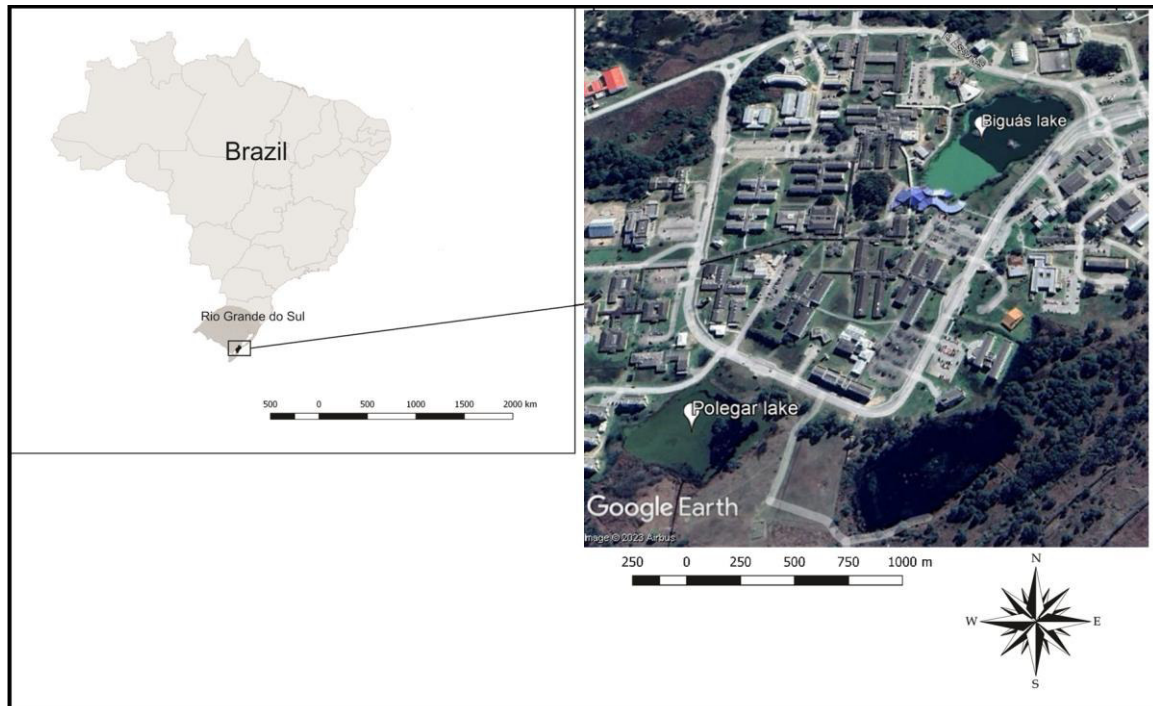


Fig. 1 Study area with the Biguás and Polegar lake indication. Rio Grande. RS. Brazil. Satellite image obtained from Google Earth®.

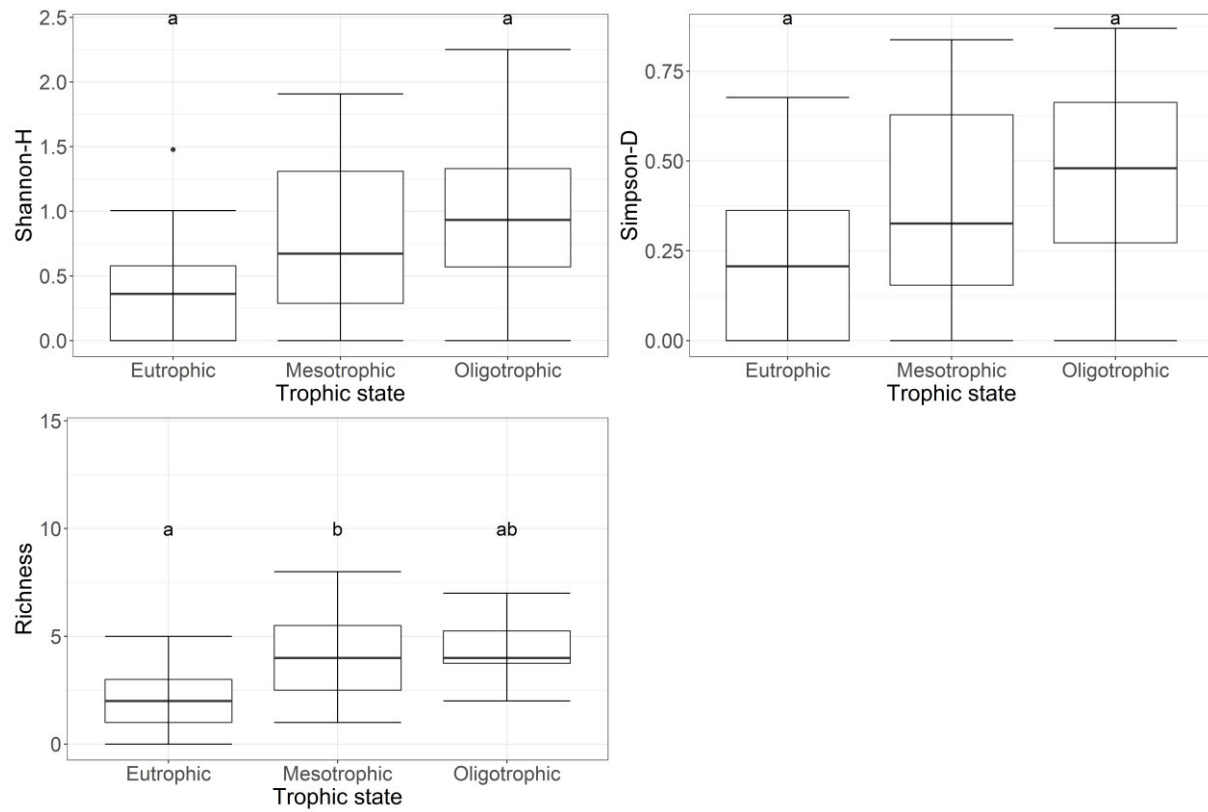


Fig. 2 Taxonomic indices (Shannon and Richness) for with trophic states., Shannon-H ($F=4.391$, $p=0.018$), the significant difference of eutrophic and oligotrophic was found. Species richness ($F=5.34$, $p=0.007$), significant difference between oligotrophic and eutrophic states, and mesotrophic and eutrophic states.

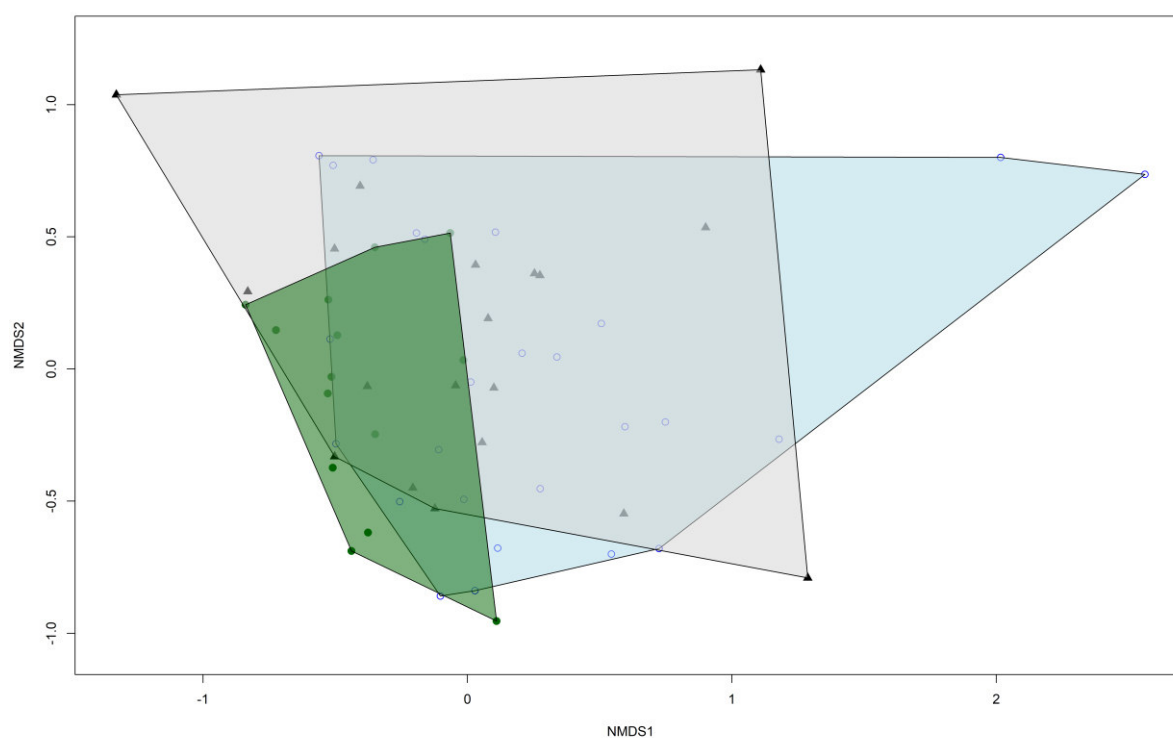


Fig. 3 Non-metric multidimensional scaling (NMDS), using Euclidean distance matrix for taxonomic composition. The green solid circles correspond to samples in eutrophic states, the black triangle to samples in mesotrophic states and the blue circles to samples in oligotrophic states.

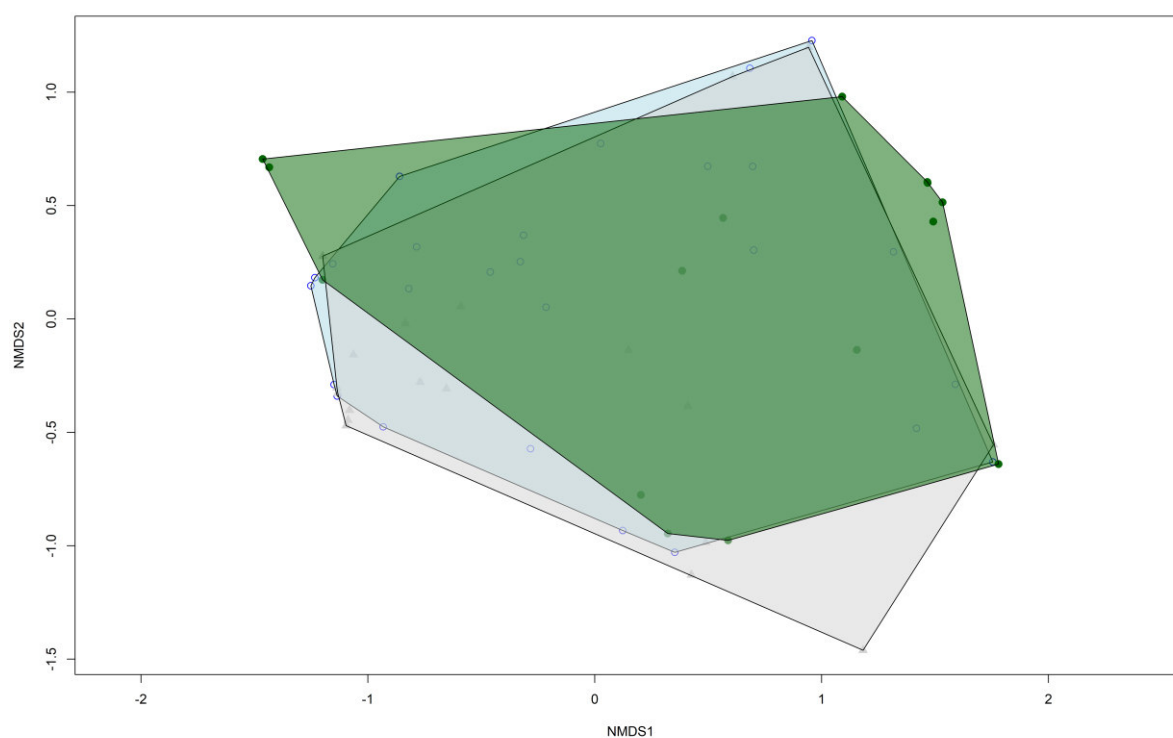


Fig. 4 Non-metric multidimensional scaling (NMDS), using Euclidean distance matrix for functional composition. The green solid circles correspond to samples in eutrophic states, the black triangle to samples in mesotrophic states and the blue circles to samples in oligotrophic states.

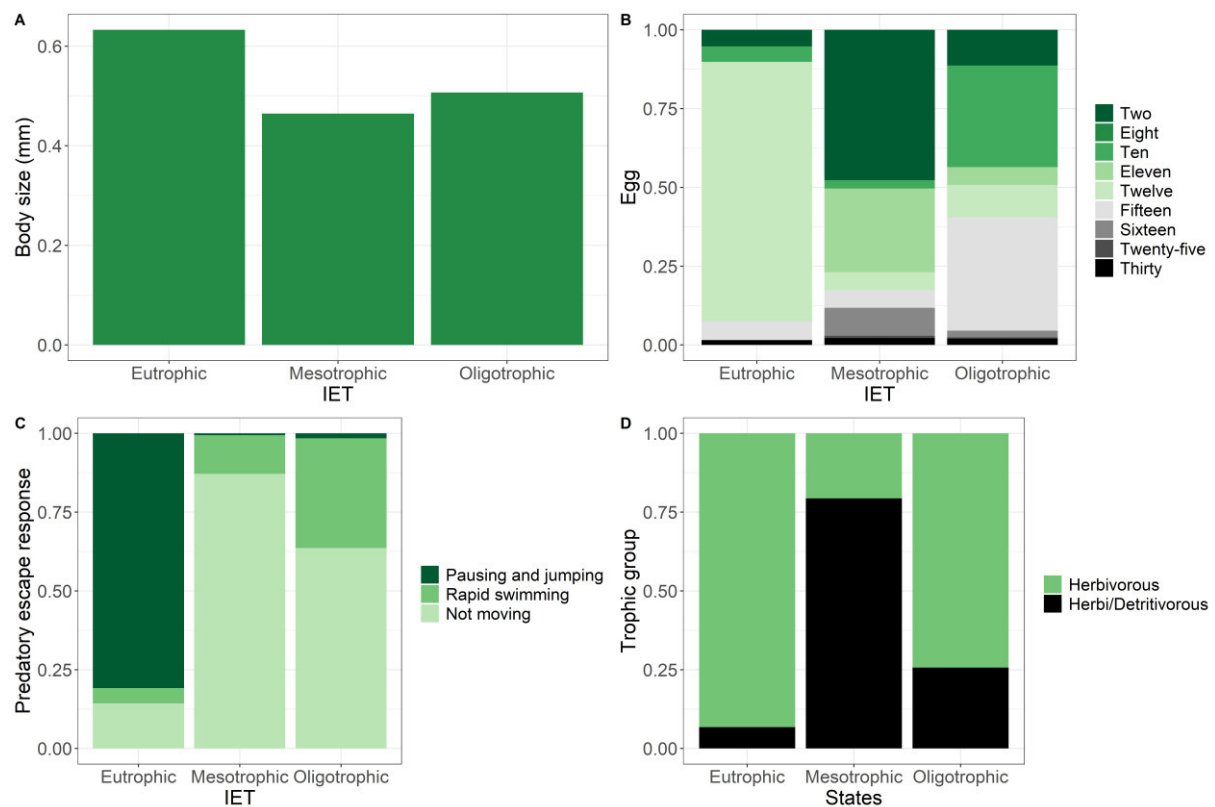


Fig. 5 Composition of functional trait in each trophic state. Using the weighted mean values of the Microcrustacean traits (CWM). (A) Median body size (mm) (B) Number of eggs for clutch (two, eight, ten, eleven, twelve, fifteen, sixteen, twenty-five and thirty) (C) Predatory escape response (pausing and jumping, rapid swimming and not moving), (D) Trophic group (herbivorous and detritivorous/herbivorous).

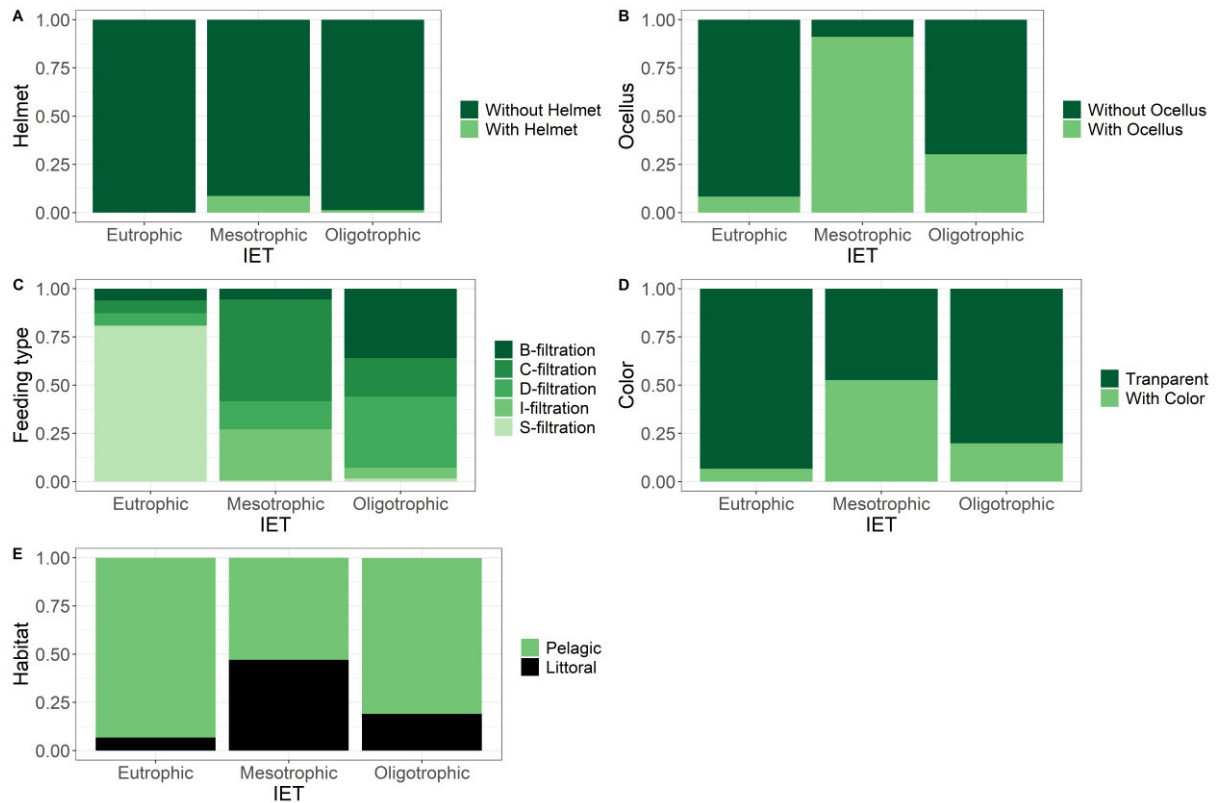


Fig. 6 Composition of functional trait in each trophic state (eutrophic, mesotrophic and oligotrophic). Using the weighted mean values of the Microcrustacean traits (CWM). (A) Presence of helmet (with helmet and without helmet), (B) Presence of ocellus (with ocellus and without ocellus), (C) Feeding type (D-filtration, S-filtration, B-filtration, C-filtration, I-filtration), (D) Presence of color (transparent and with color), and (E) Habitat (littoral and pelagic).

Supplementary information

Table S1: Limnological variables of sampling of subtropical shallow lakes in southern Brazil. Samples A1 to A26 corresponding to Polegar lake and A27 to A62 corresponding to Biguás lake. Trophic state index (TSI).

Sample	Temperature °C	Oxygen (mg.L ⁻¹)	pH	Conductivity (mS/cm2)	chlorophyll- <i>a</i> (µg.L ⁻¹)	Phosphorus (mg.L ⁻¹)	Nitrogen (mg.L ⁻¹)	TSI
A1	29.00	5.79	7.43	60.10	6.09	0.05	0.45	51.94
A2	26.00	6.60	6.85	63.80	6.09	0.05	0.45	51.94
A3	26.75	6.03	7.67	65.55	6.09	0.05	0.45	51.94
A4	20.17	10.01	7.80	109.75	0.63	0.02	0.29	47.75
A5	26.10	8.92	7.69	130.00	4.74	0.05	0.28	51.66
A6	22.10	6.18	6.25	65.20	7.16	0.02	0.34	51.07
A7	23.20	3.30	9.20	41.50	19.37	0.07	0.61	53.83
A8	25.30	9.20	7.23	96.00	4.74	0.02	0.73	50.68
A9	25.80	5.53	7.40	147.00	18.94	0.05	0.78	53.50
A10	26.80	6.37	7.40	131.50	18.52	0.02	0.57	52.40
A11	20.90	10.50	7.31	70.00	1.89	0.01	0.97	48.87
A12	29.30	6.98	7.31	75.00	11.58	0.04	0.64	52.56
A13	25.30	14.00	7.32	80.00	4.84	0.04	0.57	51.53
A14	21.00	10.10	7.79	113.15	11.10	0.02	0.18	51.70
A15	25.00	13.30	7.95	155.30	9.80	0.06	1.97	52.96
A16	24.30	2.70	6.94	95.10	1.60	0.03	0.28	49.69
A17	26.90	9.07	8.71	92.00	7.90	0.03	0.99	51.78
A18	25.80	5.70	7.81	180.00	6.70	0.03	1.68	51.22
A19	25.60	8.09	6.38	144.00	7.30	0.03	0.36	51.48
A20	22.27	8.52	10.37	60.00	2.80	0.01	0.21	48.94
A21	22.30	8.57	7.87	71.00	26.30	0.02	1.25	52.43
A22	22.51	8.60	7.63	99.00	8.80	0.02	0.29	51.06

A23	19.64	11.25	7.09	65.00	4.80	0.04	0.96	51.25
A24	26.80	11.04	7.34	90.67	19.50	0.04	0.26	53.26
A25	26.00	10.87	7.47	110.33	12.90	0.04	0.66	52.71
A26	23.27	10.74	7.59	114.11	3.80	0.04	0.19	51.21
A27	25.00	3.50	6.91	185.00	5.34	0.37	0.31	54.61
A28	21.00	5.28	8.95	189.40	7.14	0.36	0.35	54.93
A29	27.00	7.05	9.28	197.80	6.64	0.22	0.34	54.16
A30	22.00	7.00	7.65	185.70	21.48	0.17	0.67	55.28
A31	25.00	7.94	8.90	198.00	24.17	0.14	0.73	55.16
A32	24.50	6.18	7.53	195.10	4.13	0.11	0.28	52.61
A33	31.00	1.70	8.53	200.00	32.24	0.64	0.91	57.62
A34	29.00	10.06	10.59	240.00	79.30	0.61	1.96	58.69
A35	30.00	9.79	7.42	146.00	139.36	0.79	3.30	59.75
A36	27.00	6.23	7.00	128.50	94.54	0.64	2.30	58.97
A37	28.00	6.98	10.11	184.05	175.21	0.25	4.10	58.45
A38	23.30	6.99	7.48	208.00	116.95	0.17	2.80	57.41
A39	27.50	11.85	10.53	260.00	83.11	0.22	2.05	57.34
A40	29.30	10.59	10.06	280.00	206.59	0.31	4.80	58.95
A41	23.90	12.84	7.85	178.00	116.95	0.39	2.80	58.56
A42	19.50	12.73	8.84	164.00	72.08	0.40	1.52	57.97
A43	27.13	8.97	9.34	231.00	159.14	0.36	4.39	58.83
A44	26.25	9.70	10.15	236.00	199.41	0.27	4.64	58.71
A45	21.20	7.84	5.54	169.00	53.89	0.31	2.04	57.27
A46	23.20	8.58	10.77	167.50	60.10	0.23	5.24	57.00
A47	26.05	9.78	8.23	167.00	12.84	0.05	1.30	53.04
A48	25.80	7.34	10.38	197.00	178.13	0.51	4.17	59.45
A49	22.40	12.40	8.38	167.00	5.05	0.04	1.55	51.41
A50	29.70	7.15	8.16	167.00	20.63	0.07	1.05	53.97
A51	26.20	6.20	8.08	167.00	6.53	0.04	0.73	51.79
A52	24.40	5.72	9.00	163.00	11.37	0.02	0.57	51.64

A53	19.70	4.03	7.53	193.00	21.20	0.06	0.66	53.78
A54	24.20	2.48	8.13	214.00	47.70	0.06	1.15	54.92
A55	24.90	4.68	8.75	207.40	65.70	0.06	2.19	55.13
A56	26.60	6.61	7.85	334.00	26.50	0.04	1.65	53.58
A57	29.50	6.57	7.34	259.00	24.00	0.11	1.23	54.78
A58	23.55	8.95	7.26	184.50	17.40	0.15	0.11	54.84
A59	23.83	4.50	7.44	238.00	16.20	0.18	0.59	54.99
A60	23.14	9.02	7.06	137.00	12.30	0.22	1.56	54.96
A61	23.69	9.40	7.32	194.88	7.10	0.07	1.74	52.62
A62	23.31	8.15	7.23	200.00	6.60	0.09	0.65	52.86

Table S2: Functional traits of Cladocera species from two shallow subtropical lakes (Biguás and Polegar lake, Brazil). Predatory escape response (PER), (1) pausing and jumping, (2) rapid swimming and (3) not moving.

Specie	Body size	Feeding type	Trophic group	Habitat	Ocellus	Color	Helmet	PER	Egg
Bosminidae									
<i>Bosmina freyi</i>	0.34	B-filtration	Herbivore	Pelagic	Without Ocellus	Transparent	Without Helmet	3	15
<i>Bosminopsis deitersi</i>	0.27	B-filtration	Herbivore	Pelagic	Without Ocellus	Transparent	Without Helmet	3	15
Chydoridae									
<i>Acroperus tupinamba</i>	0.6	C-filtration	Herb/ Detritivore	Littoral	With Ocellus	With Color	Without Helmet	3	2
<i>Alonella dadayi</i>	0.35	C-filtration	Herb/ Detritivore	Littoral	With Ocellus	With Color	Without Helmet	3	2
<i>Anthalona neotropica</i>	0.37	C-filtration	Herb/ Detritivore	Pelagic	With Ocellus	With Color	Without Helmet	3	2
<i>Camptocercus dadayi</i>	0.75	C-filtration	Herb/ Detritivore	Littoral	With Ocellus	With Color	Without Helmet	3	2
<i>Chydorus eurynotus</i>	0.41	C-filtration	Herb/ Detritivore	Pelagic	With Ocellus	With Color	Without Helmet	3	2

<i>Chydorus parvireticulatus</i>	0.41	C-filtration	Herb/ Detritivore	Pelagic	With Ocellus	With Color	Without Helmet	3	2
<i>Coronatella monocantha</i>	0.36	C-filtration	Herb/ Detritivore	Pelagic	With Ocellus	With Color	Without Helmet	3	2
<i>Coronatella paulinae</i>	0.33	C-filtration	Herb/ Detritivore	Pelagic	With Ocellus	With Color	Without Helmet	3	2
<i>Ephemeroporus hybridus</i>	0.3	C-filtration	Herb/ Detritivore	Pelagic	With Ocellus	With Color	Without Helmet	3	2
<i>Euryalona orientalis</i>	0.83	C-filtration	Herb/ Detritivore	Littoral	With Ocellus	With Color	Without Helmet	3	2
<i>Leydigia cf striata</i>	0.72	C-filtration	Herb/ Detritivore	Littoral	With Ocellus	With Color	Without Helmet	3	2
<i>Leydigiopsis curvirostris</i>	0.71	C-filtration	Herb/ Detritivore	Littoral	With Ocellus	With Color	Without Helmet	3	2
<i>Magnospina dentifera</i>	0.48	C-filtration	Herb/ Detritivore	Littoral	With Ocellus	With Color	Without Helmet	3	2
<i>Notoalona sculpta</i>	0.38	C-filtration	Herb/ Detritivore	Littoral	With Ocellus	With Color	Without Helmet	3	2
<i>Ovalona kaingang</i>	0.36	C-filtration	Herb/ Detritivore	Littoral	With Ocellus	With Color	Without Helmet	3	2
<i>Picripleuroxus similis</i>	0.33	C-filtration	Herb/ Detritivore	Littoral	With Ocellus	With Color	Without Helmet	3	2
<i>Prendalona arvensis</i>	0.37	C-filtration	Herb/ Detritivore	Littoral	With Ocellus	With Color	Without Helmet	3	2
<i>Eurycercus meridionalis</i>	1.3	C-filtration	Herb/ Detritivore	Littoral	With Ocellus	Transparent	Without Helmet	3	2
Daphnidae									
<i>Ceriodaphnia quadrangula</i>	0.8	D-filtration	Herbivore	Pelagic	With Ocellus	Transparent	Without Helmet	2	16
<i>Ceriodaphnia cornuta</i>	0.38	D-filtration	Herbivore	Pelagic	With Ocellus	Transparent	With Helmet	2	16
<i>Ceriodaphnia lauticaudata</i>	0.52	D-filtration	Herbivore	Pelagic	With Ocellus	Transparent	Without Helmet	2	16
<i>Ceriodaphnia richardi</i>	0.7	D-filtration	Herbivore	Pelagic	With Ocellus	Transparent	Without Helmet	2	16

<i>Daphnia laevis</i>	1.4	D-filtration	Herbivore	Pelagic	With Ocellus	Transparent	With Helmet	2	25
<i>Simocephalus daphnoides</i>	0.62	D-filtration	Herbivore	Pelagic	With Ocellus	Transparent	Without Helmet	3	30
<i>Simocephalus latirostris</i>	1.25	D-filtration	Herbivore	Pelagic	With Ocellus	Transparent	Without Helmet	3	30
<i>Simocephalus serrulatus</i>	1.36	D-filtration	Herbivore	Pelagic	With Ocellus	Transparent	Without Helmet	3	30
<i>Simocephalus</i> sp	0.9	D-filtration	Herbivore	Pelagic	With Ocellus	Transparent	Without Helmet	3	30
<i>Simocephalus mixus</i>	0.75	D-filtration	Herbivore	Pelagic	With Ocellus	Transparent	Without Helmet	3	30
<i>Scapholeberis spinifera</i>	0.41	D-filtration	Herbivore	Pelagic	With Ocellus	Transparent	Without Helmet	2	8
Ilyocryptidae									
<i>Ilyocryptus spinifer</i>	0.55	I-filtration	Herb/ Detritivore	Littoral	With Ocellus	Transparent	Without Helmet	3	11
Macrothricidae									
<i>Macrothrix spinosa</i>	0.68	C-filtration	Herb/ Detritivore	Littoral	With Ocellus	With Color	Without Helmet	3	12
<i>Macrothrix elegans</i>	0.68	C-filtration	Herb/ Detritivore	Littoral	With Ocellus	With Color	Without Helmet	3	12
<i>Macrothrix squamosa</i>	0.61	C-filtration	Herb/ Detritivore	Littoral	With Ocellus	With Color	Without Helmet	3	12
<i>Macrothrix</i> sp	0.5	C-filtration	Herb/ Detritivore	Littoral	With Ocellus	With Color	Without Helmet	3	12
Moinidae									
<i>Moina</i> sp	0.6	D-filtration	Herbivore	Pelagic	Without Ocellus	Transparent	Without Helmet	2	10
Sididae									
<i>Diaphanosoma birgei</i>	0.4	S-filtration	Herbivore	Pelagic	Without Ocellus	Transparent	Without Helmet	1	12
<i>Diaphanosoma brevireme</i>	0.83	S-filtration	Herbivore	Pelagic	Without Ocellus	Transparent	Without Helmet	1	12

<i>Diaphanosoma spinulosum</i>	0.66	S-filtration	Herbivore	Pelagic	Without Ocellus	Transparent	Without Helmet	1	12
<i>Pseudosida bidentata</i>	1.4	S-filtration	Herbivore	Pelagic	Without Ocellus	Transparent	Without Helmet	1	12

Table S3: Abundance of Cladocera specie in shallow subtropical lakes (Biguás Lake and Polegar Lake, Brazil). Samples A1 to A26 corresponding to Polegar lake and A27 to A62 corresponding to Biguás lake.

Specie/sample	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14	A15	A16	A17	A18	A19	A20
Bosminidae																				
<i>Bosmina freyi</i>	0	0	0	0	671	2	64	0	1	0	0	14	0	20	38	0	33	64	1	0
<i>Bosminopsis deitersi</i>	0	0	0	0	0	0	0	0	0	0	0	5	2	1	0	0	11	2	0	0
Chydoridae																				
<i>Acroperus tupinamba</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Alonella dadayi</i>	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Anthalona neotropica</i>	0	0	0	0	0	0	0	2	0	0	0	0	7	0	14	4	0	3	0	0
<i>Camptocercus dadayi</i>	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Chydorus eurynotus</i>	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
<i>Chydorus parvireticulatus</i>	0	0	0	0	0	0	5	0	0	0	1	0	0	0	0	0	0	0	0	3
<i>Coronatella monocantha</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Coronatella paulinae</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Ephemeroporus hybridus</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

<i>Euryalona orientalis</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Leydigia cf striata</i>	0	0	0	0	0	0	0	9	0	0	0	0	0	0	0	0	0	0	0	0
<i>Leydigiopsis curvirostris</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Magnospina dentifera</i>	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Notoalona sculpta</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Ovalona kaingang</i>	0	0	0	0	0	2	6	0	7	0	0	0	4	3	2	3	2	1	6	2
<i>Picripleuroxus similis</i>	0	0	0	0	0	1	0	0	0	0	7	11	0	0	0	0	0	0	0	1
<i>Prendalona arvensis</i>	0	0	0	0	0	0	0	12	0	0	0	0	0	0	0	0	0	0	0	0
<i>Eurycercus lamellatus</i>	1	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Daphnidae																				
<i>Ceriodaphnia quadrangula</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Ceriodaphnia cornuta</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Ceriodaphnia lauticaudata</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Ceriodaphnia richardi</i>	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	3
<i>Daphnia laevis</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	5	2	0	0	0	3	0
<i>Simocephalus daphnoides</i>	0	0	0	8	0	1	0	0	0	1	1	0	0	0	0	0	0	0	0	0
<i>Simocephalus latirostris</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Simocephalus serrulatus</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Simocephalus sp</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

<i>Simocephalus mixus</i>	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Scapholeberis spinifera</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ilyocryptidae																				
<i>Ilyocryptus spinifer</i>	0	0	0	7	0	0	0	64	2	1	0	1	3	0	6	1	0	1	0	0
Macrothricidae																				
<i>Macrothrix spinosa</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Macrothrix elegans</i>	0	0	0	0	0	0	0	0	0	11	1	0	5	3	148	8	0	3	0	5
<i>Macrotrix squamosa</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Macrothrix</i> sp	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0
Moinidae																				
<i>Moina</i> sp	0	0	0	0	0	0	0	0	0	2	0	0	2	0	0	0	207	0	575	0
Sididae																				
<i>Diaphanosoma birgei</i>	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
<i>Diaphanosoma brevireme</i>	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
<i>Diaphanosoma spinulosum</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Pseudosida bidentata</i>	0	0	0	0	0	0	0	0	0	4	0	0	1	0	0	3	0	0	0	29

Continue.

Specie/sample	A21	A22	A23	A24	A25	A26	A27	A28	A29	A30	A31	A32	A33	A34	A35	A36	A37	A38	A39	A40
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Bosminidae																				
<i>Bosmina freyi</i>	8	4	0	48	0	18	0	0	0	0	0	0	0	0	0	0	0	866	0	5
<i>Bosminopsis deitersi</i>	34	0	0	7	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chydoridae																				
<i>Acroperus tupinamba</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Alonella dadayi</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Anthalona neotropica</i>	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Camptocercus dadayi</i>	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Chydorus eurynotus</i>	0	0	0	0	15	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Chydorus parvireticulatus</i>	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Coronatella monocantha</i>	0	0	0	0	6	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Coronatella paulinae</i>	0	0	0	0	6	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Ephemeroporus hybridus</i>	0	0	1	0	74	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Euryalona orientalis</i>	0	0	0	0	0	0	0	0	0	1	14	0	0	0	0	0	0	0	0	0
<i>Leydigia cf striata</i>	0	0	0	0	0	0	1	0	0	0	3	0	0	0	0	0	0	0	0	0
<i>Leydigiopsis curvirostris</i>	0	0	0	0	0	0	0	0	0	3	17	0	0	0	0	0	0	0	0	0
<i>Magnospina dentifera</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Notoalona sculpta</i>	0	0	0	0	21	22	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Ovalona kaingang</i>	1	0	1	0	1	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0

<i>Picripleuroxus similis</i>	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Prendalona arvensis</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Eurycercus lamelatus</i>	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0
Daphnidae																				
<i>Ceriodaphnia quadrangula</i>	0	9	0	0	14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Ceriodaphnia cornuta</i>	0	0	0	0	0	23	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Ceriodaphnia lauticaudata</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Ceriodaphnia richardi</i>	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Daphnia laevis</i>	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Simocephalus daphnoides</i>	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Simocephalus latirostris</i>	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0
<i>Simocephalus serrulatus</i>	0	0	0	0	0	0	28	0	0	3	7	0	0	2	0	7	0	0	0	0
<i>Simocephalus</i> sp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Simocephalus mixus</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Scapholeberis spinifera</i>	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ilyocryptidae																				
<i>Ilyocryptus spinifer</i>	2	0	0	0	1	5	0	0	0	3	37	1	0	0	0	1	0	0	0	0
Macrothricidae																				
<i>Macrothrix spinosa</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

<i>Macrothrix elegans</i>	4	3	0	0	23	9	0	0	0	0	0	0	0	0	2	0	0	0	0	0
<i>Macrotrix squamosa</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Macrothrix</i> sp	0	0	0	0	0	0	0	0	0	0	5	0	0	16	0	0	0	0	0	0
Moinidae																				
<i>Moina</i> sp	4	45	0	0	0	0	0	27	1	0	0	0	0	0	0	0	0	1	8	405
Sididae																				
<i>Diaphanosoma birgei</i>	0	0	0	0	0	0	0	2	0	0	0	0	1	0	0	0	0	0	0	0
<i>Diaphanosoma brevireme</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Diaphanosoma spinulosum</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1958	400	4834	2830
<i>Pseudosida bidentata</i>	0	0	0	1	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Continue.

Specie/sample	A41	A42	A43	A44	A45	A46	A47	A48	A49	A50	A51	A52	A53	A54	A55	A56	A57	A58	A59	A60	A61	A62
Bosminidae																						
<i>Bosmina freyi</i>	0	0	0	0	0	1	0	0	2	1	0	0	0	0	0	0	0	0	4	0	0	0
<i>Bosminopsis deitersi</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Chydoridae																						
<i>Acroperus tupinamba</i>	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Alonella dadayi</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0

<i>Anthalona neotropica</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Camptocercus dadayi</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Chydorus eurynotus</i>	0	0	2	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	105	2	10	112
<i>Chydorus parvireticulatus</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Coronatella monocantha</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	21
<i>Coronatella paulinae</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Ephemeroporus hybridus</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	461
<i>Euryalona orientalis</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Leydigia cf striata</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Leydigiopsis curvirostris</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Magnospina dentifera</i>	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Notoalona sculpta</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	254
<i>Ovalona kaingang</i>	0	19	0	0	0	734	0	0	0	1	0	0	0	2	0	0	0	4	9	8	1	0
<i>Picripleuroxus similis</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
<i>Prendalona arvensis</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Eurycercus lamelatus</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Daphnidae																						
<i>Ceriodaphnia quadrangula</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Ceriodaphnia cornuta</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	74	102

<i>Ceriodaphnia lauticaudata</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	20	0	0
<i>Ceriodaphnia richardi</i>	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
<i>Daphnia laevis</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15	0	0
<i>Simocephalus daphnoides</i>	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	3	5	0	0	0
<i>Simocephalus latirostris</i>	0	0	0	0	0	0	19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Simocephalus serrulatus</i>	212	0	1	0	0	0	1	0	0	0	4	0	0	0	0	1	0	0	0	0	0	0
<i>Simocephalus</i> sp	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Simocephalus mixus</i>	0	1	0	0	0	0	2	0	0	1	1	0	0	0	0	0	0	0	1	0	0	0
<i>Scapholeberis spinifera</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ilyocryptidae																						
<i>Ilyocryptus spinifer</i>	6	0	2	0	0	0	3	0	0	91	39	11	161	26	0	211	9	1	16	3	9	23
Macrothricidae																						
<i>Macrothrix spinosa</i>	0	0	0	113	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Macrothrix elegans</i>	38	0	0	0	0	24	0	0	0	0	0	1	1	0	0	0	0	9	14	4	27	
<i>Macrotrix squamosa</i>	0	0	0	0	0	0	0	0	0	0	2	1	0	3	0	47	0	0	0	0	0	0
<i>Macrothrix</i> sp	0	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Moinidae																						
<i>Moina</i> sp	0	74	1	0	0	60	0	159	2	0	0	0	0	0	0	0	0	0	17	14	0	0
Sididae																						

<i>Diaphanosoma birgei</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Diaphanosoma brevireme</i>	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
<i>Diaphanosoma spinulosum</i>	0	42	12	0	0	1632	0	0	0	0	0	0	0	0	0	0	0	0	9	0	0	0
<i>Pseudosida bidentata</i>	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0

CONSIDERAÇÕES FINAIS E PERSPECTIVAS

Nosso trabalho buscou entender como as alterações ambientais dos lagos rasos da região subtropical influenciam na estruturação da comunidade de microcrustáceos. Observamos que as diferentes perturbações ambientais, causadas pela alternância de estados alternativos estáveis, ou pelo aumento da eutrofização, influenciaram na diversidade funcional e/ou na diversidade taxonômica, refletindo em alterações nas cadeias tróficas e na saúde dos lagos rasos.

Para o primeiro capítulo concluímos que para a região de clima subtropical o estado de águas claras com predominância de macrófitas flutuantes abrigou uma maior diversidade funcional. Para os estados de águas claras com macrófitas submersas e estado de águas túrbidas observamos uma elevada abundância do gênero *Cypridopsis*, o que refletiu em uma menor diversidade funcional nestes estados. Além disso, destacamos que o uso da abordagem taxonômica se faz complementar aos traços funcionais e para melhores resultados sugerimos a utilização das duas abordagens.

Para o segundo capítulo nossa principal conclusão é que mudanças na diversidade taxonômica nem sempre são acompanhadas por mudanças na diversidade funcional. Neste estudo, observamos uma diminuição da diversidade taxonômica em períodos eutrofizados, porém não observamos resultados significativos para a diversidade funcional. Desta forma, a diminuição de espécies em períodos eutrofizados não representou uma perda funcional. Para os períodos de estado eutrófico observamos uma associação de espécies mais tolerantes a perturbações ambientais, como do gênero *Diaphanosoma*.

Para futuros estudos sugerimos pesquisas que elucidem as lacunas no conhecimento acerca dos traços funcionais de Ostracoda. Este importante grupo presente nos lagos rasos pode ser utilizados para responder diversos processos dentro dos ecossistemas aquáticos, porém para o uso da abordagem funcional este ainda carece de muitas informações. De acordo com SILVA; PERBICHE-NEVES (2017) poucos estudos são relatados com a comunidade de Ostracoda, e isto está diretamente associado ao baixo número de especialistas para este grupo. Desta forma, destacamos essa grande lacuna no conhecimento.

Os lagos rasos são altamente sensíveis às mudanças climáticas (ATTAYDE et al., 2022). Sendo assim outro importante fator a ser avaliado em futuros estudos é como os microcrustáceos que compõem os lagos rasos superam períodos de seca severa. Visto o atual cenário das mudanças climáticas, com aumento da temperatura e maiores períodos de estiagem, os lagos rasos permanentes podem sofrer com períodos secos. Este processo pode ser intensificado em lagos rasos pelas características de baixa profundidade e ocuparem menor área. Eventos climáticos

como o La Niña são cada vez mais frequentes, provocam secas severas em regiões como o sul do Brasil (MARENGO et al., 2012). Desta forma, investigar como períodos de seca extrema irão influenciar na comunidade de microcrustáceos se faz cada vez mais necessário. Perguntas como: Os microcrustáceos presentes em lagos rasos tem boas adaptações a seca severa? Após períodos de seca severa estes organismos conseguem se reestabelecer nos lagos rasos?

A fim de responder algumas destas perguntas, nós conduzimos experimentos onde foi avaliada a eclosão de microcrustáceos do sedimento de dois lagos rasos que passaram por períodos de seca. Induzimos este sedimento a uma seca severa pelo período de dois anos, como controle utilizamos o sedimento fresco dos lagos e colocamos para secar pelo período de 30 dias. Nossas primeiras impressões após o processamento de metade das amostras foram que, embora os microcrustáceos conseguissem eclodir do sedimento, estes demoraram mais para iniciar a eclosão do que no sedimento controle. Ainda estamos no processo de finalização das amostras provenientes dos experimentos, nossa perspectiva é que em breve estes dados serão processados e publicados.

Referencias

ATTAYDE, J. L. et al. Potential effects of warming on the trophic structure of shallow lakes in South America: a comparative analysis of subtropical and tropical systems. **Hydrobiologia**, v. 849, n. 17, p. 3859–3876, 1 out. 2022.

MARENGO, J. et al. Recent developments on the South American monsoon system. **International Journal of Climatology**, v. 32, p. 1–21, 1 jan. 2012.

SILVA, W.; PERBICHE-NEVES, G. Trends in freshwater microcrustaceans studies in Brazil between 1990 and 2014. **Brazilian Journal of Biology**, v. 77, n. 3, p. 527–534, 31 ago. 2017.

ANEXOS

Anexo 1: Artigo publicado em colaboração com pesquisadores do Laboratório de Limnologia.

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Cladocera (Crustacea, Branchiopoda) in coastal temporary environments in southern Brazil

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Anexo 2: Artigo desenvolvido em parceria com colegas e professora durante a disciplina de cienciometria.

Environ Biol Fish (2020) 103:719–731
<https://doi.org/10.1007/s10641-020-00978-5>

Scientific knowledge on threatened species of the Brazilian Red List: freshwater fish as a case study



Manuela P. Tourinho • Ana Paula T. Costa •
Karoline P. Martins • Maiby Glorize S. Bandeira •
Fabiana G. Barbosa 

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Anexo 3: Nota desenvolvida com colegas e professor durante a disciplina de Biologia de Vertebrados.

Herpetology Notes, volume 12: 991-993 (2019) (published online on 17 October 2019)

**The effect of observer during calling surveys on breeding sites:
potential bias on estimating the abundance of calling males of
Pseudis minuta Günther, 1858 (Anura, Hylidae)**

Elisa Stuani Dosso¹, Adreani Araujo da Conceição², Karina Soares Dias¹, Karoline Pereira Martins^{2,*},
Sandra Halfen Silveira¹, and Alexandro M. Tozetti³

Anexo 4: Artigo publicado em colaboração com pesquisadores do Laboratório de Limnologia.

Hydrobiologia
<https://doi.org/10.1007/s10750-020-04315-w>



PRIMARY RESEARCH PAPER

**Hydration time influences microcrustacean hatching
in intermittent wetlands: in situ and ex situ approaches**

Maiby Glorize da Silva Bandeira  • Karoline Pereira Martins •
Cleber Palma-Silva • Luiz Ubiratan Hepp • Edélti Faria Albertoni

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Anexo 5: Capítulo de livro desenvolvido em colaboração com pesquisadores do Laboratório de Limnologia.

CAPÍTULO 6

STRATEGY FOR THE HATCHING OF MICROCRUSTACEANS ENDEMIC TO INTERMITTENT ENVIRONMENTS ALONG ANNUAL HYDROPERIODS

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for hatching and reestablishment of the species. We followed four consecutive hydroperiods in three intermittent wetlands over one year; three short (SH1, SH2, and SH3), and one long (LH). *Branchinecta iheringi* hatched in all hydroperiods of the year (SH1: 4 ± 6.9 org; SH2: 7 ± 4.3 org; SH3: 7 ± 5.1 org; LH: 35.3 ± 43.3 org). *E. pampa*, however, hatched only in the long hydroperiod (LH: 51.6 ± 61.2 org). The hatching responses and life cycles of the two species were different. The water retention time and the temperature variation had a significant effect on the reestablishment of the species. Monitoring the hatching strategies of the two species allows us to demonstrate that they presented different responses to the annual hydroperiods. *Branchinecta iheringi* responded immediately to the hatching stimuli while *E. pampa* needed a longer time to initiate hatching.

KEYWORDS: Anostraca; Diplostraca; dormancy; temporary ponds

Anexo 6: Artigo publicado em colaboração com pesquisadores do Laboratório de Limnologia.



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ECOSYSTEMS

Microcrustaceans in rice fields: A scientometric analysis from 1977 to 2019

MAIBY GLORIZE DA S. BANDEIRA, KAROLINE P. MARTINS, CLEBER PALMA-SILVA, FABIANA G. BARBOSA, LUIZ U. HEPP & EDÉLTI F. ALBERTONI

Abstract: We evaluated the worldwide trends in studies of the active and dormant forms of microcrustaceans in rice fields, and the potential of this environment as a stock of diversity through a scientometric analysis. Web of Science and Scopus databases were used to compile the 77 studies published before 2019. Publications were distributed over 35 years, with a positive correlation between the number of studies and the year of publication ($\rho = 0.34$). The identified studies were from 18 countries, and 58.4% were conducted in Japan, Italy, the United States, and Spain. Most studies addressed more than two groups of microcrustaceans (37.6%), followed by those focused on Cladocera (27.2%) and Ostracoda (18.1%). We quantified 301 species from six groups of microcrustaceans, the majority of which were Cladocera (41.5%) and Ostracoda (39.8%). The greatest richness of microcrustaceans identified in studies were found in Italy, Thailand, Malaysia, Spain, France, Japan, and Brazil. Of the studies, 87% were centered on the active forms of microcrustaceans rather than dormant forms. We found that 15.5% of the countries that grow rice have identified the richness of microcrustaceans, and even though they are artificial environments, rice fields have high potential to store a high diversity of microcrustaceans.

Key words: Crustacea, paddy, scientific production, wetlands, zooplankton.

Anexo 7: Artigo publicado em colaboração com pesquisadores do Laboratório de Limnologia.



DIVERSIDADE DE INVERTEBRADOS AQUÁTICOS EM ÁREAS ÚMIDAS NO EXTREMO SUL DO BRASIL

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