UNIVERSIDADE FEDERAL RURAL DE PERNAMBUCO
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CLASSIFICAÇÃO MORFO-FUNCIONAL DO FITOPLÂNCTON E A RELAÇÃO COM O MICRO/MESOZOOPLÂNCTON EM RESERVATÓRIOS TROPICAIS

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Dissertação apresentada ao Programa de Pós-Graduação em Botânica da Universidade Federal Rural de Pernambuco, como requisito para a obtenção do título de Mestre.

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Aos meus pais, Ângela e Antonio,
e familiares, por todo amor e incentivo,
Dedico.

Amo vocês!

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"Dando sempre graças por tudo a nosso Deus e Pai,
em nome de nosso Senhor Jesus Cristo."
(Efésios 5:20)

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RESUMO

A classificação baseada na morfologia é uma abordagem considerada importante para prever os efeitos das mudanças ambientais sobre a comunidade fitoplanctônica, sendo uma ferramenta útil para entender a herbivoria e a predação exercida pelo zooplâncton. Ambientes que apresentam diferentes estados tróficos mostram modificações no modo de interação fitoplâncton-zooplâncton. Este trabalho tem como objetivo analisar a interação fitoplâncton-zooplâncton, através dos grupos funcionais fitoplanctônicos baseados na morfologia (GFBM), em dois reservatórios tropicais com diferentes estados tróficos. Foram realizadas coletas mensais, de julho/2016 a abril/2017, na região limnética dos reservatórios Tapacurá e Tabocas, para análises bióticas e abióticas. Experimentos *in situ* também foram realizados nestes ecossistemas, onde foram mantidos microcosmos com adição do micro- e mesozooplâncton e um controle sem zooplâncton. Tabocas apresentou-se mesotrófico durante o estudo, as comunidades estudadas estiveram predominantemente constituídas por clorófitas de pequeno a médio porte e pelo mesozooplâncton. Tapacurá, por outro lado, apresentou-se supereutrófico durante o estudo, constituído por cianobactérias filamentosas e coloniais e pelo micro e mesozooplâncton. Nos experimentos, foi verificado que no reservatório mesotrófico, na presença do micro e mesozooplâncton, todos os grupos morfo-funcionais fitoplanctônicos apresentaram taxas de crescimento com valores negativos. A taxa de ingestão, para este ambiente, evidenciou que as clorófitas de pequeno a médio porte (2 – 50µm) foram altamente ingeridas pelo micro e mesozooplâncton. No resevatório supereutrófico, a taxa de crescimento fitoplanctônico diferiu significativamente apenas para organismos flagelados unicelulares e as diatomáceas; no entanto, apenas os pequenos flagelados com estruturas silicosas, organismos de tamanho médio sem estruturas especializadas e organismos com exoesqueleto silicoso (diatomáceas) tiveram crescimento negativo na presença do microzooplâncton, e as cianobactérias coloniais tiveram crescimento negativo na presença do micro e mesozooplâncton. Na taxa de ingestão foi observado que o microzooplâncton ingeriu em maior quantidade cianobactérias coloniais, e o mesozooplâncton, cianobactérias filamentosas. Estes resultados mostram que em reservatórios mesotróficos a comunidade fitoplanctônica é constituída por grupos fitoplanctônicos altamente susceptíveis à ingestão pelo mesozooplâncton, enquanto que em reservatórios altamente eutrofizados há predominância de cianobactérias que são ingeridas, principalmente, pelo microzooplâncton.

Palavras-chave: cianobactérias, clorofíceas, estado trófico, grupos funcionais, microcosmos, predação

ABSTRACT

The classification based on morphology is an approach considered important to predict the effects of environmental changes on the phytoplankton community, being a useful tool to understand the herbivory and predation exerted by zooplankton. Environments that present different trophic states show changes in the phytoplankton-zooplankton interaction mode. The objective of this work is to analyze phytoplankton-zooplankton interaction, through phytoplankton functional groups based on morphology (FGBM), in two tropical reservoirs with different trophic states. Monthly collections were carried out from July/2016 to April/2017, in the limnetic region of the Tapacurá and Tabocas reservoirs, for biotic and abiotic analyzes. *In situ* experiments were also carried out in these ecosystems, where microcosms were maintained with micro and mesozooplankton addition and a control without zooplankton. Tabocas was mesotrophic during the study, the studied communities were predominantly constituted by small to medium chlorophytes and by mesozooplankton. Tapacurá, on the other hand, was supereutrophic during the study, constituted by filamentous and colonial cyanobacteria and by micro and mesozooplankton. In the experiments, it was verified that in the mesotrophic reservoir, in the presence of the micro and mesozooplankton, all phytoplankton morpho-functional groups presented growth rates with negative values. The ingestion rate, for this environment, showed that small to medium chlorophytes (2 - 50 μm) were highly ingested by micro and mesozooplankton. In the supereutrophic reservoir, the phytoplankton growth rate differed significantly only for unicellular flagellate and diatoms; however, only small flagellates with siliceous structures, medium-sized organisms without specialized structures and organisms with silica exoskeleton (diatoms) had a negative growth in presence of microzooplankton, and colonial cyanobacteria had negative growth in the presence of micro and mesozooplankton. In the rate of ingestion it was observed that the microzooplankton ingested in greater quantity colonial cyanobacteria, and the mesozooplankton, filamentous cyanobacteria. These results show that in mesotrophic reservoirs the phytoplankton community is constituted by phytoplankton groups highly susceptible to mesozooplankton ingestion, whereas in highly eutrophic reservoirs there is a predominance of cyanobacteria that are mainly ingested by microzooplankton.

Keywords: chlorophytes, cyanobacteria, functional groups, microcosms, predation, trophic status

INTRODUÇÃO

Uma ferramenta considerada significativa para prever os efeitos das mudanças ambientais sobre a comunidade fitoplanctônica é a classificação baseada na morfologia. Nessa abordagem, as espécies fitoplanctônicas são enquadradas em grupos morfológicos, classificados com base em características como volume e a presença de mucilagem, flagelos, aerótopos, heterócitos ou estruturas siliciosas pertencentes ao exoesqueleto, de modo que mostram uma relação mais próxima a determinadas condições ambientais apresentadas pelas diferentes zonas climáticas, como, por exemplo, a temperatura (KRUK et al., 2010), como também, explicar variações do fitoplâncton que ocorrem em diferentes regiões geográficas (SALMASSO et al., 2015).

A composição e biomassa do fitoplâncton dependem de uma complexa combinação de fatores, tais como temperatura e luz, disponibilidade de nutrientes e da comunidade zooplanctônica, de maneira que as condições ambientais são fortemente influenciadas pelos períodos de precipitação, modificando o volume e a profundidade destes ecossistemas (DANTAS, BITTENCOURT-OLIVEIRA e MOURA, 2012). Além das condições climáticas, a eutrofização tem influenciado na dinâmica da comunidade fitoplanctônica em reservatórios. O aumento no aporte de nutrientes favorece, por exemplo, o aumento da biomassa do fitoplâncton, especialmente das cianobactérias, as quais se tornam dominantes e causam deterioração da qualidade do corpo d’água e diminuição da diversidade biológica (CHEN et al., 2009; DEJENIE et al., 2009; CAREY et al., 2012).

Outro aspecto que pode ser modificado com a eutrofização é o modo de interação fitoplâncton-zooplâncton. De acordo com Blancher (1984), as estruturas das comunidades fitoplanctônica e zooplanctônica são resultantes de interações biológicas, como pressão de predação e competição interespecífica por disponibilidade de nutrientes. Pinto-Coelho et al. (2005) mostraram que a eutrofização tem relação direta com a estrutura da comunidade zooplanctônica, devido às respostas significativas do tamanho e biomassa do zooplâncton em função do aumento das concentrações do fósforo total. Outros estudos mostram que essa relação ocorre devido comum dominância das cianobactérias em ambientes eutróficos, que são consideradas pouco palatáveis ao zooplâncton e que influenciam na dinâmica desses organismos (SOARES et al., 2010; GER et al., 2014 e 2016).

A comunidade zooplanctônica nos reservatórios do Brasil é composta, sobretudo, por Rotifera, principal componente do microzooplâncton (<200 µm), e Cladocera e Copepoda, que constituem o mezooplâncton (> 200 µm) (ALMEIDA et al., 2012; GARCIA et al., 2016). As espécies pertencentes a estes grupos diferem quanto aos itens alimentares, sendo a alimentação dos rotíferos composta por microalgas de pequeno porte, bactérias e detritos, a boa parte dos cladóceros exerce herbivoria à presas de tamanhos diversos, enquanto os copépodos normalmente se alimentam de presas maiores (MELO JUNIOR et al., 2007; COLINA et al., 2016). Os hábitos alimentares dos rotíferos e cladóceros são semelhantes, pois ambos são filtradores e retêm as presas em seus aparelhos de alimentação para poder consumi-las, diferente dos copépodos, que selecionam e manipulam suas presas (COLINA et al., 2016).

Estudos realizados por Davis et al. (2012) no Lago Erie, localizado em região temperada, mostraram que o mesozooplâncton é capaz de consumir indivíduos fitoplanctônicos de diversos tamanhos corporais; no entanto, sua biomassa varia quando ocorrem elevadas densidades de cianobactérias no ambiente. Em contrapartida, o microzooplâncton não mostra relação com a biomassa fitoplanctônica em campo, porém apresenta alta taxa de alimentação na presença das cianobactérias no cultivo, evidenciando a preferência no consumo desse grupo algal.

Colina et al. (2016) apontam que o grau de susceptibilidade de uma alga à predação pelo zooplâncton é reflexo das diferenças morfológicas apresentadas pelas espécies fitoplanctônicas, e classificam estas em grupos funcionais baseados na morfologia (MBFG). De acordo com os autores, cladóceros e copépodos têm preferência alimentar por organismos de grupos morfológicos fitoplanctônicos de grande porte (entre 20 e 200 µm), enquanto os rotíferos preferem consumir organismos que não possuem estruturas especializadas e com tamanho corporal de pequeno a médio (entre 0,2 e 20 µm).

Desta forma, os grupos funcionais morfológicos são uma boa ferramenta para auxiliar na previsão dos efeitos das mudanças ambientais sobre a composição da comunidade fitoplanctônica, de modo que poderá refletir no comportamento do micro e mesozooplâncton, os quais são influenciados pelo grau de eutrofização do ambiente em que se encontram. O presente trabalho objetiva, portanto, entender como ocorre a interação fitoplâncton-zooplâncton em dois reservatórios tropicais com diferentes estados tróficos em função das características morfológicas apresentadas pelas espécies fitoplanctônicas, bem como compreender o papel do zooplâncton sobre o fitoplâncton, principalmente as cianobactérias em reservatórios eutróficos, contribuindo para o uso a biomanipulação como alternativa para o controle dessas algas.

REVISÃO BIBLIOGRÁFICA

As interações zooplâncton-fitoplâncton têm sido foco de inúmeros estudos que procuram entender a ecologia do plâncton (JAMES e FORSYTH, 1990; ELSER e

GOLDMAN, 1991), as quais são essenciais para a previsão de fenômenos planctônicos em ecossistemas de água doce (McQUEEN et al., 1989). Haney (1987) mostra que a interação entre o zooplâncton e as cianobactérias se dá por meio de duas ordens, sendo a primeira relacionada diretamente com a herbivoria e com o fornecimento de nutrientes que o zooplâncton oferece através de seus excrementos, e a segunda representada pelos efeitos indiretos, de modo que o zooplâncton, consumindo vários tipos algais, irá aumentar a competição dos diferentes grupos fitoplanctônicos pelos nutrientes disponíveis (Figura 1).

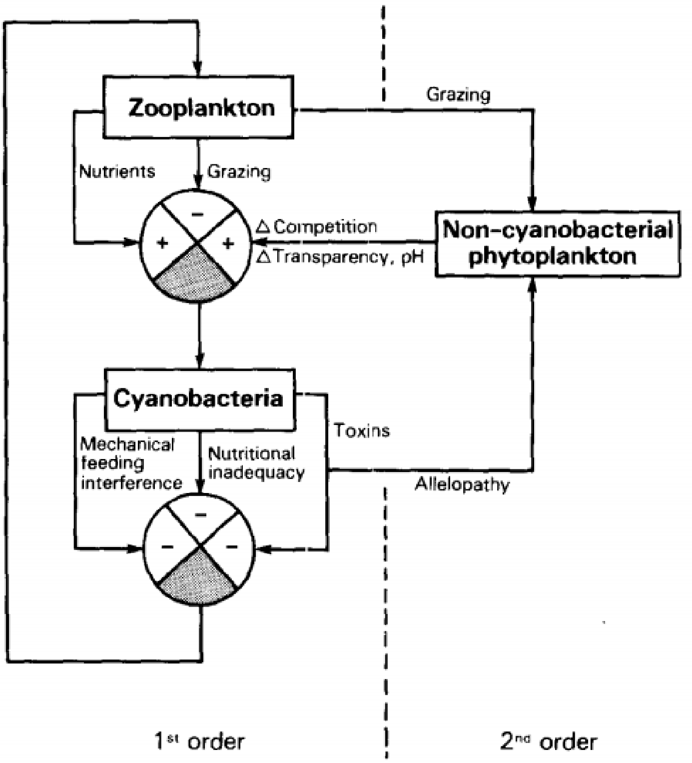

Figura 1. Modelo hipotético de interações entre cianobactérias e zooplâncton. Fonte: Haney (1987).

Estudos têm sido desenvolvidos em laboratório e no ambiente natural com o objetivo de entender a interação entre zooplâncton e fitoplâncton (HANSEN, BJORNSEN e HANSEN, 1994; DOS SANTOS SEVERIANO et al., 2017); no entanto, a maioria desses estudos foi desenvolvida com organismos zooplanctônicos que apresentam hábitos alimentares generalistas, como, por exemplo, organismos pertencentes ao gênero *Daphnia*, que se alimentam do fitoplâncton de diferentes tamanhos (LAMPERT, 1987; PAGANO, 2008; HE, et al., 2015). Por outro lado, estudos com copépodos e rotíferos, que buscam compreender a preferência alimentar considerando as características morfológicas dos grupos fitoplanctônicos ainda, têm sido pouco desenvolvidos.

Interação fitoplâncton-zooplâncton em reservatórios com diferentes estados tróficos

Desde a década de 1990, estudos mostram que, em ecossistemas aquáticos eutróficos, o zooplâncton é composto, geralmente, por espécies de tamanho corporal pequeno, com uma proporção maior de rotíferos e náuplios de copépodos (MAYER et al., 1997; ZINGEL, 1999), os quais substituem gradualmente os cladóceros e copépodos adultos e se tornam abundantes em períodos sazonais de altas temperaturas, de modo que se tornam responsáveis pela maior taxa do consumo de fitoplâncton, principalmente organismos que apresentam pequeno tamanho (GLIWICZ, 2003).

Em sistemas tropicais e subtropicais há escassez de organismos zooplanctônicos de grande tamanho corporal, como algumas espécies de Cladocera e Copepoda, sendo os Rotifera e as pequenas espécies de Cladocera os principais componentes que predominam nesses sistemas, de modo que a dominância é influenciada pela variação do tamanho e tipo de alimento, resultando no crescimento de espécies de cianobactérias e clorófitas de grande tamanho (BOON, 1994; PAGANO, 2008).

Estudos mais recentes, como Urrutia-Cordeiro et al. (2015) e Tõnno et al. (2016), apontam que a comunidade zooplanctônica em ambientes de água doce eutrofizados estão se tornando cada vez mais predominantemente constituídas por cladóceros e copépodos ciclopóides de pequeno tamanho corporal, os quais, muitas vezes, coexistem com florações de cianobactérias. Entretanto, Eskinazi-Sant'Anna et al. (2013) evidenciam padrões de dominância de rotíferos e copépodos calanoidas em reservatórios tropicais eutróficos. Por coexistirem com as cianobactérias, estes organismos zooplanctônicos tendem a se alimentar delas, resultando em uma alimentação desfavorável, e, consequentemente, há uma redução ou morte destes organismos (PORTER e MCDONOUGH, 1984).

Estudos como o de Pan, Zhang e Sun (2014) buscam entender a interação fitoplâncton-zooplâncton, mais especificamente entre cianobactérias e cladóceros, sob condições oligotróficas a hipereutróficas, e afirmam que as morfologias do fitoplâncton e zooplâncton se modificam em função da concentração dos nutrientes, de modo que a variação entre sistemas oligo/mesotróficos e super/hipereutróficos implicam em diferentes formas de interações.

Algumas espécies de cianobactérias são consideradas presas de difícil consumo devido às diferentes características morfológicas e fisiológicas, tais como a presença de mucilagem, que dificultam a digestão (REYNOLDS, 2007; FRAU et al., 2017), e a produção de toxinas, que faz com que o zooplâncton não seja eficiente no controle da biomassa dessas espécies (GLOBER et al., 2007). Os organismos zooplanctônicos que são capazes de consumir este grupo algal, em sua maioria, apresentam adaptações morfológicas como, por exemplo, a presença de projeções abdominais que têm a função de limpar a carapaça, eliminando os restos das cianobactérias que ficam acumulados (BOON, 1994).

Dos Santos-Severiano et al. (2018) mostram que, em reservatórios eutróficos de regiões tropicais, o zooplâncton, principalmente pequenos rotíferos e copépodos que fazem parte do microzooplâncton, é capaz de controlar a comunidade fitoplanctônica, como também as cianobactérias coloniais formadoras de florações, como *Microcystis*. No caso das cianobactérias que apresentam longos filamentos, os rotíferos e copépodos, antes de ingerirem este tipo de presa, quebram os filamentos reduzindo o tamanho para ingeri-los (KÂ et al., 2012).

O efeito da herbivoria sobre as populações fitoplanctônicas não se dá apenas na disponibilidade e composição do alimento, mas também é determinado pela composição das espécies zooplanctônicas e seus mecanismos de alimentação (RÜCKERT e GIANI, 2008). Embora algumas características morfológicas e fisiológicas apresentadas pelo fitoplâncton sejam consideradas nocivas para o zooplâncton, na maioria dos casos, estes dois grupos planctônicos coexistem em ambientes naturais, sendo observada uma flexibilidade no consumo de grupos algais nocivos, como as cianobactérias (GER et al., 2016).

As cianobactérias podem passar por mudanças significativas no comprimento de filamentos em função da predação pelo zooplâncton, influenciando assim na morfologia deste grupo algal, como também de outros organismos fitoplanctônicos, como mostra James e Forsyth (1990). Ger et al. (2016) apontam que o inverso pode ocorrer também, de modo que o tempo de exposição às cianobactérias pode modificar as comunidades zooplanctônicas, tornando-as melhor adaptadas, e assim, selecionando genes tolerantes que serão introduzidos nas comunidades ao longo da vida das mesmas.

Para Dawidowicz (1990), a comunidade zooplanctônica composta por espécies de tamanhos diferentes influencia diretamente na composição e na dinâmica do fitoplâncton, sendo o mesozooplâncton, como cladóceros de maior porte, mais eficiente no controle da densidade dos organismos fitoplanctônicos de tamanhos diversos. Sommer et al. (2001) e Chen et al. (2016), da mesma forma, evidenciam que o mesozooplâncton em ambientes mesotróficos desempenha papel fundamental sobre a estrutura do fitoplâncton, de maneira que os cladóceros reduzem o fitoplâncton de tamanho pequeno, enquanto os copépodos reduzem os de maior porte.

Outros estudos mostram, através de experimentos, que ocorrem mudanças na biomassa fitoplanctônica, de maneira que o número de indivíduos menores (<5µm) diminui na presença do microzooplâncton, favorecendo o rápido crescimento do fitoplâncton de maior porte (WONG et al., 2016), e que o mesozooplâncton é responsável pela redução tanto de organismos fitoplanctônicos pequenos, quanto de maior tamanho (> 20 µm), de maneira que as características morfológicas, como o volume e a área superficial dos organismos, são fatores importantes para determinação das respostas à herbivoria (BERGQUIST et al., 1985).

Em ambientes oligotróficos, o mesozooplâncton é responsável por diminuir a biomassa fitoplanctônica através da herbivoria, de modo que se houver redução na biomassa do mesozooplâncton, haverá provavelmente aumento da biomassa do microzooplâncton e, consequentemente, da comunidade fitoplanctônica (JASSER; KOSTRZEWSKA-SZLAKOWSKA, 2012). Reul et al. (2014) mostram, através de experimentos com adição de nutrientes e CO_2 e submetidos a altas intensidades luminosas, que ocorre aumento na biomassa do microzooplâncton na ausência do mesozooplâncton, coincidindo com uma queda na abundância dos organismos fitoplanctônicos menores e um aumento de organismos maiores.

De acordo com o observado por Frau et al. (2017), em ambientes tropicais e subtropicais, espera-se que o microzooplâncton não exerça efeitos diretos de predação no fitoplâncton devido à dominância de grandes organismos do fitoplâncton. No entanto, Davis et al. (2012) mostraram, através de estudo em campo e em cultivo, que o microzooplâncton é capaz de consumir indivíduos fitoplanctônicos de diversos grupos, incluindo as cianobactérias, quando comparado com o mesozooplâncton.

Grupos funcionais baseados na morfologia – GFBM do fitoplâncton

Os principais critérios utilizados para a identificação do fitoplâncton através de modelos de classificação baseados na morfologia (incluindo as características estruturais), fisiologia e ecologia, são apresentados por Salmaso et al. (2015), como a classificação funcional proposta por Reynolds et al. (2002) e a classificação em grupos funcionais fitoplanctônicos baseados na morfologia, de Kruk et al. (2010).

Reynolds et al. (2002) agruparam as espécies fitoplanctônicas de acordo com características funcionais baseadas nas semelhanças morfológicas e fisiológicas, como: presença de mucilagem, espinhos, heterócitos e parede celular composta por sílica, que atuam em conjunto com características ambientais, por exemplo, luz, temperatura, nutrientes e biológicas, como o zooplâncton, mostrando a relação entre elas e apresentando uma classificação dessas espécies em códigos, os quais totalizaram 31 grupos. Padisák et al. (2009) reorganizaram a classificação proposta por Reynolds e colaboradores, modificando e reorganizando a alocação de habitats correspondentes às espécies fitoplanctônicas, sendo reconhecidas mais de 40 grupos.

A classificação do fitoplâncton de acordo com critérios, como, características morfométricas, estruturais, funcionais e taxonômicas proposta por Salmaso e Padisák (2007) leva em consideração a organização celular, o tamanho, a forma, o hábito alimentar (autotrófico ou mixotrófico), a presença de flagelos, aerótopos e mucilagem, os quais influenciam diretamente nos processos funcionais e ecológicos das espécies fitoplanctônicas, sendo requisito preliminar a classificação das espécies em nível de ordem ou gênero.

Para Kruk et al. (2010), uma classificação baseada em características morfológicas simples pode capturar a maior parte da variabilidade nas propriedades funcionais do fitoplâncton em função das condições ambientais, de maneira que esses autores classificaram os organismos fitoplanctônicos em sete grupos baseados na morfologia através de dados obtidos em mais de 200 lagos localizados em zonas climáticas distintas, que vão de subpolar a tropical, sendo considerada uma abordagem objetiva e independente de classificações taxonômicas e fisiológicas.

Como resposta morfo-funcional do fitoplâncton à herbivoria pelo zooplâncton, Colina et al. (2016) avaliaram a susceptibilidade das espécies fitoplanctônicas ao consumo, classificando-as em sete grupos funcionais com base na morfologia (GFBM), como mostra a tabela 1, de modo que os rotíferos consomem efetivamente espécies de pequeno a médio porte com baixa suscepetibilidade alimentar, os cladóceros consomem espécies de tamanho corporal maior, e os copépodos consomem espécies de diferentes tamanhos.

Kruk et al. (2010), mostram que espécies fitoplanctônicas que apresentam alta taxa de crescimento podem se recuperar rapidamente da herbivoria, como clorofíceas e cianobactérias de pequeno porte corporal, que são altamente palatáveis; já organismos que apresentam tamanho corporal maior e estruturas morfológicas especializadas, como espinhos e parede celular resistentes composta por sílica e mucilagem, podem ser consideradas pouco palatáveis para o zooplâncton, representadas pelos grupos fitoplanctônicos, especialmente por cianobactérias e espécies de diatomáceas.

ANEXO

Tabela 1. Características morfológicas, táxons representativos para cada grupo morfo-funcional e grau de susceptibilidade à predação pelo zooplâncton. Adaptado de Colina et al. (2016).

GFBM	**Características**	**Táxon representativo**	**Susceptibilidade à predação**
I	Pequenos organismos que ocupam grande área e volume	*Merismopedia tenuissima, Planktosphaeria gelatinosa*	Alta
II	Pequenos flagelados com estruturas silicosas	*Mallomonas caudata*	Baixa
III	Filamentos largos com aerótopos	*Cylindrospermopsis raciborskii, Planktothrix agardhii*	Baixa
IV	Organismos de tamanho médio sem estruturas especializadas	*Cosmarium* sp., *Eutetramorus nygaardii, Staurastrum* sp.	Alta
V	Flagelados unicelulares de médio a grande porte	*Rhodomonas lacustris, Peridinium* sp.	Média
VI	Organismos sem flagelos com exoesqueleto silicoso	*Aulacoseira granulata, Thalassiosira* sp.	Média
VII	Grandes colônias mucilaginosas	*Microcystis aeruginosa, Botryococcus braunii*	Baixa

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MARINE & FRESHWATER RESEARCH

PHYTOPLANKTON-ZOOPLANKTON RELATIONSHIP BASED ON PHYTOPLANKTON MORFO-FUNCTIONAL GROUPS IN TWO TROPICAL RESERVOIRS

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Abstract: Environments with different trophic states modify the phytoplankton-zooplankton interaction mode. The objective of this study was to analyze phytoplankton-zooplankton interaction using morpho-functional phytoplankton groups in two tropical reservoirs with different trophic states. We assembled 5L microcosms and maintained them for 24 hours in these ecosystems. Phytoplankton communities were collected to evaluate the effect of micro- and mesozooplankton predation. The mesotrophic reservoir showed predominance of chlorophytes (group IV) and mesozooplankton during the study period, were we found that in the presence of micro and mesozooplankton, all phytoplankton groups presented significant negative growth rates and higher ingestion values, mainly to group IV. In the supereutrophic reservoir, ingestion rates showed that the micro and mesozooplankton reduced the biomass of colonial (>200 μm) and filamentous (>200 μm) cyanobacteria, respectively. Our results show that the predominance of Calanoida copepods in the supereutrophic reservoir differs from the zooplankton community structure usually found in these tropical ecosystems. Thus, we suggest that Copepoda Calanoida are the most suitable zooplankton group for the reduction of biomass of different morpho-functional groups in mesotrophic reservoirs together with cladocerans, and for the control of filamentous and colonial cyanobacteria in supereutrophic reservoirs.

Additional keywords: algae, biomonitoring, ecology, eutrophication, freshwater, microcosms

Introduction

The phytoplankton community structure is influenced by a complex combination of environmental factors, such as temperature, nutrients (Lira *et al*. 2014), and zooplankton (Tallberg *et al*. 2007). This relationship between phytoplankton and the environment can be evaluated by classifying phytoplankton species into functional groups according to behavioral, physiological, and morphological aspects, such as size, shape and presence of mucilage, spines, heterocytes, gas-vacuoles, and flagella. Such approach explains the phytoplanktonic variations in different geographic regions (Salmasso *et al*. 2015), which presents the variability in environmental conditions (Padisák *et al*. 2009; Kruk *et al*. 2010) and is considered a useful tool for ecological studies.

As a tool to understand the relationship between phytoplankton and zooplankton, Colina *et al*. (2016) categorized phytoplankton species into seven functional groups based on morphology (FGBM) to determine the dynamics of predation exerted by zooplankton (see Supplementary Material Table S1). The degree of susceptibility of an alga to predation by zooplankton is considered a reflection of the morphological differences presented by phytoplankton. For example, phytoplankton species with large cell size and/or mucilage, spines, and rigid cell walls formed by silica reduce the zooplankton's predation capacity (Rückert and Giani 2008).

In tropical and subtropical reservoirs, zooplankton is mainly composed of Rotifera, a dominant microzooplankton (<200 μm), along with Copepod nauplii. Late juveniles and adults of Copepoda and Cladocera are present, constituting the mesozooplankton (> 200 μm) (Almeida *et al*. 2012; Garcia *et al*. 2016). Rotifers and cladocerans are filter of particulates, however, rotifers feed mainly on organic microparticles, microalgae with small cell size, and bacteria, because they are smaller than cladocerans, who are larger and feed on larger prey. On the other hand, copepods are more selective about the type of food they ingest due to their chemosensory and mechanosensory (Colina *et al*. 2016; Fuchs and Franks 2010) localizados nas antenas, apêndices de alimentação e superfície corporal (Huys and Boxshall 1991, Heuschele and Selander 2014) that allow them to distinguish the most palatable foods.

In eutrophic reservoirs, reduced abundance of larger cladocerans and the subsequent dominance of rotifers and small copepods, under conditions of cyanobacteria dominance have been commonly observed (Gliwicz 2003). This change in the zooplankton community structure is caused by increased exposure of cladocerans to the harmful effects of cyanobacteria, since these organisms are generalists and do not select their food (Ger *et al*. 2014, 2016) and end up with clogged filtration apparatus by colonial forms (Bednarska and Dawidowicz 2007).

Microzooplankton play a major role in controlling the phytoplankton community in eutrophic reservoirs, and compared to mesozooplankton, they have developed adaptations that allow them to consume cyanobacteria species (Davis *et al*. 2012). Other studies, such as Pérez-Morales, Sarma and Nandini (2014) and Tõnno *et al*. (2016), demonstrate that the coexistence between zooplankton and cyanobacteria occurs because of predation of other palatable algae in the presence of cyanobacteria. However, further studies are needed to evaluate the real role that micro and mesozooplankton play in controlling phytoplankton biomass in reservoirs.

Considering the above, the objective of this work was to analyze the phytoplankton-zooplankton interaction, using phytoplanktonic functional groups based on morphology, in two reservoirs in Northeast Brazil that present different trophic degrees. We tested the hypothesis that the herbivorous relationships of zooplankton with the phytoplankton community differ between reservoirs in different trophic states, so that mesozooplankton has a greater influence on phytoplankton in mesotrophic reservoirs, whereas microzooplankton is dominant in supereutrophic reservoirs assuming a fundamental role in dynamics of the phytoplankton community.

Materials and methods

Study area

This study was carried out in the Tapacurá (8°02’31.9” S and 35°11’46.5” W) and Tabocas (8°14'58.3"S and 36°22'42.1"W) reservoirs in the state of Pernambuco, Brazil, respectively, where, both reservoirs have climate As according to the Köppen's climate classification for Brazil (Alvares *et al.* 2013). The Tapacurá reservoir is supereutrophic (this work) and has a maximum depth of 21m and maximum accumulation of capacity of 94 x 10^6m^3 (Dantas, Bittencourt-Oliveira and Moura 2012). This reservoir is mainly used for flood containment and public supply, with rainy seasons occurring between April and September, and dry seasons between October and March according to Pernambuco State Water and Climate Agency (2016). The Tabocas reservoir is mesotrophic (this work), with a maximum depth of 13m and a maximum accumulation capacity of 1.2 x 10^6 m^3. This ecosystem is used for public supply, with rainy seasons occurring between March and July, and the dry seasons between August and February according to Pernambuco State Water and Climate Agency (2016).

Sample collection, processing, and analysis

Monthly sampling was carried out between July 2016 and April 2017 in the subsurface layer, from a single sampling point in the limnetic region of the reservoirs. *In situ* we measured luminous intensity (µmol photons $m^{-2}s^{-1}$) using a photometer LI-250A, water temperature (ºC), dissolved oxygen (mg L^{-1}), pH, and electrical conductivity (µScm^{-1}) using a HANNA HI 9829 multiparameter probe. Water transparency (cm) was measured by the disappearance of the Secchi disk (m). Rainfall (mm), mean air temperature (° C), relative air humidity (%), and wind speed (m s^{-1}) were obtained from the National Institute of Meteorology (INMET) website.

We collected samples from the subsurface of the water to determine chlorophyll *a* concentrations and nutrients, which we used to estimate the trophic status of the reservoirs. Samples were stored in plastic containers, transported under refrigeration, and frozen at -4°C until the analysis. Chlorophyll *a* was analyzed according to Lawton *et al*. (1999). The concentrations of dissolved inorganic nitrogen (µg DIN L^{-1}), nitrite (µg $N\text{-}NO_2$ L^{-1}), nitrate (µg $N\text{-}NO_3$ L^{-1}), and ammonia (µg $N\text{-}NH_3$ L^{-1}) were determined according to Golterman (1978), Mackereth, Heron and Talling (1978), and Koroleff (1976), respectively. Total phosphorus (µg PT L^{-1}) and orthophosphate (µg $P\text{-}PO_4$ L^{-1}) were measured according to A.P.H.A (1995) methodology, and the trophic status index was calculated according to Cunha, Calijuri and Lamparelli (2013).

Samples of the phytoplankton community were collected directly from the water column (subsurface), using amber plastic bottles (150 mL) and were preserved with 1% acetic lugol. Phytoplanktonic organisms were identified under an optical microscope (Zeiss/ Axioskop), analyzing 15 semi-permanent slides, using specialized literature including Prescott, Bicudo and Vinyard (1982), Komárek and Anagnostidis (1999, 2005), Popovský and Pfiester (1990), Krammer and Lange-Bertalot (1991). Species densities (indL^{-1}) were calculated using the Utermöhl (1958) method and the average biovolume of each species was determined according to Hillebrand *et al*. (1999). We classified species into functional groups based on morphology (FGBM), according to the models proposed by Colina *et al.* (2016).

To study zooplankton, we collected 50L of water from each reservoir and filtered it with a plankton net 68 µm mesh for microzooplankton and 200 µm for mesozooplankton. Samples were placed in 200 mL plastic bottles and preserved with neutral formol at 4%. We identification zooplanktonic organisms using specific literature for each zooplankton group (Rotifera, Copepod, and Cladocera), such as Koste (1978), Elmoor-Loureiro (1997), and Neumann-Leitão *et al*. (1989). Sub-samples were analyzed under optical microscope (Zeiss/Axioskop) in a Sedgwick-Rafter chamber with a capacity of 2 mL for the determination of densities (ind L^{-1}). The rotifer biomass (mgL^{-1}) was estimated using density data and mean biovolume of the taxa according to the formulas by Ruttner-Kolisko (1977), while the formulas from Dumont *et al*. (1975) were used for copepods and cladocerans.

Microcosms "in situ"

In situ experiments were carried out in the Tabocas (mesotrophic) (November/2016) and Tapacurá (supereutrophic) (April/2017) reservoirs. We prepared 18 microcosms using transparent 5L plastic bottles, filled with water collected from the limnetic region of each reservoir, which we previously filtered through a 68 µm plankton net to remove zooplankton. In twelve (12) bottles we added zooplanktonic organisms collected from each reservoir, 6 (six) bottles we added microzooplankton, and 6 (six) bottles we added mesozooplankton. We used 6 (six) other bottles with no zooplankton as controls.

Zooplankton was collected by filtering 600 L of water from the reservoir through mesh nets (200 µm and 68 µm to separate meso and microzooplankton, respectively). The zooplankton we collected in each net (one for each size of zooplankton, micro, and mesozooplankton) was carefully transferred to a vessel with 600 mL of reservoir water, that was previously filtered through 25 µm mesh. The sample with the zooplanktonic organisms was then homogenized and distributed evenly between experimental bottles at the concentration of 100 mL per bottle, with a total of 100 L of filtered water from the reservoir per bottle.

After adding the zooplankton, we used three control and treatment (with micro and mesozooplankton) bottles to collect samples to analyzing the composition and density of phytoplankton and zooplankton communities in the initial conditions of the experiment ($T_{initial}$). The remaining bottles (n = 9) (the control and treatments in triplicates) were sealed with resistant plastic so that no air bubbles were formed and/or water was lost. Bottles were then capped and suspended in the limnetic region of the reservoirs for 24 hours (T_{final} of the experiment), where we evaluated the same biotic measurements that we took at the beginning of the experiment ($T_{initial}$), as previously described.

Phytoplankton growth rate, zooplankton ingestion rate and electivity

In the experiments, we calculated the phytoplankton growth rate (*r*, day^{-1}) using FGBM and the zooplankton ingestion rate (IR), both according to Marin *et al*. (1986).

Statistical analysis

To verify the influence of the environmental variables (abiotic variables and zooplankton) on the phytoplankton morpho-functional groups in the reservoirs, a Redundancy Analysis (RDA) was performed, using the ordistep function for variable selection. The environmental data were standardized and phytoplankton data were log-transformed. The redundancy analysis was selected on the basis in the length of the first gradient of a Detrended Correspondence Analysis (DCA). ANOVA *one way* was used to evaluate possible significant differences between phytoplankton growth rates and micro and mesozooplankton ingestion rates in the experiments *in situ*, considering treatments and control (significance level p <0.05), followed by Tukey's post hoc test. Predicting normality and homoscedasticity, using the Kolmogorov-Sminorv and Bartlett test, respectively, were calculated prior to this analysis. Statistical analyzes were performed in RStudio 3.4 software.

Results

Temporal dynamics of the abiotic variables, phytoplankton community, and the (micro/meso) zooplankton by FGBM in the reservoirs

The behavior of the climatic variables, the abiotic water variables analyzed *in situ*, and the chlorophyll *a* of the studied reservoirs are shown in table 1.

In the mesotrophic reservoir, dissolved inorganic nitrogen (DIN) and ammonia (NH_3) presented the highest averages, with 930±390 μgL^{-1} and 737±293 μgL^{-1}, respectively, and we observed that the highest concentrations occurred in March/2017 with 3227.4 µgL^{-1} (DIN) and 2472.7 µgL^{-1} (NH_3), respectively. This reservoir presented a mesotrophic state for six months of the study, while between November/2016 and February/2017 it was eutrophic to hypereutrophic (Fig. 1*a*). In the supereutrophic reservoir, concentrations of total phosphorus and orthophosphate (PO_4) presented the highest averages than other nutrients, with 988±30 μgL^{-1} and 747±23 μgL^{-1}, respectively, with higher concentrations in April/2017 (1157.8 μgL^{-1} TP) and March/2017 (859.9 μgL^{-1} PO_4). The TSI ranged from supereutrophic to hypereutrophic (Fig. 1*b*).

We identified a total of 59 phytoplankton species in the mesotrophic reservoir, belonging to the seven FGBM, with group IV the most abundant in species (29) and biomass (see Supplementary Material Table S2, Fig. 2*a*). In the supereutrophic reservoir, we identified 41 species belonging to the seven FGBM, with group IV presenting 11 species (see Supplementary Material Table S3), and group VII with the greatest biomass, presenting co-dominance with group III between July/2016 and November/2016 (Fig. 2*b*).

The microzooplankton in the mesotrophic reservoir was composed of Rotifera, Copepod Cyclopoida, and Calanoida (copepodites and nauplii larvae) and Cladocera, with higher biomass in March/2017, and co-dominance of Calanoida and Cladocera. In the supereutrophic reservoir, the microzooplankton was represented by the same zooplankton groups, with Calanoida predominant in biomass (Fig. 3*a*, *c*). For the mesozooplankton in both reservoirs we recorded the predominance of Calanoida copepods throughout the study period (Fig. 3*b*, *d*).

Redundancy analysis (RDA) of the FGBM and environmental variables of the reservoirs with different trophic states

In the mesotrophic reservoir the RDA model responded 81.29% of the influence of environmental variables on the morpho-functional groups (F = 20.473, p = 0.001). Axis 1 dispersed on the positive side groups I, IV, V and VI, directly related to conductivity (0.52) and inversely related to transparency (-0.93), depth (-0.89) and mesozooplâncton cyclopoids (-0.81). Mesozooplankton rotifers (-0.65) and microzooplâncton calanoids (-0.45) were connected to the axis 2 where they were negatively related to the group III (Fig. 4*a*). While in the supereutrophic reservoir, axes 1 and 2 corresponded to 90.12% of RDA (F = 23.933, p = 0.001), with depth (-0.91) correlated positively with group III and negatively with group VII; and dissolved inorganic nitrogen (0.60) and nitrate (0.49) influenced group VI, such as shows Fig. 4*b*.

Microcosms "in situ"

In the mesotrophic reservoir, all FGBM presented a negative growth rate in the presence of micro and mesozooplankton. Groups II (F = 4.408, p = 0.05) and IV (F = 7.513 and p = 0.02) differed significantly between control and micro and mesozooplankton, respectively (Fig. 5, see Supplementary Material Table S4). In the supereutrophic reservoir, groups II, IV, VI, and VII presented negative growth rates in the presence of the microzooplankton, whereas in the mesozooplankton, only the VII group showed negative phytoplankton growth. Groups V differed significantly between control and treatments with zooplankton (F = 16.01, p = 0.003), and group VI differed significantly between control and microzooplankton (F = 9.694, p = 0.01) (Fig. 6, see Supplementary Material Table S4).

In the phytoplankton community of the mesotrophic reservoir, group IV was predominant in biomass (8888.30±800 μgL^{-1}), and a reduction in the total phytoplankton biomass was observed at the end of the experiment (T_{final}) in the zooplankton addition treatments (Fig. 7*a*). For the zooplankton community, composed mainly of Copepoda Calanoida (1924±1105 $\mu g\ DW^{-3}$) and Cladocera (756±278 $\mu g\ DW^{-3}$), there was a decrease in the total microzooplankton biomass at the end of the experiment (T_{final}), whereas for mesozooplankton, biomass increased at the end of the experiment (T_{final}) (Fig. 7*b*). In supereutrophic reservoir, the fitoplankton was predominantly composed of biomass by group VII, with a biomass of 25472.66±1702 μgL^{-1} (Fig. 7*c*). microzooplankton did not present variations in biomass, constituted by Calanoida and Cyclopoida adults and nauplii. The mesozooplankton consisted predominantly of Calanoida copepods (588.36±350 $\mu g\ DW^{-3}$), with a reduction in biomass from $T_{initial}$ to T_{final} (Fig. 7*d*).

In the reservoir mesotrophic, the ingestion rate did not have value significant between the micro and mesozooplankton (see Supplementary Material Table S5), being the mesozooplankton responsible for higher ingestion values, mainly to group IV (Fig. 8*a*), whereas, in the reservoir supereutrophic, the microzooplankton was responsible for the high rates of ingestion of group VII (colonial cyanobacteria) and mesozooplankton for the high rates of ingestion of group III (filamentous cyanobacteria), however, did not show significant values (Fig. 8*b*, see Supplementary Material Table S5).

Discussion

Effects of environmental variables on functional groups based on morphology (FGBM)

Our results confirm the hypothesis that reservoirs with different trophic states present distinct relationships between phytoplankton and zooplankton, since the mesotrophic reservoir was composed mainly of chlorophytes (group IV) and mesozooplankton, while in the supereutrophic reservoir, microzooplankton predominated and cyanobacteria (groups III and VII). Although no negative relationship was observed between microzooplankton and phytoplankton in this reservoir, zooplankton exerted a *top-down* control on the morpho-functional groups in the in situ experiment.

In the mesotrophic reservoir, the morpho-functional groups I, IV, V and VI presented positive relation with the conductivity, and negative relation with the group Cyclopoida of the mesozooplankton, water transparency and depth, as evidenced in the RDA. Representative species of these morpho-functional groups are favored by increased conductivity, as seen by Ariyadej *et al*. (2004) in the oligo-mesotrophic reservoir Banglang, Thailand. While the negative relationship with the depth and transparency of water can be explained by the reduction of light as these two factors increase. Some species may migrate vertically in the water column to meet their need for light through structures such as flagella (Graham and Wilcox 2000), and nutrients, as they have a high linear dimension (MDL) (Kruk *et al*. 2010).

In addition, zooplankton is an important regulating factor for phytoplankton (Havens *et al*. 2009) in addition to the physical and chemical variables, so that the herbivory pressure exerted by zooplankton results in a decrease in phytoplankton biomass (Rangel *et al*. 2012). According to Colina *et al*. (2016), microcrustaceans prefer to consume large prey such as species of morpho-functional groups III, IV, V and VI, and this phytoplankton-zooplankton relation is observed in the mesotrophic reservoir, since rotifers and copepods were negatively related to the morpho-functional groups found in this ecosystem (Fig. 4*a*).

The morpho-functional groups found in the supereutrophic reservoir were influenced by the physical and chemical variables of the environment. The filamentous cyanobacteria (group III) were positively related to depth, and these algae were tolerant to light limitation (Naselli-Flores and Barone 2012), which may explain this relation, so that they were not affected by the light limitation in larger depths in the reservoir. However, the colony cyanobacteria (group VII) were negatively correlated with depth and nitrogen (nitrate and DIN), as evidenced in the RDA, where, due to their morphological characteristics, such as the formation of large colonies, the distribution is typically on the surface of the column (Wu and Kong 2009).

In addition, colonial cyanobacteria are sensitive to light deficiency (Kruk and Segura 2012), which can cause a reduction in colony size (Li *et al*. 2013), which is reduced as the depth increases. Due to the absence of nitrogen-fixing cells (N_2), the species of group VII are unable to supply nitrogen deficiency by N_2 fixation (Ward *et al*. 2000, Harke *et al.* 2016), with ammonia being preferentially more absorbed than nitrate and nitrite (Flores and Herrero 2005). In contrast to cyanobacteria (group VII), diatoms (group VI) were positively influenced by nitrogen, nitrate and DIN, as observed in other studies (Présing *et al*. 1997, Borges, Train and Rodrigues 2008), where nitrate was responsible for diatom growth.

The zooplankton community of tropical eutrophic reservoirs is predominantly composed of the Copepoda Cyclopoida group (Kâ *et al*. 2012). However, our results presented different structural pattern, being Copepoda Calanoida predominant in the micro and mesozooplankton in the supereutrophic reservoir. This structural pattern of zooplankton was also evidenced by Soares *et al*. (2009) and Eskinazi-Sant'Anna *et al*. (2013) in tropical eutrophic reservoirs. Thus, long exposure to cyanobacteria, whether filamentous or colonial, may increase zooplankton tolerance in eutrophic ecosystems, making future generations more resistant to cyanobacteria blooms (Gustafsson, Rengefors and Hansson 2005; Ger *et al*. 2014), as well as allowing zooplankton to remain in these ecosystems. In addition, in zooplanktonic ecosystems, zooplanktonic biomass is proportionally smaller in relation to phytoplankton biomass, since the base of the primary productivity pyramid is composed of less edible phytoplanktonic organisms (Heathcote *et al*. 2016).

Microcosms "in situ"

The results of the in situ experiments show that the relationship between zooplankton and phytoplankton differs in reservoirs with different trophic states, since mesozooplankton was the main modifier of phytoplankton in the mesotrophic reservoir, which is composed of phytoplankton groups susceptible to predation, while in the supereutrophic reservoir microzooplankton was tolerant to high concentrations of algal groups with low susceptibility to predation.

In the mesotrophic reservoir it was observed that zooplankton consumed all seven functional groups, being the mesozooplankton, represented by Copepoda Calanoida and Cladocera, responsible for reducing phytoplankton biomass, mainly chlorophytes (group IV). This morpho-functional group is the most ingested mainly by cladocerans and rotifers because they present medium size, absence of mucilage, spines and structures that make zooplankton difficult to ingest (Kruk *et al*. 2016, Colina *et al*. 2016), and high nutritional value of proteins and fatty acids (Boersma 2000, Sterner and Elser 2002). According to Fragoso Jr *et al*. (2009), the food preference of zooplankton on phytoplankton follows an order in which chlorophytes are most consumed, followed by diatoms, debris and cyanobacteria.

Cyanobacteria negatively influence zooplanktonic organisms, one of which causes interference with filtration (Boonecker *et al*. 2007). However, our results show that filamentous cyanobacteria and colonies were ingested by zooplankton. In the supereutrophic reservoir, the microzooplankton (rotifers, nauplii and small copepods) had a higher rate of ingestion to the colonial cyanobacteria (VII). The rotifers and small copepods compose zooplankton in tropical eutrophic reservoirs and are able to reduce the biomass of colonial cyanobacteria (Dos Santos-Severiano *et al*. 2018), as well as other phytoplankton groups such as diatoms and chlorophytes (Dos Santos-Severiano *et al*. 2017). The mesozooplankton, mainly composed of Calanoida copepods, ingested more filamentous cyanobacteria (group III) in relation to microzooplankton. Copepods have mechano- and chemoreceptors, as well as specialized muscles, which aid in the feeding of various phytoplanktonic groups (Litchman *et al*. 2013). According to Colina *et al*. (2016), this zooplankton group is able to consume several morpho-functional groups (III, IV, V and VI).

In the presence of zooplanktonic filtering organisms, mainly large cladocerans, the growth of phytoplankton, especially chlorophytes, diatoms and cyanobacteria, is effectively limited, as observed by Kozak, Gołdyn and Dondajewska (2015). However, in our study we observed the predominance of calanoid copepods in both micro and mesozooplankton, which were responsible for modifying the structure of the phytoplankton community in both reservoirs, being this same pattern in the zooplankton community structure seen in others (Panosso 2003, Sousa *et al*. 2008 and Eskinazi-Sant'Anna *et al*. 2013).

Our results show that the differences in the trophic water conditions influence the dynamics and structure of the phytoplankton and zooplankton communities, so that the phytoplankton-zooplankton interaction is modified as a function of the different morphological and physiological characteristics presented by both the phytoplankton groups and their responses to environmental variables, as well as micro and mesozooplankton, such as size and food habits. Copepoda Calanoida were predominant in both reservoirs, differing from the zooplankton structuring pattern found in most tropical eutrophic ecosystems, in which Copepoda Cyclopoida are dominant. Thus, we suggest that Copepoda Calanoida may be the most suitable zooplankton group for the biomanipulation of biomass of different morpho-functional groups in mesotrophic reservoirs, together with small cladocerans, and for the control of filamentous and colonial cyanobacteria in supereutrophic reservoirs.

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Table 1. Abiotic variables analyzed *in situ* and chlorophyll *a* in the mesotrophic and supereutrophic reservoirs between July 2016 and April 2017. Dept = Depth, Tran = Water transparency, Rain = Rainfall, Temp = Water temperature, Temp air = Air temperature, Humi = Relative humidity, Wind = Wind speed, Lumi = Luminous intensity of water, Oxyg = Dissolved oxygen, Satu = Saturation of oxygen, Cond = Electric conductivity, Soli = Total dissolved solids, Chla = Chlorophyll *a*.

Variables/months	**MESOTROPHIC**										**SUPEREUTROPHIC**									
	2016						2017				2016						2017			
	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
Dept (m)	4.0	3.1	1.6	1.5	1.6	1.6	1.3	0.9	1.9	1.5	10.0	10.0	11.4	11.8	10.0	9.6	8.6	9.4	8.8	9.0
Tran (m)	2.2	1.3	0.6	0.2	0.2	0.2	0.1	0.2	0.1	0.0	1.2	1.1	0.7	0.9	0.3	0.6	0.7	0.6	0.6	0.5
Rain (mm)	11.2	6.2	0.3	0.0	0.0	4.4	0.0	3.8	17.5	50.2	110.3	57.5	57.4	14.1	17.8	68.0	28.7	21.1	156.2	289.7
Temp (°C)	25.3	24.2	27.8	28.6	25.5	26.3	29.5	25.7	26.7	26.2	26.9	26.7	28.4	28.8	29.3	29.7	29.5	29.0	30.5	30.0
Temp air (°C)	28.6	30.1	32.0	33.1	33.4	33.8	33.4	33.5	33.6	31.8	28.3	28.9	29.8	31.2	32.0	31.9	31.9	32.5	31.5	30.8
Humi (%)	85.3	76.5	78.8	76.8	74.5	75.9	79.1	77.0	77.5	81.1	80.4	77.2	73.7	70.1	69.8	70.9	69.4	67.8	74.6	80.6
Wind (m s^{-1})	3.0	3.3	4.0	4.0	4.0	3.4	3.4	3.2	2.9	3.1	1.7	1.9	2.1	2.4	2.2	2.1	2.0	2.0	1.7	1.5
Lumi (µmol ph m^{-2} s^{-1})	-	72.0	523.0	1042.0	245.0	610.0	525.0	73.0	516.0	259.0	655.0	389.0	381.0	484.0	516.0	907.0	298.0	410.0	656.0	939.0
Oxyg (mg L^{-1})	5.9	5.4	5.8	6.0	6.7	6.2	9.3	4.1	3.7	3.2	4.8	6.0	7.8	8.4	7.7	6.2	4.8	3.0	5.4	3.9
Satu (%)	76.9	68.3	79.4	84.9	89.2	81.8	134.0	54.0	50.0	43.0	50.8	75.0	98.1	84.4	103.0	82.2	61.7	3.9	74.0	51.5
pH	4.4	8.1	8.4	8.1	9.7	9.9	11.4	8.3	10.1	11.0	8.0	8.4	9.2	8.5	9.0	9.2	9.2	9.1	12.6	13.3
Cond (µS cm^{-1})	95.0	100.0	120.0	147.0	154.0	175.0	208.0	224.0	228.0	172.0	410.0	410.0	425.0	445.0	450.0	459.0	483.0	492.0	540.0	530.0
Soli (TDS)	47.0	50.0	60.0	73.0	77.0	87.0	104.0	112.0	114.0	86.0	205.0	205.0	213.0	223.0	225.0	230.0	241.0	246.0	270.0	265.0
Chla	18.2	30.4	11.1	11.1	29.6	95.1	219.2	483.8	10.9	2.0	58.8	64.8	54.5	69.9	77.4	67.5	38.7	94.8	122.8	141.0

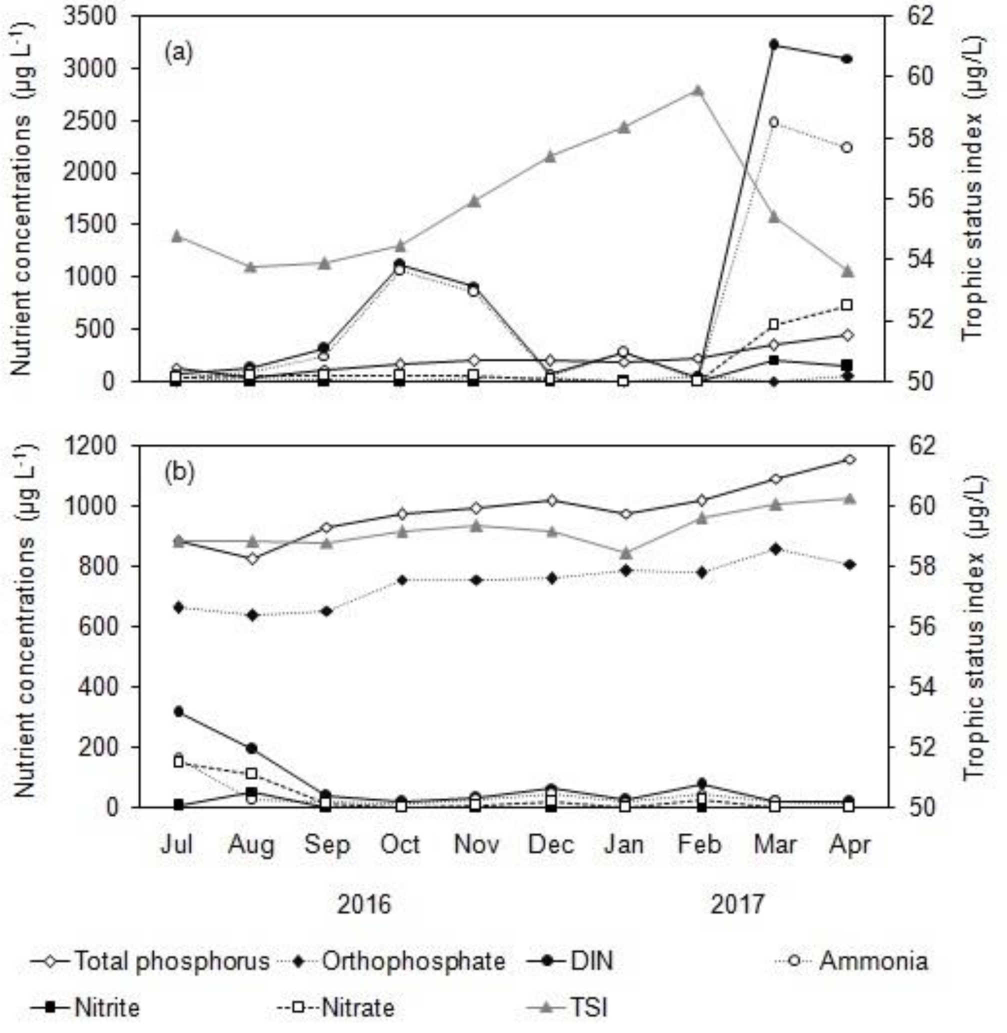


Fig. 1 Variation of nutrient concentration total phosphorus (PT), orthophosphate (PO_4), dissolved inorganic nitrogen (DIN), ammonia (NH_3), nitrite (NO_2) and nitrate (NO_3) and Trophic Status Index (TSI) in the mesotrophic (a) and supereutrophic (b) reservoirs between July 2016 and April 2017.

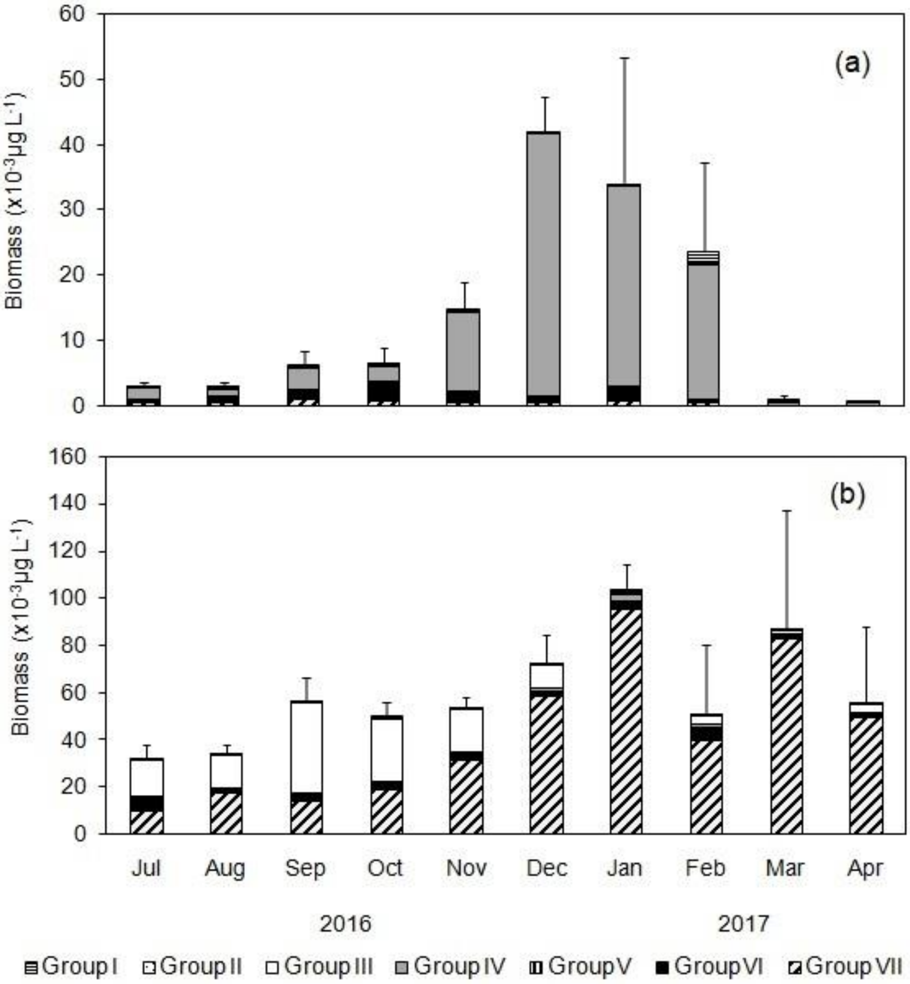


Fig. 2 Variation of biomass (x10^{-3}µgL^{-1}) of the phytoplankton community by functional group based on morphology (FGBM) in mesotrophic (a) and supereutrophic (b) reservoirs between July 2016 and April 2017.

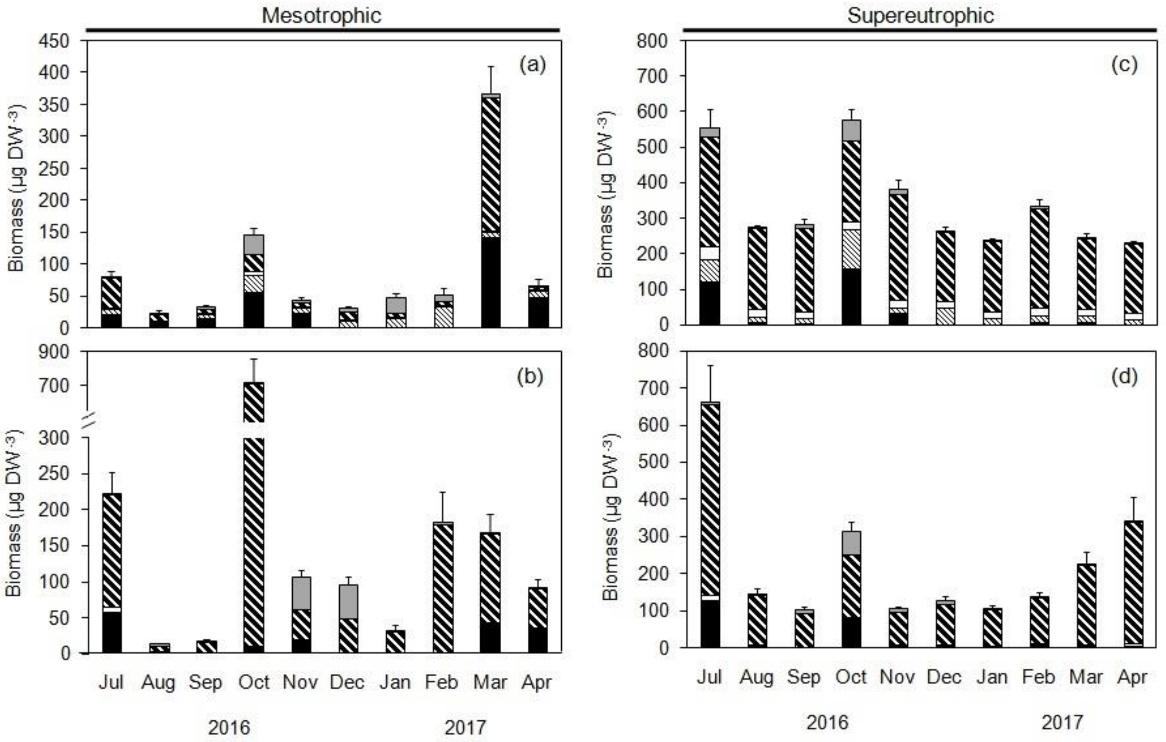
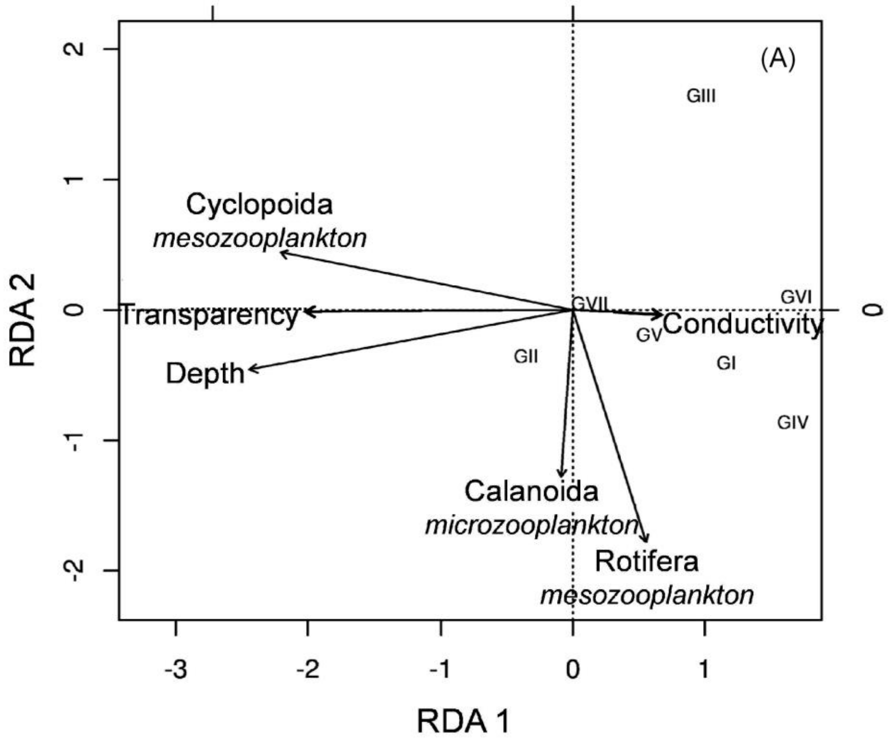


Fig. 3 Variation of biomass (µg DW^{-3}) of the microzooplankton (a and c) and mesozooplankton (b and d) groups in mesotrophic and supereutrophic reservoirs, between July of 2016 and April of 2017. ▒ = Rotifera, ▧ = Copepoda Calanoida, □ = Copepoda Cyclopoida, ▨ = Nauplii, ■ = Cladocera.



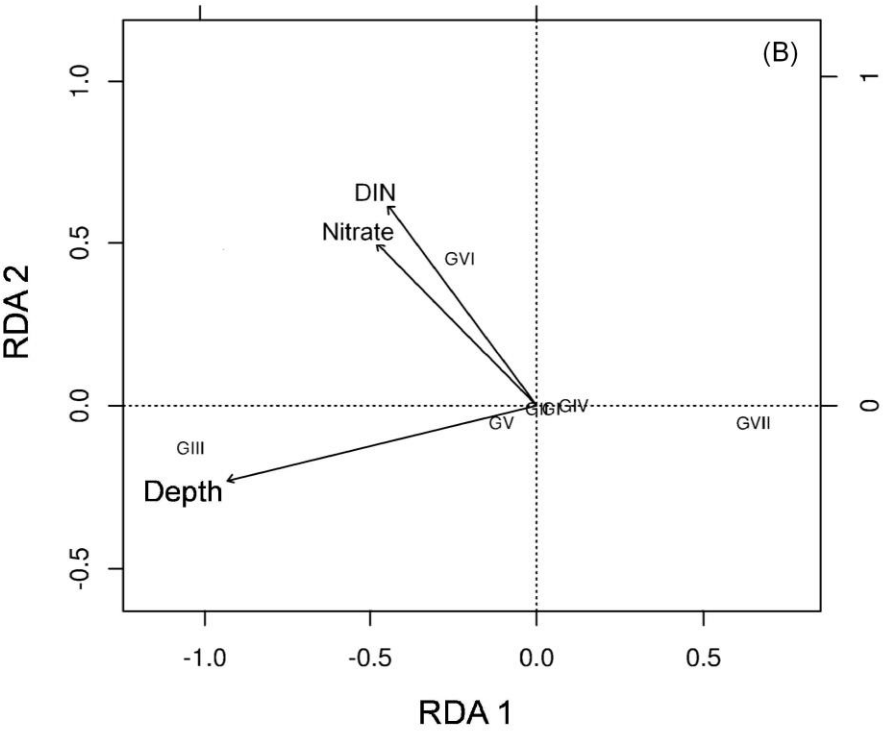


Fig. 4 Redundancy Analysis (RDA) for the correlation between FGBM, abiotic variables and zooplankton in the mesotrophic (a) and supereutrophic (b) reservoirs. Functional groups based on morphology = I, II, III, IV, V, VI, VII.

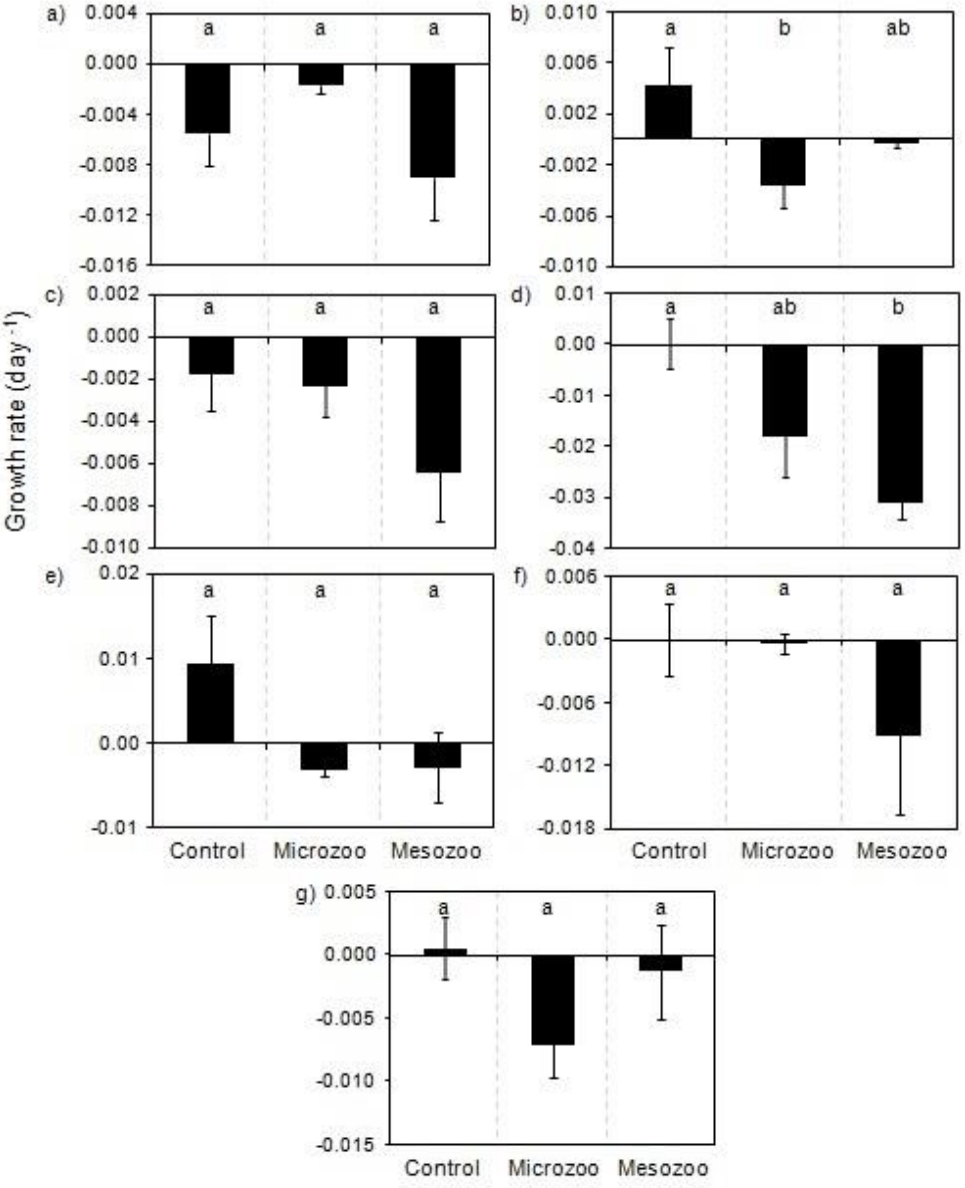


Fig. 5 Mean growth rate and standard error (vertical bars) of the functional groups based on the morphology I (a), II (b), III (c), IV (d), V (e), VI (f), VII (g) in the experiment in mesotrophic reservoir. “a”, “b” and “ab” show the significant differences between control and treatments (same letters do not differ significantly, and “ab” differ between treatments). Control = absence of zooplankton; Microzoo = presence of microzooplankton; Mesozoo = presence of mesozooplankton.

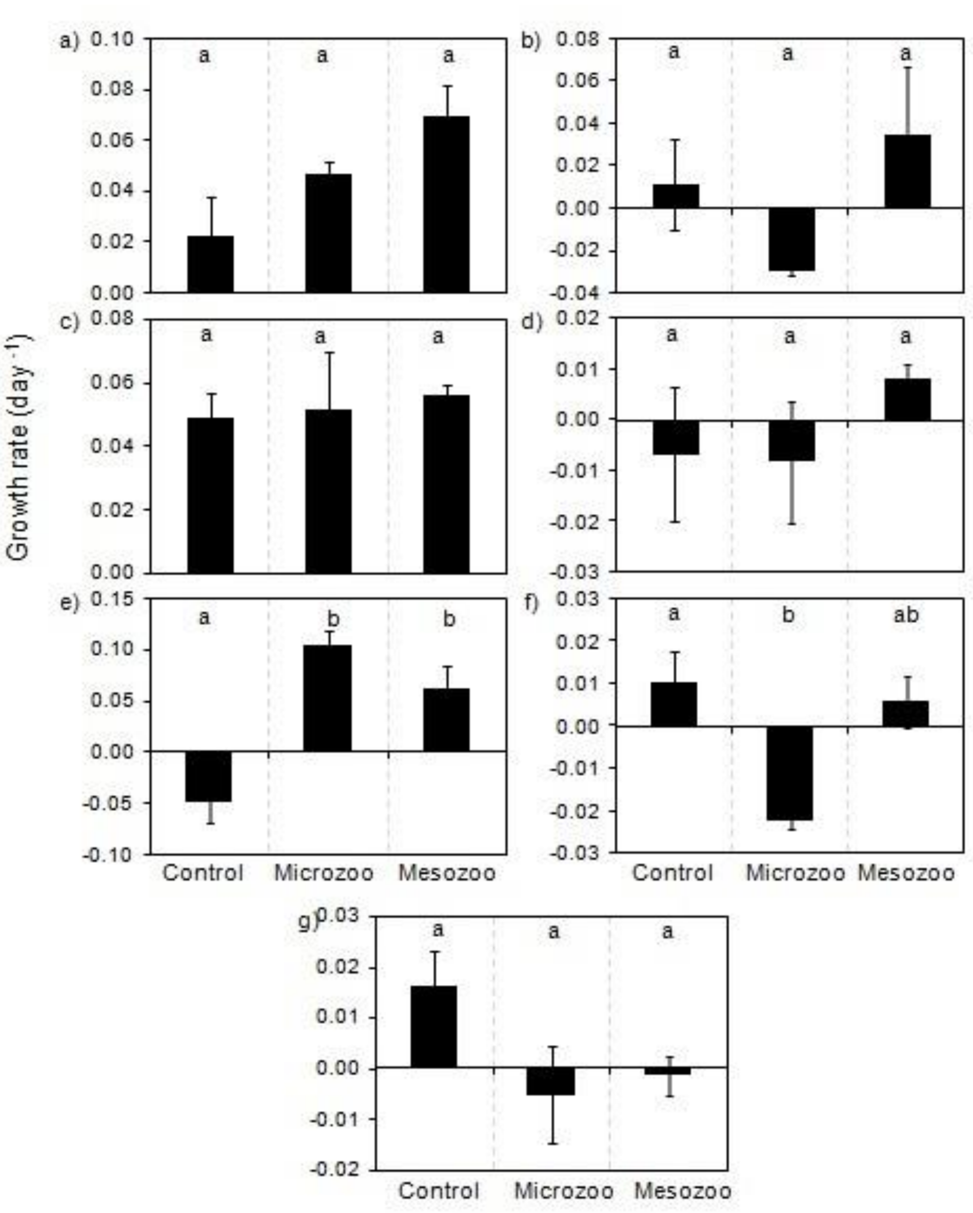


Fig. 6 Mean growth rate and standard error (vertical bars) of the functional groups based on the morphology I (a), II (b), III (c), IV (d), V (e), VI (f), VII (g) in the experiment in supereutrophic reservoir. “a”, “b” and “ab” show the significant differences between control and treatments (same letters do not differ significantly, and “ab” differ between treatments). Control = absence of zooplankton; Microzoo = presence of microzooplankton; Mesozoo = presence of mesozooplankton.

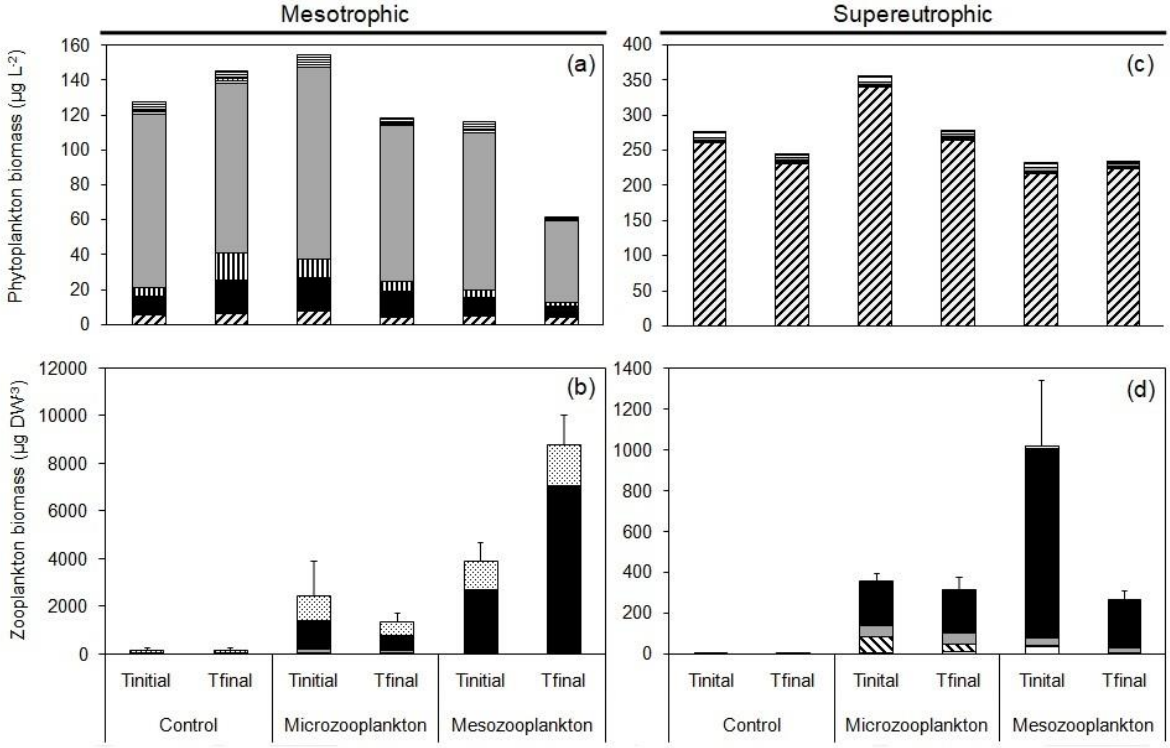


Fig. 7 Biomass phytoplanktonic (µg L^{-2}) and zooplanktonic (µg DW^{-3}) and standard error (vertical bars) of the FGBM and zooplankton groups in the experiment conducted in the mesotrophic (a and b) and supereutrophic reservoirs (c and d). Control = absence of zooplankton; Microzooplankton = presence of microzooplankton; Mesozooplankton = presence of mesozooplankton; Tinitial = beginning of experiment; Tfinal = end of experiment. Functional groups based on morphology: ▤ = group I, ░ = group II, ☐ = group III, ▒ = group IV, ▥ = group V, ■ = group VI, ▨ = group VII. Zooplankton: ☐ = Rotifera, ▧ = Nauplii, ▒ = Copepoda Cyclopoida, ■ = Copepoda Calanoida, ░ = Cladocera.

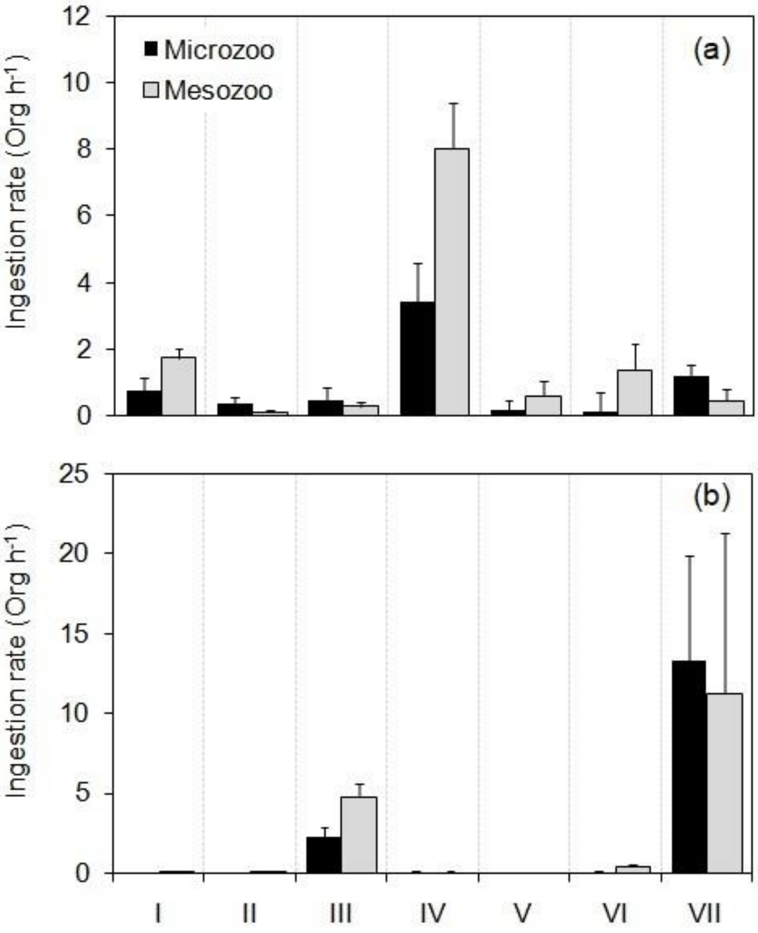


Fig. 8 Ingestion rate (day $^{-}$1) and standard error (vertical bars) of the zooplankton groups in the experiment in the reservoirs Mesotrophic (a) and Supereutrophic (b). Microzoo = presence of microzooplankton; Mesozoo = presence of mesozooplankton. I, II, III, IV, V, VI and VII = functional groups based on morphology. * = there was a difference between treatments.

Supplementary material

Table S1. Morphological and physiological characteristics (toxicity), representative taxa for each morpho-functional group, and the degree of susceptibility to predation by zooplankton. Adapted from Colina *et al*. (2016).

FGBM	Characteristics	Representative taxon	Toxic potential	Susceptibility to predation
I	Small organisms occupying large areas	*Merismopedia tenuissima*, *Planktosphaeria gelatinosa*	0	High
II	Small flagellates with siliceous structures	*Mallomonas caudata*	0	Low
III	Broad filaments with gas-vacuoles	*Cylindrospermopsis raciborskii*, *Planktothrix agardhii*	1	Low
IV	Organisms of medium size without specialized structures	*Cosmarium* sp., , *Staurastrum* sp., *Geitlerinema amphibium*	0	High
V	Medium to large single-celled flagellates	*Rhodomonas lacustris*, *Peridinium* sp.	1	Medium
VI	Organisms without flagella with silicoso exoskeleton	*Aulacoseira granulata*, *Thalassiosira* sp.	0	Medium
VII	Large mucilaginous colonies	*Microcystis aeruginosa*, *Botryococcus braunii*	1	Low

Table S2. Taxonomic composition of the phytoplankton community by functional group based on morphology (FGBM) in the mesotrophic reservoir.

FGBM	Species identified
I	*Ankistrodesmus fusiformis*, *Merismopedia tenuissima*, *Monoraphidium griffthii* and *Planktosphaeria gelatinosa*
II	*Mallomonas caudata*
III	*Cylindrospermopsis raciborskii*, *Dolichospermum* sp. and *Planktothrix agardhii*
IV	*Closterium* sp.1, *Closterium* sp.2, *Coelastrum indicum*, *Coenocystis* sp., *Cosmarium commissurale*, *C. margaritatum*, *Desmodesmus quadricauda*, *Dictyosphaerium elegans*, *Euastrum abruptum*, *Eutetramorus nygaardii*, *E. planctonicus*, *Geitlerinema amphibium*, *Kirchneriella obesa*, *Pediastrum tetras*, *Pseudanabaena* sp., *Quadrigula closterioides*, *Scenedesmus acuminatus*, *Sphaeroscystis schroeteri*, *Staurastrum curvimarginatum*, *S. cuspidatus*, *S. dilatatum*, *S. leptocladum*, *S. orbiculare*, *S. tetracerum*, *S. trifidum*, *Staurastrum* sp., *Tetraedron gracile*, *T. mediocris* e *T. trigonum*
V	*Chroomonas* sp., *Cryptomonas* sp., *Euglena* sp., *Peridinium* sp., *Rhodomonas lacustris*, *Trachelomonas hispida* and *T. volvocina*
VI	*Aulacoseira granulata*, *Cylindrotheca closterium*, *Cymbella* sp., *Eunotia* sp., *Navicula* sp., *Surirella* sp., *Thalassiosira* sp. and *Ulnaria ulna*
VII	*Aphanocapsa* sp. and *Botryococcus braunii*

Table S3. Taxonomic composition of the phytoplankton community by functional group based on morphology (FGBM) in thesupereutrophic reservoir.

FGBM	Species identified
I	*Merismopedia tenuissima*, *Monoraphidium griffthii* and *Planktosphaeria gelatinosa*
II	*Mallomonas caudata*
III	*Anabaena* sp.,*Cylindrospermopsis raciborskii, Dolichospermum viguieri, Planktothrix agardhii* and *Sphaerospermopsis aphanizomenoides*
IV	*Actinastrum hantszchii, Closterium* sp., *Coelastrum indicum, Dictyosphaerium elegans, D. pulchellum, Geitlerinema amphibium, Kirchneriella obesa, Micractinium pusillum, M. quadrisetum, Pseudanabaena* sp. and *Scenedesmus acuminatus*
V	*Chroomonas* sp., *Cryptomonas* sp., *Euglena* sp., *Peridinium* sp., *Rhodomonas lacustris, Trachelomonas híspida* and *T. volvocina*
VI	*Aulacoseira granulata, A. granulata var. angustissima, Cylindrotheca closterium, Cyclotella meneghiniana, Eunotia* sp., *Gomphonema* sp., *Navicula* sp. and *Ulnaria ulna*
VII	*Aphanocapsa* sp., *Botryococcus braunii, Microcystis aeruginosa, M. panniformis, Sphaerocavum brasilensis* and *Woronichinia karelica*

Table S4. Statistical analysis - ANOVA one way - of the growth rate of phytoplankton groups based on morphology (FGBM) in *in situ* experiments.

	MESOTROPHIC			**SUPEREUTROPHIC**		
	Df	**F**	***p***	**Df**	**F**	***p***
Group I	2	2.082	0.206	2	4.169	0.073
Group II	2	4.408	**0.057**	2	2.049	0.209
Group III	2	1.942	0.224	2	0.094	0.912
Group IV	2	7.513	**0.023**	2	0.754	0.51
Group V	2	3.103	0.119	2	16.01	**0.003**
Group VI	2	1.204	0.364	2	9.694	**0.013**
Group VII	2	1.886	0.231	2	2.46	0.166

Table S5. Statistical analysis - ANOVA one way - of the ingestion rate of micro and mesozooplankton on phytoplankton groups based on morphology (FGBM) in *in situ* experiments.

	MESOTROPHIC			**SUPEREUTROPHIC**		
	Df	**F**	***p***	**Df**	**F**	***p***
Group I	1	3.673	0.128	1	0.719	0.444
Group II	1	0.45	0.539	1	1.73	0.259
Group III	1	0.284	0.622	1	6.184	0.0677
Group IV	1	6.467	0.063	1	0.003	0.96
Group V	1	0.721	0.444	1	0.5	0.519
Group VI	1	1.641	0.269	1	5.961	0.071
Group VII	1	2.36	0.199	1	0.029	0.872