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Impacto do deplecionamento artificial do nível d'água de um reservatório tropical sobre a comunidade de macroinvertebrados bentônicos

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Orientador: Prof. Dr. Marcos Gomes Nogueira

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Sumário

Apresentação da tese

O objetivo geral deste trabalho foi investigar os efeitos do deplecionamento artificial do nível d'água, empregado em um reservatório tropical para fins de controle do crescimento excessivo de plantas aquáticas, sobre a comunidade de macroinvertebrados bentônicos.

Primeiramente, apresentamos uma introdução geral abordando a problemática da proliferação de macrófitas aquáticas em reservatórios e as técnicas existentes para o controle e manejo dessas plantas, destacando o procedimento de deplecionamento artificial do nível d'água, foco desta pesquisa. Além disso, fizemos uma breve revisão dos estudos de caso realizados no reservatório de Salto Grande (rio Paranapanema-SP/PR), selecionado como área deste estudo, onde o deplecionamento artificial é utilizado.

Na sequência, elencamos nossos objetivos gerais e específicos, bem como nossas hipóteses. Dois capítulos foram elaborados, os quais foram redigidos em inglês sob formato de artigo científico. O primeiro deles trata da distribuição espacial e temporal dos macroinvertebrados bentônicos em diferentes fases do processo de deplecionamento. O segundo avalia a variação da estrutura e do papel funcional da comunidade de macroinvertebrados bentônicos da região litorânea nos períodos pré e pós-deplecionamento do nível d'água.

As considerações finais foram fundamentadas nos resultados encontrados em ambos os capítulos. Nossas conclusões fornecem importantes informações ecológicas sobre a estrutura e funcionamento da comunidade de macroinvertebrados bentônicos frente ao deplecionamento do nível d'água em reservatórios tropicais do tipo fio d'água. Contribuímos, assim, para o melhor conhecimento dos efeitos dessa técnica sobre esses organismos e esperamos que as informações sirvam de subsídio para tomada de decisão em processos de gestão.

Introdução Geral

1) Métodos de controle e manejo de macrófitas aquáticas em reservatórios

A construção de reservatórios implica no surgimento de ecossistemas que possuem características intermediárias entre ambientes lóticos e lênticos. Tais empreendimentos promovem consideráveis alterações no regime dos rios e, consequentemente, na estrutura física, química e biológica do meio aquático (e.g. Tundisi et al., 1999; 2018; Rosemberg, et al., 2000; Poff and Zimmerman, 2010; Nogueira et al., 2012; Simões et al., 2015; Santos et al., 2018). Estudos apontam para uma redução na biodiversidade (Vörösmarty et al., 2010; Winemiller et al., 2016; Ruocco et al., 2018) e atrelam estas modificações a perdas econômicas (Tundisi et al., 2014), como as relacionadas à proliferação de cianobactérias (Azevedo, 1998; Sanches et al., 2012) e macrófitas aquáticas (Pompêo, 2008, 2017).

No caso das macrófitas aquáticas, seu desenvolvimento é favorecido pela atenuação da velocidade da água e pelo aumento do tempo de residência decorrentes do represamento (Bianchini Jr. and Cunha-Santino, 2014). Embora essas plantas sejam fundamentais para o metabolismo dos ecossistemas, participando da ciclagem de nutrientes, fluxo de energia, dinâmica dos sedimentos e fornecendo hábitats, recursos e refúgios para diversos organismos (Pompêo, 2017), podem ser consideradas como "daninhas" quando seu crescimento acentuado causa problemas para os usos múltiplos do reservatório (Thomaz, 2002; Pompêo, 2008). As macrófitas podem obstruir as grades de tomadas d'água para turbinas geradoras de energia elétrica, o que ocasiona prejuízos à geração de eletricidade; podem comprometer as atividades de navegação, a pesca, os esportes náuticos e também podem afetar a saúde pública, uma vez que constituem hábitats propícios para procriação de insetos vetores de doenças humanas (Thomaz and Bini, 2003; Esteves, 2011).

Dessa forma, programas de monitoramento e ações de manejo das macrófitas aquáticas são essenciais para compreensão do problema e controle do crescimento excessivo de suas populações em reservatórios. Objetiva-se que os métodos utilizados sejam capazes de solucionar os prejuízos decorrentes das grandes infestações e causem o mínimo impacto aos usos múltiplos do sistema, à qualidade da água e à biota, sendo sustentáveis a longo prazo (Pompêo, 2017). No entanto, no Brasil destaca-se a ausência de uma legislação específica envolvendo o monitoramento e controle de plantas aquáticas em sistemas abertos (rios e reservatórios) (Pompêo, 2008), sendo "autorizado o uso de produtos ou agentes de processos químicos, biológicos ou físicos para o controle do crescimento da fauna e flora em corpos hídricos superficiais" (Resolução CONAMA 467, 2015).

Cada um dos distintos procedimentos de controle (químico, biológico ou físico direto e indireto) apresenta vantagens e desvantagens, com maior ou menor eficiência de acordo com a espécie que se pretende controlar (Pompêo, 2017). Todavia, cabe ressaltar que na maioria das vezes os métodos de manejo atualmente aplicados são estudados e avaliados em sistemas fechados, em escala experimental (Marcondes et al., 2003; Berti, 2013), sendo desconhecida sua eficiência e os reais impactos causados nos ecossistemas.

O controle químico, realizado através do uso de agrotóxicos, é comprovadamente eficiente, apresentando resultados rápidos, com baixo investimento (Mello, 2008), porém foi considerado como sendo o método que causa maior impacto ambiental, quando comparado aos demais (Berti, 2013). Isto se deve ao fato de os compostos químicos aplicados atuarem não somente sobre a planta alvo, mas também nos demais organismos presentes no hábitat, afetando níveis tróficos superiores das cadeias alimentares (Pompêo, 2017). Ainda, os herbicidas permanecem na água, podendo agir por muito tempo e longe do local de aplicação (Negrisoli et al., 2003; Pompêo, 2017). O controle biológico, em contrapartida, é considerado o menos impactante (Berti, 2013). Apesar disso, esse método apresenta elevado custo, longo tempo de investimento para obtenção de resultados e representa um risco na introdução de espécies exóticas (Cuda, 2014), exigindo um controle rigoroso da nova espécie introduzida no meio (Berti, 2013).

Com relação aos métodos físicos, alguns são aplicados diretamente sobre a planta, sendo considerados diretos, enquanto que outros são aplicados de forma indireta (Pompêo, 2017). São exemplos de aplicação direta o uso de tesouras, ganchos, lâminas cortantes e deslizantes, dragagem e ceifadeiras. Entre os vários mecanismos que podem ser aplicados, o método físico direto costuma ser o primeiro a ser considerado. As desvantagens desse procedimento relacionam-se principalmente à dispersão de partes cortadas das plantas que funcionarão como inóculos para novas colonizações, além de promoverem alterações nas condições limnológicas da água, como aumento na concentração de nutrientes e redução do oxigênio (Pompêo, 2017). Além do mais, a remoção mecânica pode trazer prejuízos à fauna local (Bellaud, 2014). Importante de se destacar, é que planos de manejo com implementação de controle físico direto também devem incluir os devidos destinos para a biomassa removida e estabelecer as áreas para descarte ou uso desse material (Pompêo, 2017).

Quanto aos métodos indiretos, podemos citar a aplicação de chama, tingimento da coluna d'água, uso de telas para cobertura do sedimento e alterações no nível de água. O uso da chama apresenta elevada especificidade no controle de plantas emersas, já que se faz necessário o contato do equipamento com as folhas ou planta aquática. Sua desvantagem refere-se ao preço dos combustíveis utilizados (Marchi et al., 2005; Berti, 2013). Já o tingimento da água pode prejudicar não só o desenvolvimento das macrófitas infestantes, como o de outras comunidades aquáticas. Da mesma maneira, o uso de telas sobre o sedimento pode impedir o crescimento de macrófitas enraizadas, mas também reduzir a área habitável para organismos bentônicos ou para aqueles que utilizam o sedimento para desova (Pompêo, 2008). Perigos a barqueiros e nadadores também devem ser destacados (Pompêo, 2008). Além disso, em ambientes rasos, com zona eufótica completa, as macrófitas também podem colonizar a porção superior à tela (Pompêo, 2008; Berti, 2013).

As alterações do nível d'água, por sua vez, consistem em modificar a altura da lâmina d'água, permitindo tanto aumento como diminuição do nível do reservatório (Pompêo, 2008; Berti, 2013; Pompêo, 2017). A "Operação Rock", realizada pela Companhia Hidroelétrica do São Francisco no sistema Moxotó - Paulo Afonso (BA) em meados da década de 90, é um exemplo de manejo que promoveu aumento do nível e consequente aumento de vazão no reservatório. A fim de resolver o problema de infestação de *Egeria densa* que ficava retida nas grades de proteção da entrada de água das turbinas, foi decidido acumular água no reservatório e, em dada cota, as comportas foram abertas permitindo a saída de um grande volume de água a jusante. Com o aumento da vazão de saída foi eliminada considerável biomassa da macrófita.

No entanto, em poucos meses após esta operação registrou-se reinfestação de *E. densa* no reservatório (Pompêo, 2008), sugerindo ineficiência da ação. Tal procedimento também pode ser desvantajoso se considerarmos o contexto de instalação de reservatórios em cascata e transferência de efeito, visto que as plantas liberadas à jusante se tornarão um problema para os próximos reservatórios do sistema.

Ao contrário do que foi registrado no sistema Moxotó - Paulo Afonso, a técnica de diminuição do nível d'água, chamada de deplecionamento ou rebaixamento artificial, tem sido empregada com êxito há cerca de 14 anos no reservatório de Salto Grande (rio Paranapanema - SP/PR) para controlar o crescimento excessivo da macrófita submersa *Egeria* spp. Segundo avaliação da empresa concessionária, além de eficaz, o deplecionamento artificial realizado em um curto período de tempo apresenta uma boa relação de custo-benefício (AMCR, comunicação pessoal). Durante o procedimento, a diminuição do nível d'água promove a exposição da região litorânea, prejudicando, assim, as espécies que possuem biótipo submerso, já que ficam susceptíveis ao dessecamento e consequente morte (Thomaz et al., 2006; Pierini et al., 2006). Reduções drásticas de biomassa de planta foram observadas em curtos períodos de seca severa natural (Thomaz et al., 2006), além de diagnosticada uma baixa resiliência de seus propágulos diante da exposição ao ambiente seco (Pierini et al., 2006).

Porém, este método ainda é considerado potencial comprometedor dos usos múltiplos do sistema, visto a redução temporária do volume útil do reservatório (Pompêo, 2017). Estudos realizados com objetivo de avaliar os impactos da variação do nível d'água em reservatórios no médio e longo prazo (i.e. sazonalmente) têm mostrado importantes alterações nas condições limnológicas (Brandimarte et al., 2008; Naliato et al., 2009; Valdespino-Castillo et al., 2014) e na dinâmica da biota, interferindo em todos os níveis tróficos do ecossistema (Nogueira, 2001; Nadai and Henry, 2009; Shimabukuro and Henry, 2011; Santos et al., 2013; Valeriano-Riveros et al., 2014; Zerlin and Henry, 2014). Contudo, os efeitos do deplecionamento artificial do nível d'água de curto prazo sobre as propriedades físicas, químicas e biológicas de reservatórios tropicais devem ser melhor entendidos.

2) O deplecionamento artificial do nível d'água no reservatório de Salto Grande, rio Paranapanema SP/PR

O reservatório de Salto Grande (22°57'26,80" S – 49°57'09,12" O), objeto do nosso estudo, localiza-se no final da porção alta e início da porção média da bacia do rio Paranapanema (SP/PR), sendo o quinto da cascata de 11 reservatórios instalados nesse rio. Com uma área de 12 km^2, volume de 44,2 hm^3 e vazão média de 395 $m^3\ s^{-1}$, opera a fio d'água com tempo de residência em torno de 1,5 dias (Nogueira et al., 2012). Classificado como meso-eutrófico de acordo com o índice de estado trófico, modelo original de Carlson (1977) (Pomari, et al., 2018), o reservatório recebe um aporte significativo de sedimentos e nutrientes provenientes do rio Pardo, seu principal tributário (Nogueira et al., 2012). Na mesma margem (direita), o rio Novo desemboca próximo à zona da barragem. Além dos tributários, o reservatório possui uma pequena baía e duas lagoas laterais conectadas ao seu corpo central, constituindo assim, um sistema de alta complexidade espacial.

Inaugurado no ano de 1958, Salto Grande está sujeito ao processo natural de "envelhecimento", acumulando os efeitos finais das ações que ocorrem em sua bacia hidrográfica. Podemos citar como exemplos o uso intensivo do solo no entorno, que causa erosão e escoamento de sedimentos, e o despejo de esgotos domésticos, que somado às atividades agrícolas, acarreta um incremento nutricional (Nogueira et al., 2012). Tais condições potencializam o crescimento da vegetação aquática, com consequente comprometimento dos usos múltiplos do reservatório. No caso, a espécie submersa *Egeria* spp. é particularmente favorecida e requer atenção. A presença de grandes populações dessa planta reduz o fluxo de água nas lagoas laterais, diminui a concentração de oxigênio dissolvido nos períodos noturnos, acumula resíduos sólidos, além de gerar dificuldades de acesso à pescadores, banhistas e embarcações na região (AMCR, Comunicação pessoal).

A alternativa encontrada por gestores para o manejo e controle do crescimento excessivo de *Egeria* spp e, secundariamente, de *Urochloa* spp. no reservatório de Salto Grande foi a implementação da técnica de deplecionamento artificial do nível de água. O procedimento foi realizado pela primeira vez em 2004 em caráter experimental e, diante do sucesso obtido em termos de redução de biomassa e da área infestada por essas plantas, passou a ser repetido anualmente a partir de 2011, sempre na época de estiagem (principalmente no inverno), quando as populações apresentam menor densidade devido à senescência das formas adultas.

Estabelecida a data para realização do procedimento, a diminuição artificial do nível d'água se inicia com uma redução abrupta da cota operacional do reservatório, que é rebaixada cerca de 2,50 metros num intervalo de 24 horas. Essa condição de águas baixas é mantida durante aproximadamente 15 dias consecutivos com objetivo de expor as macrófitas presentes na região litorânea à desidratação e consequente morte. Após esse período de tempo, recomenda-se que o material vegetal seja removido e o volume de água pode então ser reestabelecido. O reestabelicimento da cota operacional dura 24 horas, quando o processo se encerra.

Estudos realizados nas lagoas marginais conectadas ao reservatório de Salto Grande revelam consideráveis variações nas condições limnológicas quando comparados os períodos que antecedem o deplecionamento, durante o procedimento e após o reenchimento do reservatório (Vianna, 2008; Debastiani-Júnior and Nogueira, 2015; Portinho and Nogueira, 2017). Sugere-se que as mudanças na qualidade da água sejam ainda mais acentuadas nas lagoas marginais, devido à elevada biomassa de plantas submersas e à menor profundidade registrada nesses ambientes (AMCR, comunicação pessoal). Dentre as alterações detectadas, podemos citar uma acentuada diminuição na concentração de oxigênio e pH, e um incremento de temperatura, condutividade elétrica, clorofila, fósforo total e amônia no período de águas baixas, ou seja, durante o procedimento (Debastiani-Júnior and Nogueira, 2015).

Com relação à resposta das assembleias zooplanctônicas das lagoas frente ao manejo do nível d'água, notou-se uma diminuição da riqueza e diversidade de espécies durante o processo, sendo que imediatamente no início do deplecionamento registrou-se um aumento temporário da abundância/dominância de espécies oportunistas (i.e. bosminídeos) (Debastiani-Júnior and Nogueira, 2015). Entretanto, poucas semanas após o reenchimento do reservatório, observou-se um enriquecimento na comunidade, que apresentou, inclusive, o ingresso de espécies não-planctônicas (Debastiani-Júnior and Nogueira, 2015). Isso provavelmente devido à eclosão de ovos que se encontravam dormentes no sedimento (Portinho and Nogueira, 2017). Assim, de maneira geral, a diminuição do nível d'água parece não afetar negativamente o zooplâncton.

Basicamente o mesmo padrão descrito anteriormente foi observado para a ictiofauna das lagoas marginais. Com exceção de alguns registros esporádicos, não se detectou mortalidade de peixes e, após uma redução inicial da riqueza, houve o retorno dos valores determinados previamente ao deplecionamento (Vianna, 2008). Alguns dados descrevem eventuais aumentos da riqueza de peixes no corpo do reservatório durante o processo de deplecionamento, os quais podem estar associados a um efeito de concentração da fauna devido ao menor volume de água, e/ou ao deslocamento dos peixes que habitavam os ambientes laterais para o centro do reservatório (AMCR, comunicação pessoal).

Para a comunidade de macroinvertebrados associados às macrófitas aquáticas das lagoas marginais, foi observado um incremento na riqueza, diversidade e equitabilidade da fauna fitófila após o procedimento de deplecionamento, com destaque para redução na densidade de espécies dominantes, corroborando, assim, com a Hipótese de Distúrbio Intermediário (Marçal, 2014). Aqui, a perturbação decorrente do deplecionamento artificial pareceu resgatar a variabilidade ambiental (atenuada pelas condições de represamento), refletindo na ocorrência e organização dos organismos (Marçal, 2014). Por outro lado, a análise da fauna de macroinvertebrados bentônicos dessas lagoas mostrou que apesar de existir um aumento no número de táxons encontrados no pós-deplecionamento, esse valor ainda é menor do que os detectados no período que antecedeu a ação de manejo (Lage, 2008).

Sabendo-se que a estabilidade relativa das comunidades é determinada pela resistência e resiliência dos organismos frente a perturbações e que o sedimento integra informações do ambiente aquático, podendo acumular os efeitos das perturbações de nível d’água, o objetivo geral deste trabalho foi investigar os impactos do deplecionamento artificial do nível d’água sobre a comunidade de macroinvertebrados bentônicos nos diferentes compartimentos de um reservatório tropical.

Objetivos específicos e hipóteses

Capítulo I: "Artificial water level drawdown: a strategy for aquatic macrophytes control that does not affect the benthic macroinvertebrates community structure"

- Objetivo: Avaliar a distribuição espacial e temporal da comunidade de macroinvertebrados bentônicos em relação ao deplecionamento artificial do nível d'água de um reservatório tropical.

- Hipótese: Haverá uma redução nos valores dos atributos ecológicos da comunidade de macroinvertebrados bentônicos frente ao processo de deplecionamento do nível d'água, com dominância dos táxons considerados tolerantes na fase pós-deplecionamento. Além disso, os impactos serão distintos de acordo com os compartimentos do reservatório avaliados.

Capítulo II: "Immediate functional response of littoral benthic macroinvertebrates community to the artificial drawdown employed in a tropical reservoir for macrophytes control"

- Objetivo: Avaliar a variação da estrutura e o papel funcional da comunidade de macroinvertebrados bentônicos da região litorânea do reservatório exposta ao deplecionamento artificial do nível d'água de curto prazo em um reservatório tropical.

- Hipótese: Ocorrerá alteração na estrutura e no papel funcional da comunidade, com redução nos valores dos índices de diversidade taxonômica e funcional na fase pós-deplecionamento, decorrentes da redução de táxons sensíveis.

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Capítulo I

"Artificial water level drawdown: a strategy for aquatic macrophytes control that does not affect the benthic macroinvertebrates community structure"

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Abstract

Artificial water level fluctuation is an alternative to control submerged macrophytes infestation in reservoir systems. A short-term drawdown, for example, exposes the plants to dehydration and consequent death, promoting a decrease in biomass. Nevertheless, the knowledge of how this operational procedure affects other biotic components of the ecosystem is scarce for tropical region. The aim of this study was to determine the influence of water level drawdown employed to macrophytes control on benthic macroinvertebrates community of a tropical run-of-river reservoir, investigating the spatial and temporal distribution of these organisms. Samples were collected on samplings days undertaken during the pre-drawdown phase, low water (i.e., during-drawdown) and after re-filling (i.e., post-drawdown), in longitudinal and lateral compartments of the reservoir. Macroinvertebrates richness, density, Shannon’s diversity and Pielou’s equitability indexes, even as the community structure ordination were evaluated. No significant differences were detected for these ecological attributes between the water level phases. Neither between reservoir compartments comparison, except for density, that was significantly higher in longitudinal compartment of reservoir, mainly because *Corbicula fluminea*, *Melanoides tuberculata* and Oligochaeta contribution. The NMDS and PERMANOVA tests corroborated the structural difference only in spatial distribution of the community. So we concluded that artificial water level drawdown over a short timeframe technique to control submerged macrophytes does not seem negatively impact the benthic macroinvertebrates fauna of tropical reservoir.

Keywords: aquatic invertebrates; Salto Grande Reservoir; submerged plants; tropical reservoirs; water level management.

Introduction

Artificial water level fluctuation is an indirect physical method for aquatic macrophytes control (Pômpeo, 2017). It has being used to mitigate problems of economic losses caused by these plants in reservoir systems around the world (Cook et al., 2006; Pômpeo, 2008; Pompêo, 2017), where the massive occurrence of macrophytes can result in clog of hydropower intake turbines, disruption of navigation and recreational activities (Bini and Thomaz, 2005; Boschilia et al., 2012; Portinho and Nogueira, 2017). Advantages of this management strategy are related to not be toxic (Cook, 1980; Pômpeo, 2017), not threat native species by competition (Cuda, 2014) and have low cost to be employed with satisfactory results (Cook, 1980; Thomaz, 2002).

In water level manipulation, managers need to regulate the reservoir operational quota. In drawdown water level, the aquatic macrophytes will be exposed to the environmental conditions, such as freezing or dryness, and in a short period of time their tissues will be dehydrated taking to the death of the entire plant (Cook et al., 2006; Portinho and Nogueira, 2017). This technique has been the main method applied in order to control and prevent excessive growth of nuisance plants in North America reservoirs (Cook et al., 2006). It has also being employed in tropical and subtropical reservoirs of South America, mainly because the proliferation of Hydrocharitaceae native species (Thomaz, 2002; Thomaz et al., 2006; Debastiani-Júnior and Nogueira, 2015; Portinho and Nogueira, 2017).

However, changes in water level are frequently followed by modification in water quality and limnological conditions (Baumgärtner et al., 2008; Wantzen et al., 2008; White et al., 2008; Naliato et al., 2009; Valdespino-Castillo et al., 2014; Debastiani-Júnior and Nogueira, 2015). It can affect the whole system hydrodynamics, changing the stratification and light penetration (Pompêo, 2008), nutrient retention, sediment settling, depth and other important physical and chemical variables (McEwen and Butler, 2010). Abiotic changes, in turn, influence on diversity, density and resilience of reservoirs biota (e.g. Wilcox and Meeker, 1991; Furey et al., 2006; Shimabukuro and Henry, 2011; Santos et al., 2013; Valeriano-Riveros et al., 2014; Zerlin and Henry, 2014; Debastiani-Júnior and Nogueira, 2015). Furthermore, the impact on biota can be more assertive when the timing of water release or impoundment coincides with important life history events of organisms (Gregory et al., 2000; Durant et al., 2007; McEwen and Butler, 2010).

Considering that the management of water level regimes by artificial drawdown often occurs much more rapidly than natural drying events in tropical regions, knowledge of the effects on other biotic components of the ecosystem is necessary (Debastiani-Júnior and Nogueira, 2015; Portinho and Nogueira, 2017). Amongst freshwater biota, benthic macroinvertebrates are the most commonly used for the assessment and monitoring of the ecological status of lakes and reservoirs, because they often reflect changes in the environmental conditions (Rosenberg and Resh, 1993). Studies revealed a strong decline in species richness with high amplitude of water level fluctuations (Aroviita and Hämäläinen, 2008), besides changes in ecosystem functions associated to these invertebrates (Wantzen et al., 2008), such as the leaf-litter decomposition by shredders (Bjelke et al., 2004). Nonetheless, few studies have investigated the effects of the artificial water level manipulation on benthic macroinvertebrates in tropical reservoirs (Magbanua et al., 2015), mainly addressing the effect of extreme changes in water level over a short time period.

In this study, we aimed to analyze the spatial and temporal distribution of the benthic macroinvertebrates community in a tropical reservoir under an artificial short-term water level drawdown. Changes in the ecological attributes were assessed comparing data from distinct compartments of the reservoir (longitudinal and lateral dimensions) in the period before drawdown (i.e., the pre-drawdown phase), during the low water (i.e., during drawdown phase) and after re-filling (i.e., the post-drawdown phase). Physical and chemical characteristics of water and sediment were also examined to identify the environmental changes that may have been affecting the benthic macroinvertebrates communities related to the drawdown. We predicted a reduction in the values of richness, density and diversity of the benthic macroinvertebrates during the water level management, with higher impact in lateral compartment. Additionally, the predominance of tolerant taxa in the post-drawdown phase as results of the advection and water quality alterations was expected too.

Material and methods

Study area

The study was conducted in Salto Grande Reservoir (22°57’S, 49°57’W), located in the Paranapanema River (southeastern Brazil). The reservoir has an area of 12 km², a volume of 44.2 hm³, a mean water retention time of 1.5 days and a mean water discharge of 395 m³ s^{-1} (Nogueira et al., 2012). Despite its small size, the reservoir presents high spatial complexity, because besides the longitudinal gradient typically observed in reservoir systems (upstream – dam), Salto Grande has also considerable lateral influences (Perbiche-Neves and Nogueira, 2010). The Pardo River, on the right bank, is the main tributary. The Novo River, on the same bank, is important because it flows into a wetland near the dam zone. One bay and two marginal lagoons integrate the system too (Figure 1).

The management of the water level by artificial drawdown has been practiced annually in Salto Grande Reservoir, always during autumn–winter season (from June to August), as part of a long-term program used by the CTG Brasil hydropower energy company (before by Duke Energy Brasil) to mitigate the detrimental effects of *Egeria* spp. stands (Debastiani-Júnior and Nogueira, 2015; Portinho and Nogueira, 2017). Water level drawdown begins with the artificial and abrupt decrease in the reservoir's operational quota, which is lowered about 2.50 meters within 24 hours. The low water condition is maintained for approximately 15 consecutive days in order to expose the macrophytes present in the littoral region to dryness. After this time, the volume of water is restored. The re-filling of the water level lasts 24 hours, when the process ends.

Sampling design

The Salto Grande Reservoir was drawdrown by ~2 m over a period of 14 days, between July 13, 2013 and July 27, 2013 (Figure 2). Samples were collected on sampling days undertaken during the pre-drawdown phase (July 9, 2013), low water phase (July 25, 2013) and post-drawdown phase (September 24, 2013) in distinct areas of the reservoir, including the main longitudinal axis (lotic, transitional zone and lentic zones), denominated longitudinal compartment, and the lateral environments (lagoons, bay and Novo River tributary), denominated lateral compartment (Figure 1). The Pardo River was not included in the sampling sites because due to the high suspended material and high water velocity, macrophytes growth are absent in the region.

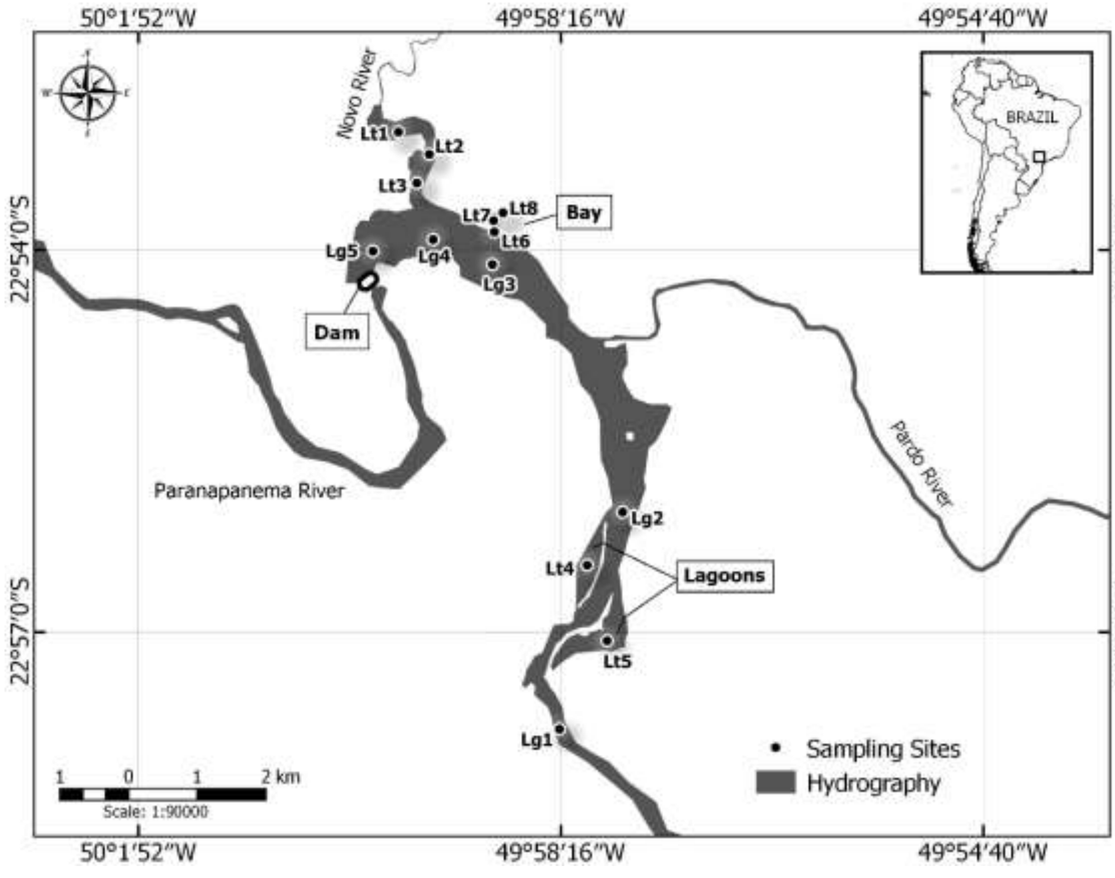

Figure 1. Geographic location of the study area showing the position of longitudinal (Lg) and lateral (Lt) sampling sites in Salto Grande Reservoir, Paranapanema River, Southeastern Brazil.

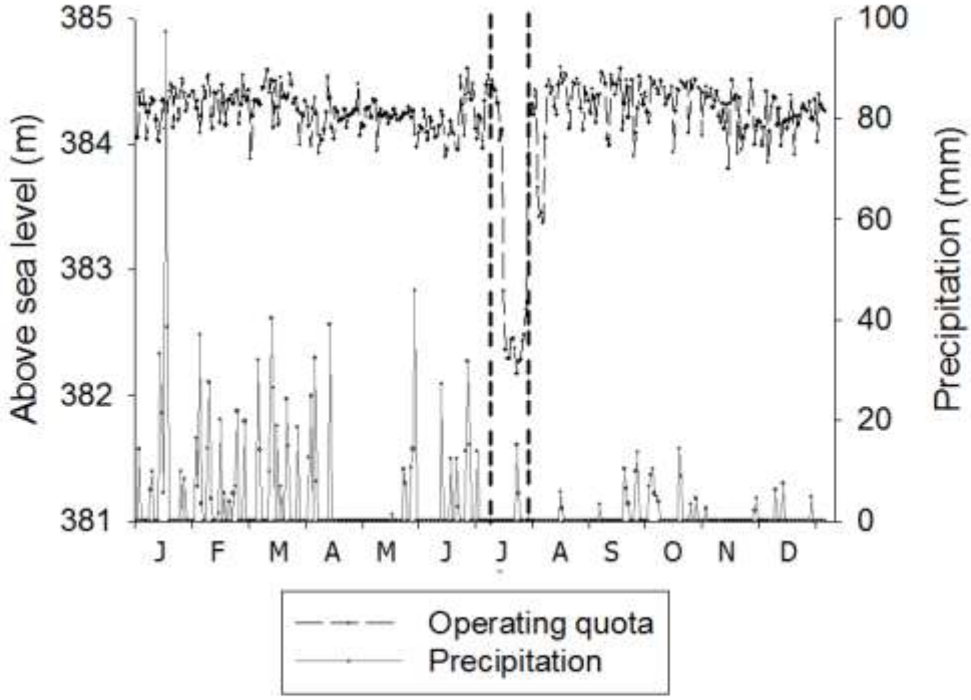

Figure 2. Water level fluctuation in Salto Grande Reservoir and daily precipitation registred in the year 2013. The dotted line indicates the timing of drawdown for the low water phase. Precipitation data source: INMET site.

In each site, the following parameters were measured at the bottom of the water column: temperature (Temp), dissolved oxygen (DO), pH, electric conductivity (K), turbidity (Tb), total dissolved solids (TDS) and oxide-reduction potential (ORP), using a calibrated Horiba probe (U-52). Depth (Dpt) was measured with a Speedtech® sonar. Sediment samples were collected for determination of organic matter content (OM) (Hakanson and Janson, 1983), particle size (VCS: very coarse sand; CS: coarse sand; MS: medium sand; FS: fine sand; VFS: very fine sand; SC: silt and clay) (Hakanson and Janson, 1983) and phosphorus (SP) and nitrogen concentration (SN) (APHA, 2012).

Simultaneously, benthic samples were collected in triplicate with a van Veen sampler (0.0198 m^2), washed through 250-µm mesh size sieves, fixed in 4% formalin and stored in 70% alcohol. In the laboratory, the organisms were counted and identified to the lowest taxonomic level based on specialized literature (Gaillard and Castellanos, 1976; Pennak, 1989; Brinkhurst and Marchese, 1989; Lopretto and Tell, 1995; Merritt and Cummins, 1996; Mariano and Froehlich, 2007; Domínguez and Fernández, 2009; Krantz and Walter, 2009; Mugnai et al., 2010).

Data analysis

A two-way ANOVA followed by Tukey's test was applied for detection of environmental differences between water level phases, compartments and their interaction. All limnologic parameters were log(x+1) transformed except for pH, and sediment parameters were arco-sene transformed. Different transformation methods were based on Gotelli and Ellison (2016) recommendations for continuous and percentual data. A Principal Component Analysis (PCA) was performed to identify spatial and temporal patterns of variation in the environmental data.

The macroinvertebrates count was converted in density (individuals per m^2) prior to statistical analyses. For comparisons between water level phases, compartments and their interaction, the following macroinvertebrates structure descriptors were used: richness, density, relative abundance, Shannon's diversity and Pielou's equitability indexes. All ecological attributes data were square-root transformed (Gotelli and Ellison, 2016) to reduce the influence of outliers and to fulfill the requirements of parametric two-way ANOVA. When significant factors were identified, Tukey's post hoc test was applied.

To characterize the macroinvertebrates community structure, we used non-metric multidimensional scaling (NMDS) derived from Bray-Curtis similarity matrices using square-root transformed density data. A PERMANOVA was then used to determine whether the variation in benthic macroinvertebrates community structure was significant. A specific composition analysis (SIMPER) was applied to determine the main taxa responsible for the observed differences.

Finally, a redundancy analysis (RDA) was performed to analyze the relationship between benthic macroinvertebrates community structure and environmental variables. For this, only the environmental variables with contribution in the two first components of PCA analysis were used and only the taxa with scores >0.5 were represented in the graph. An ANOVA was employed to check the RDA model significance.

All analyses of this study were conducted in R Cran software (RStudio, v. 1.1.456), using car, vegan and MASS packages.

Results

Environmental variables

Water properties and sediment characteristics differ between distinct water level phases (F=28.67, p=0.00), between compartments of the reservoir (F= 8.68, p=0.00) and also between the interaction of both factors (F=1.86, p=0.05).

Depth and temperature decreased significantly during drawdown and increased in the post-drawdown phase (Table 1; Table 2; Appendix 1A). The opposite was observed for turbidity data. The pH was significantly lower during and after artificial drawdown. Total dissolved solids and oxide-reduction potential increased during the low water phase and remained at similar concentrations in post-drawdown phase (Table 1; Table 2; Appendix 1A). Very coarse sand was significantly higher in post-drawdown (Table 1; Table 2; Appendix 1B).

In the lateral compartment of reservoir, depth, temperature (Table 1; Table 2; Appendix 2A) and the fractions of medium, fine and very fine sand were significantly lower (Table 1; Table 2; Appendix 2B). Total dissolved solids (Table 1; Table 2; Appendix 2A), organic matter content as well silt and clay sediment grains were significantly higher (Table 1; Table 2; Appendix 2B).

Related to the interaction between phases and compartments, the temperature was the only parameter that exhibited significant differences, with lower values in both compartments during drawdown phase (Table 2).

Table 1. Mean values and standard deviation (SD) of environmental variables measured in Salto Grande Reservoir in pre-drawdown, during drawdown and post-drawdown phases, in the longitudinal and lateral compartments.

Environmental variables	Pre-Drawdown		During Drawdown		Post-Drawdown	
	Longitudinal	Lateral	Longitudinal	Lateral	Longitudinal	Lateral
Dpt	9.02 (6.03)	3.74 (1.53)	4.82 (3.35)	2.16 (0.80)	7.52 (4.96)	3.85 (1.65)
Temp	20.04 (0.32)	19.68 (0.62)	17.23 (1.11)	15.56 (1.40)	20.24 (0.36)	20.61 (0.25)
DO	9.04 (0.81)	9.58 (1.68)	10.81 (0.46)	9.97 (2.20)	10.17 (0.69)	8.00 (2.64)
pH	7.23 (0.33)	6.74 (0.26)	6.31 (0.23)	6.35 (0.54)	6.09 (0.26)	6.08 (0.53)
K	62.70 (3.02)	60.13 (8.37)	64.00 (3.32)	64.25 (8.73)	67.60 (5.50)	71.63 (18.18)
Tb	2.82 (2.59)	7.84 (20.75)	30.66 (15.20)	31.30 (18.48)	9.70 (6.58)	7.04 (4.01)
TDS	40.12 (1.92)	38.47 (5.35)	41.80 (2.05)	41.88 (5.74)	44.00 (3.74)	46.75 (11.62)
ORP	162.60 (19.36)	166.00 (23.15)	396.80 (12.60)	381.25 (32.55)	374.80 (17.46)	375.00 (36.71)
OM%	9.61 (4.75)	15.57 (2.32)	8.02 (4.36)	14.97 (1.13)	11.07 (5.73)	14.23 (4.53)
VCS%	0.66 (0.86)	0.05 (0.05)	0.42 (0.81)	0.09 (0.15)	1.00 (0.72)	1.79 (3.62)
CS%	2.93 (6.30)	0.14 (0.07)	2.16 (4.27)	0.11 (0.06)	1.31 (1.36)	2.19 (5.04)
MS%	4.81 (10.23)	0.11 (0.07)	2.37 (4.35)	0.15 (0.08)	1.29 (0.64)	1.43 (2.89)
FS%	5.52 (5.17)	0.28 (0.17)	14.41 (18.19)	0.41 (0.36)	12.05 (23.41)	2.78 (4.04)
VFS%	21.01 (14.03)	1.84 (1.71)	20.25 (12.25)	1.90 (1.93)	16.17 (15.18)	13.31 (17.43)
SC%	65.07 (18.07)	97.59 (1.81)	60.39 (25.81)	97.34 (2.26)	68.18 (30.17)	78.50 (21.54)
SP	0.09 (0.04)	0.08 (0.01)	0.14 (0.12)	0.15 (0.10)	0.17 (0.12)	0.07 (0.07)
SN	1.08 (0.37)	1.20 (0.44)	1.49 (1.21)	0.95 (0.35)	2.36 (0.93)	1.23 (0.90)

Dpt: depth; Temp: temperature; DO: dissolved oxygen; K: electric eletric conductivity; Tb: turbidity; TDS: total dissolved solids; ORP: oxide-reduction potential; OM: organic matter; VCS: very coarse sand; CS: coarse sand; MS: medium sand; FS: fine sand; VFS: very fine sand; SC: silt and clay; SP: sediment phosphorus concentration; SN: sediment nitrogen concentration.

Table 2. F values and significance level (*p*) results of two-way ANOVA applied to environmental variables measured in Salto Grande Reservoir, considering the three water level phases and the two analyzed compartments.

Environmental variables	Phases		Compartments		Phases*Compartments	
	F	*p*	F	*p*	F	*p*
Dpt	**4.14**	**0.03**	**13.98**	**0.00**	0.15	0.86
Temp	**86.88**	**0.00**	**5.14**	**0.03**	**4.84**	**0.01**
DO	2.18	0.13	2.63	0.11	1.84	0.18
pH	**14.10**	**0.00**	1.55	0.22	1.51	0.24
K	2.14	0.13	0.00	0.95	0.23	0.80
Tb	**25.37**	**0.00**	0.38	0.54	0.19	0.82
TDS	**13748.52**	**0.00**	**33.13**	**0.00**	0.61	0.55
ORP	**299.80**	**0.00**	0.20	0.66	0.30	0.74
OM	0.16	0.86	**16.48**	**0.00**	0.74	0.49
VCS	**5.81**	**0.01**	0.70	0.41	0.56	0.58
CS	0.91	0.41	2.02	0.17	0.51	0.61
MS	0.41	0.66	**4.39**	**0.04**	0.64	0.53
FS	0.66	0.53	**11.33**	**0.00**	0.61	0.55
VFS	1.21	0.31	**16.60**	**0.00**	2.51	0.10
SC	1.95	0.16	**24.41**	**0.00**	2.52	0.10
SP	0.64	0.54	2.25	0.15	1.05	0.37
SN	1.67	0.21	1.92	0.18	1.18	0.33

Dpt: depth; Temp: temperature; DO: dissolved oxygen; K: eletric conductivity; Tb: turbidity; TDS: total dissolved solids; ORP: oxide-reduction potential; OM: organic matter; VCS: very coarse sand; CS: coarse sand; MS: medium sand; FS: fine sand; VFS: very fine sand; SC: silt and clay; SP: sediment phosphorus concentration; SN: sediment nitrogen concentration.

The pre-drawdown phase was separated on the first axis of PCA analyses (62% of variance explicability), associated with high values of pH and low total dissolved solids. The second axis (15% of explicability) pointed an association of low water phase (during drawdown) with high turbidity (Figure 3, Table 3).

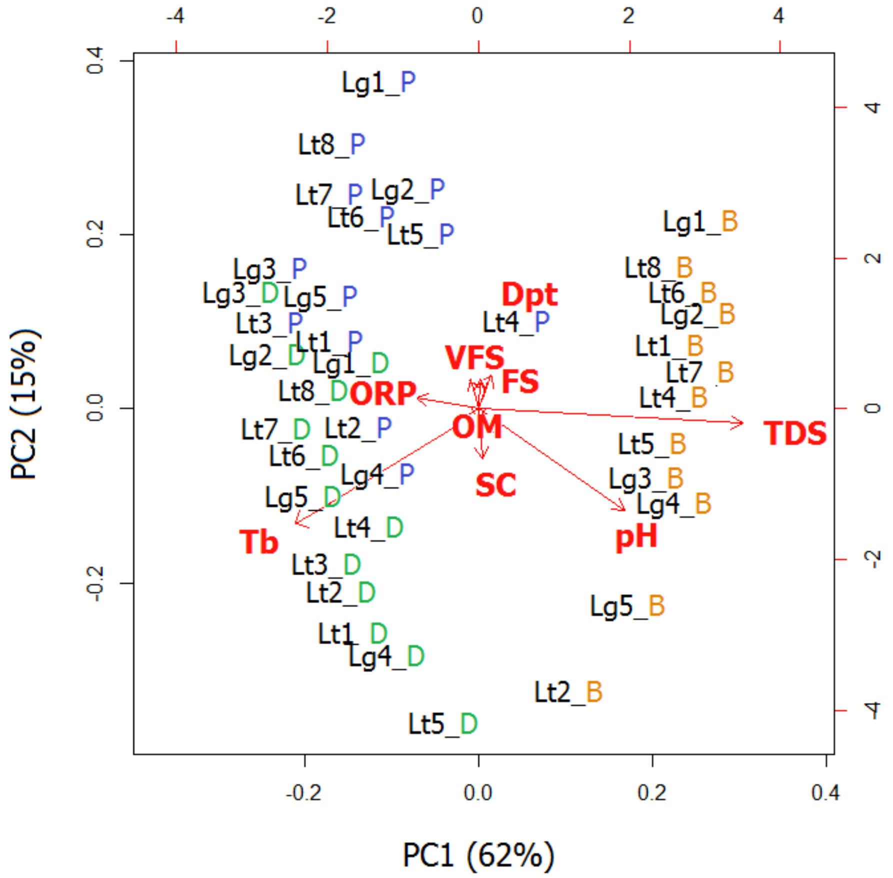

Figure 3. PCA based on the environmental variables measured in Salto Grande Reservoir, considering the three water level phases and the two analyzed compartments. Lg: longitudinal compartment; Lt: Lateral compartment; 1-8: sample sites; B: before drawdown; D: during drawdown; P: post-drawdown; Dpt: depth; Tb: turbidity; TDS: total dissolved solids; ORP: oxide-reduction potential; OM: organic matter; FS: fine sand; VFS: very fine sand; SC: silt and clay.

Table 3. Coefficient values of linear combinations of environmental variables in the two main axes of Principal Component Analysis (PCA). Parameters without values were related to other PCA axes.

Environmental variables	PC1	PC2
Depth	-	0.30
pH	0.41	-0.58
Turbidity	-0.49	-0.63
Total dissolved solids	0.75	-
Oxide-reduction potential	-0.17	-
Organic matter	-	-0.14
Fine sand	-	0.17
Very fine sand	-	0.16
Silt and clay	-	-0.29

Macroinvertebrates community

Thirty-eight taxa belonging to Platyhelminthes, Nemertea, Nematoda, Mollusca, Annelida, Crustacea, Arachnida and Insecta were found in Salto Grande Reservoir during the study period (Table 4). Diptera pupae were not included in this count.

Nemertea occurred exclusively in pre-drawdown phase, while another thirteen taxa (*Biomphalaria*, Oribatida, *Tricorythopsis*, *Tricorythodes*, *Chimarra*, *Neotrichia*, *Argia*, *Neocordulia*, *Zenithoptera*, Orthocladiinae, Hydroscaphidae, *Neoelmis*, *Macrelmis*) were observed only in low water and three (*Chaoborus*, Psychodidae and Veliidae) in post-drawdown. Hydracarina, Cernotina, *Cyrnellus*, Diptera pupae and Ceratopogonidae were recorded in pre and during drawdown phase, disappearing after re-filling water. Still, *Pomacea* and *Hyalella* were observed in low water phase, remaining after the end of water management (Table 4).

Twenty-one taxa (1 Platyhelminthes, 1 Nemertea, 4 Gastropoda, 1 Crustacea, 2 Arachnida, 2 Ephemeroptera, 3 Trichoptera, 3 Odonata, 3 Diptera and 1 Coleoptera) were exclusive of the lateral compartment of reservoir and seven taxa (*Neotrichia*, *Phyllocycla*, *Progomphus*, Psychodidae, Veliidae, *Neoelmis* and *Macrelmis*) were observed only in the longitudinal compartment (Table 4).

Table 4. Density (ind. m²) of benthic macroinvertebrates found in Salto Grande Reservoir in pre-drawdown, during and post-drawdown phases, in the longitudinal (Lg) and lateral (Lt) compartments.

	Pre-Drawdown		During Drawdown		Post-Drawdown	
	Lg	Lt	Lg	Lt	Lg	Lt
PLATYHELMINTHES						
Turbellaria	0	17	0	337	0	34
NEMERTEA	0	34	0	0	0	0
NEMATODA	17	220	25	1010	17	220
MOLLUSCA						
Bivalvia						
Limnoperna fortune	17	0	0	51	168	135
Corbicula fluminea	6095	944	8663	404	5556	169
Gastropoda						
Biomphalaria	0	0	0	17	0	0
Texadina	371	0	871	34	506	0
Melanoides tuberculata	1094	257	3565	34	4849	17
P*hysa*	0	67	0	118	0	67
Pomacea	0	0	0	34	0	17
Ancylidae	0	68	0	387	0	118
ANNELIDA						
Oligochaeta	5791	1794	6474	5573	4731	3199
Hirudinea – Glossiphonidae	67	135	17	471	0	236

ARTHROPODA						
Crustacea						
Hyalella	0	0	0	17	0	17
Ostracoda	3232	1263	1654	2223	472	1616
Arachnida						
Hydrachnidae	0	17	0	269	0	0
Oribatida	0	0	0	84	0	0
Insecta						
Ephemeroptera						
Tricorythopsis	0	0	0	17	0	0
Tricorythodes	0	0	0	34	0	0
Trichoptera						
Cernotina	0	34	0	320	0	0
Chimarra	0	0	0	34	0	0
Cyrnellus	0	17	0	270	0	0
Neotrichia	0	0	13	0	0	0
Odonata						
Argia	0	0	0	17	0	0
Neocordulia	0	0	0	17	0	0
Phyllocycla	17	0	25	0	34	0
Progomphus	17	0	0	0	17	0
Zenithoptera	0	0	0	17	0	0
Diptera						
Diptera pupae	0	34	0	51	0	0
Chironominae	0	943	13	1717	67	220
Orthocladiinae	0	0	0	34	0	0
Tanypodinae	0	249	25	405	84	168
Chaoboridae – *Chaoborus*	0	0	0	0	0	34
Psychodidae	0	0	0	0	17	0
Ceratopogonidae	0	34	0	51	0	0
Hemiptera						
Veliidae	0	0	0	0	17	0
Coleoptera						
Hydroscaphidae	0	0	0	17	0	0
Neoelmis	0	0	13	0	0	0
Macrelmis	0	0	13	0	0	0

The analyses of ecological attributes (richness, density, Shannon's diversity and Pielou's equitability) showed significant difference only for density when compared the reservoir compartments (Figures 4 and 5; Table 5)

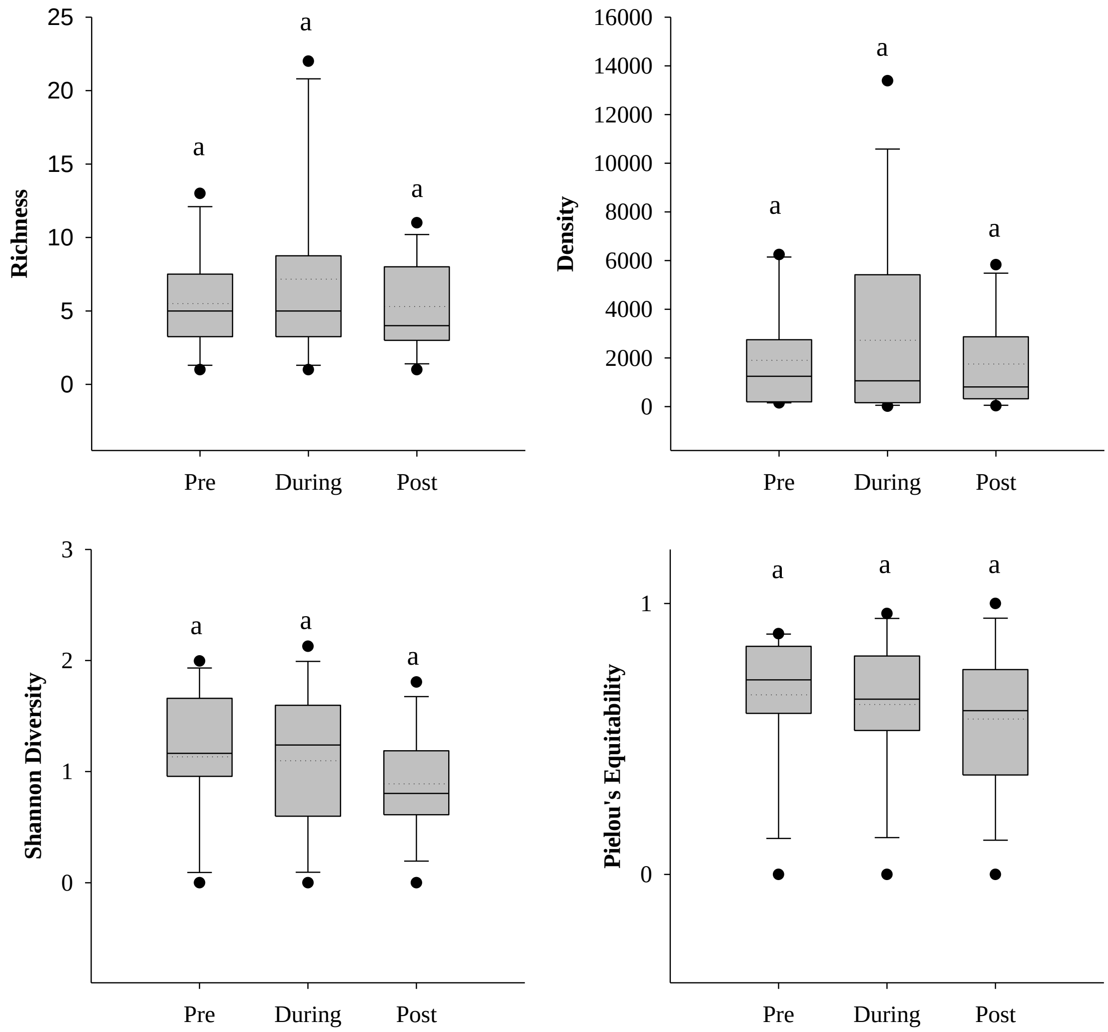

Figure 4. Box plot for ecological attributes of the benthic macroinvertebrates community found in Salto Grande Reservoir, considering the pre-drawdown, during and post-drawdown phases. Dotted line: mean value; Circle symbol: outliers. Letters correspond to comparison test results.

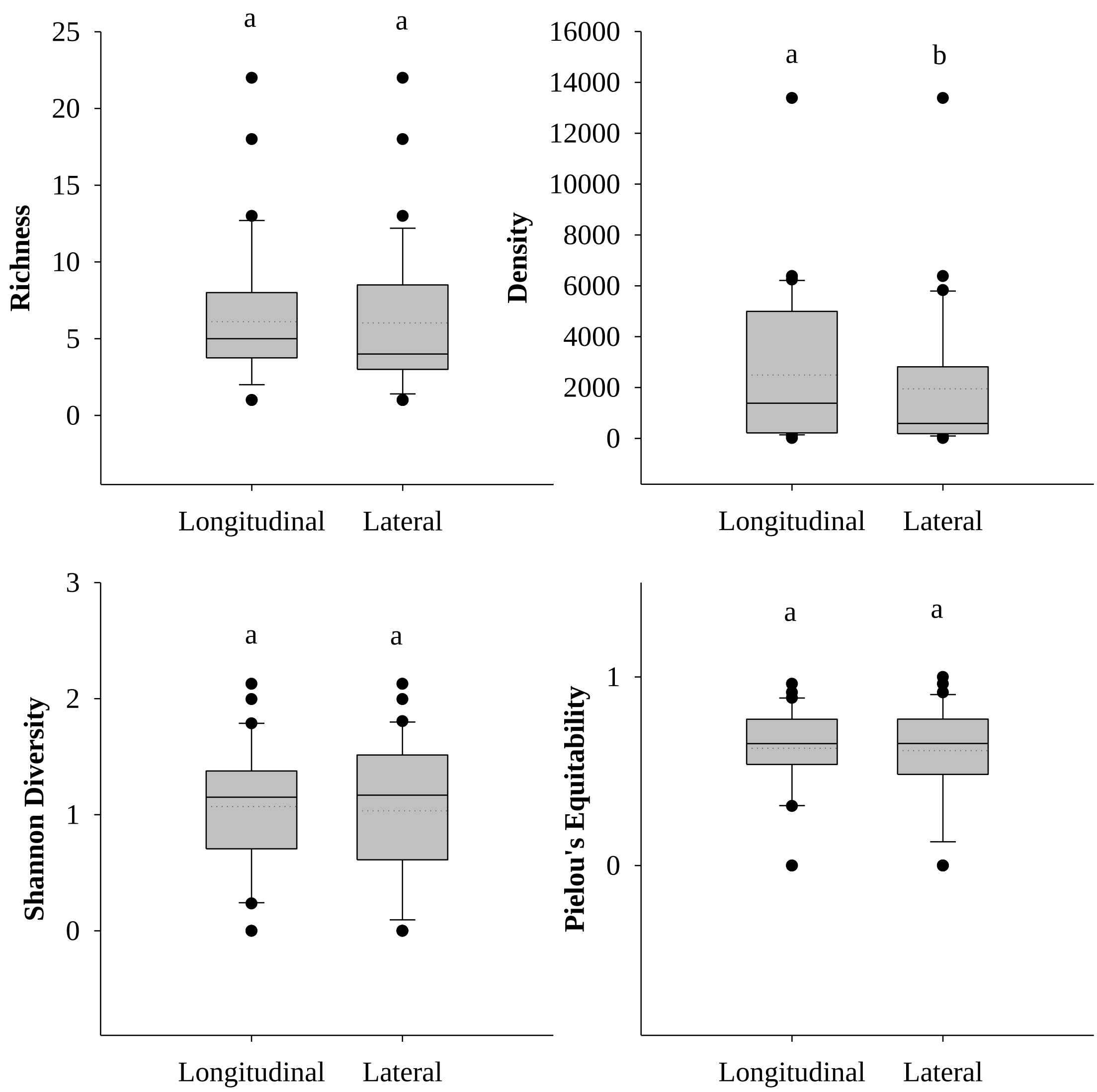

Figure 5. Box plot for ecological attributes of the benthic macroinvertebrates community found in Salto Grande Reservoir during the study, considering the longitudinal and lateral compartments. Dotted line: mean value; Circle symbol: outliers. Letters correspond to comparison test results.

Table 5. F values and significance level (*p*) results of two-way ANOVA applied to the ecological attributes of macroinvertebrates community observed in Salto Grande Reservoir, considering the three water level phases and the two analyzed compartments.

Ecological attributes	Phases		Compartments		Phases*Compartments	
	F	*p*	F	*p*	F	*p*
Richness	0.15	0.86	0.24	0.62	0.75	0.48
Density	0.14	0.87	**10.38**	**0.01**	0.06	0.94
Shannon’s diversity	0.28	0.76	0.000	0.99	0.12	0.89
Pielou’s equitability	0.15	0.86	0.36	0.55	0.19	0.83

Results of NMDS analysis indicated differences among the reservoir compartments in terms of structure of the macroinvertebrate communities, which was corroborated by the PERMANOVA test (F=7.08; $p<0.001$) (Figure 6). *Corbicula fluminea* ($p<0.000$), *Melanoides tuberculata* ($p<0.000$), *Texadina* ($p<0.001$), *Phyllocycla* ($p<0.001$), *Progomphus* ($p<0.001$), Psychodidae ($p<0.01$), Veliidae ($p<0.01$), *Neotrichia* ($p<0.01$), *Neoelmis* ($p<0.01$) and *Macrelmis* ($p<0.01$) were the main taxa that discriminated the two compartments, all with higher density in the longitudinal axes.

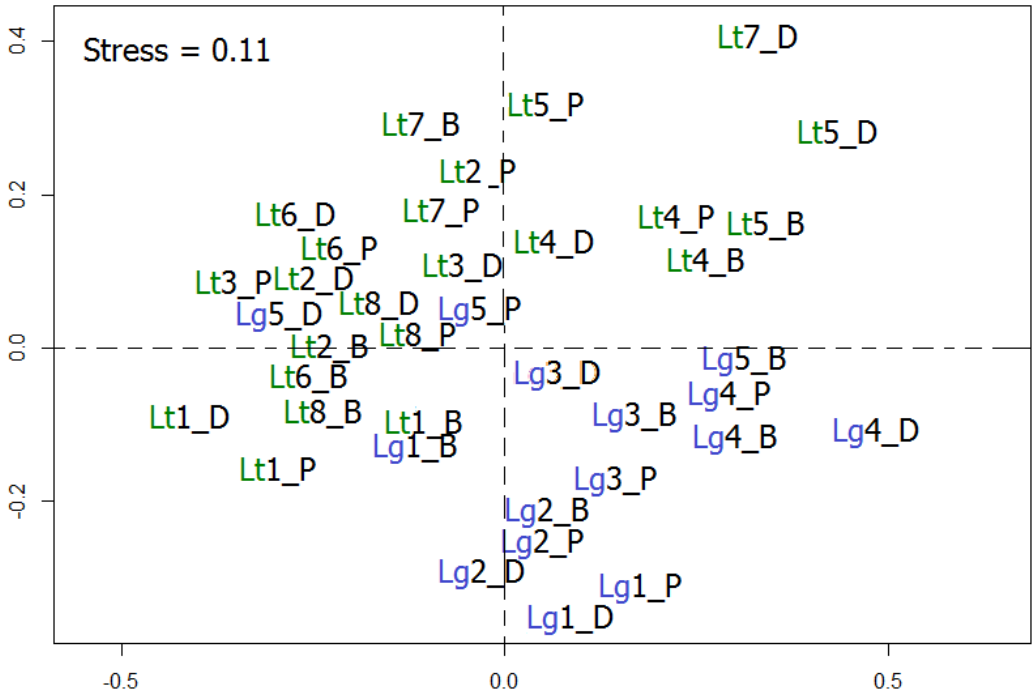

Figure 6. Ordination diagram (NMDS) of the benthic macroinvertebrate communities' structure in Salto Grande Reservoir during the study period. Lg: longitudinal compartment; Lt: Lateral compartment; 1-8: sample sites; B: before drawdown; D: during drawdown; P: post-drawdown.

Annelida Oligochaeta was the most representative taxon in all water level phases. Relative abundance of *Corbicula fluminea* and Ostracoda decreased during low water and soon after artificial drawdown. The opposite was observed for *Melanoides tuberculata*. Other taxa with a contribution of less than 10% have higher relative abundance during low water before decreasing during the post phase (Figure 7A).

Related to the compartments of the reservoir, *Corbicula fluminea* was more abundant in the longitudinal compartment, whilst Oligochaeta was more abundant in the lateral compartment. Other taxa with a contribution of less than 10% have greater relative abundance in lateral areas (Figure 7B).

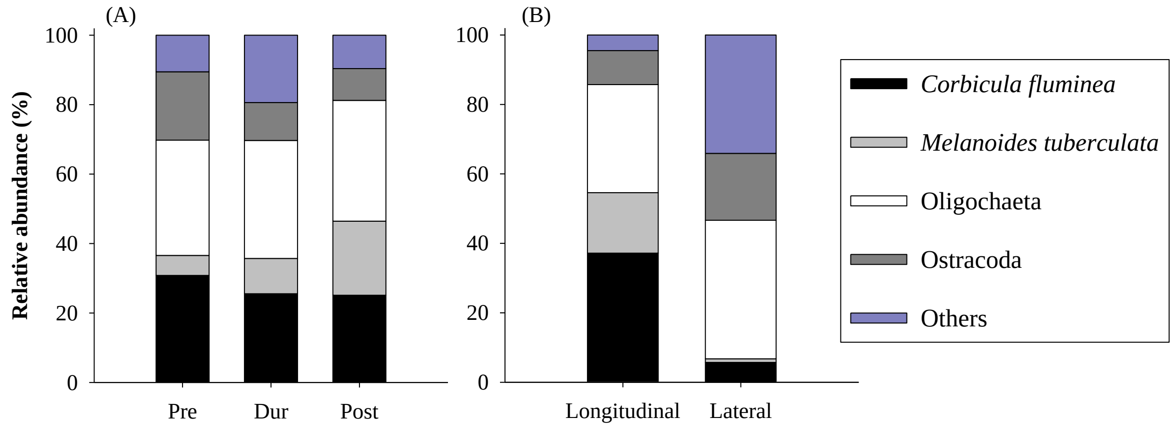

Figure 7. Relative abundance of the main macroinvertebrates taxonomic groups found in Salto Grande Reservoir during pre-drawdown, during and post-drawdown phases (A) in the longitudinal and lateral compartments (B). Other: taxa with less than 10% of contribution.

The first two axes of the RDA plot explained 31% of the total variation and the model was considered significant (F=1.90; *p*=0.02) (Figure 8, Appendix 3). According to this analysis, *Melanoides tuberculata, Corbicula fluminea*, *Texadina* and *Limnoperna fortunei* distribution were related to higher depth and pH, and lower total dissolved solids values in water, as with fine and very fine sand grain percentage in sediment observed in the longitudinal compartment of reservoir (negative quadrant of RDA2). Ostracoda, Oligochaeta, Chironominae, Nematoda, Tanypodinae, Ancylidae, *Cernotina* and Glossiphonidae were correlated with low turbidity and high oxide-reduction potential values in the water, organic matter and silt and clay percentages in the sediments of the lateral compartment of reservoir (positive quadrant of RDA2).

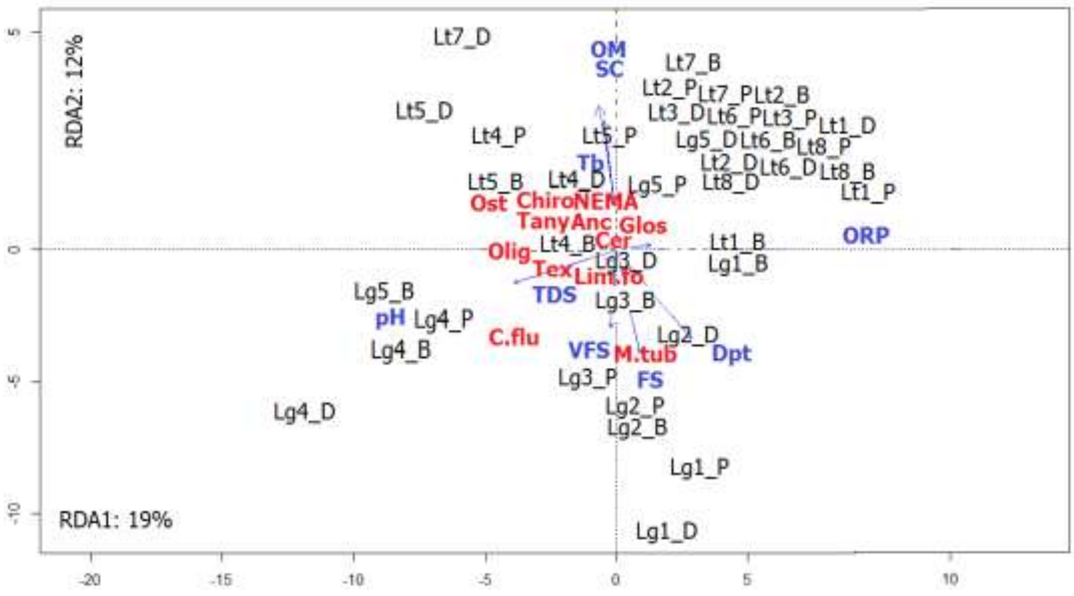

Figure 8. Ordination diagram (biplot) based on a redundancy analysis (RDA) of benthic macroinvertebrates and selected environmental variables. Lg: longitudinal compartment; Lt: Lateral compartment; 1-8: sample sites; B: before drawdown; D: during drawdown; P: post-drawdown. Dpt: depth; Tb: turbidity; TDS: total dissolved solids; ORP: oxide-reduction potential; OM: organic matter; FS: fine sand; VFS: very fine sand; SC: silt and clay; M. tub: *Melanoides tuberculata*; C.flu: *Corbicula fluminea*; Lim.fo: *Limnoperna fortunei*; Chiro: Chironominae; NEMA: Nematoda; Olig: Oligochaeta; Ost: Ostracoda; Tany: Tanypodinae; Cer: *Cernotina*; Glos: Glossiphonidae; Anc: Ancylidae; Tex: *Texadina*.

Discussion

The artificial drawdown carried out in Salto Grande Reservoir over a short timeframe significantly altered the water quality and the sediment characteristics. In disagreement with the initial hypothesis, no significant changes were found in taxa richness, density, diversity and equitability of benthic macroinvertebrates among the water level phases; neither in their community structure ordination. The differences were observed only between the longitudinal and lateral reservoir compartments, with higher density in the longitudinal . The results from this study suggest that artificial drawdown may potentially be used to control the excessive growth of submerged macrophytes without negatively affects this community in tropical reservoir systems. Additionally, our findings highlight the importance of lateral areas for diversity maintenance of macroinvertebrates fauna.

We detected water temperature changes considering reservoir compartment and water level phases interaction. Lateral shallower sites, because of the reduced water volume, undergo greater impacts with water level depletion in terms of depth and consequently in temperature, that exhibited higher variation (Straskraba et al., 1993; Furey et al., 2004). The temperature decline noted in low water phase may be related to cold fronts entrance, coming from south latitudes, which are common during the winter season (Tundisi et al., 2004; Tundisi et al., 2010). The effects of this meteorological phenomenum is particularly more evident in a reservoir like Salto Grande, a run-of-river system with a short water retention time (mean of 1.5 days) (Nogueira et al., 2012), specially during the operational drawdown, when the water volume is reduced.

The lower pH and higher ORP values found during and after the drawdown procedure probably occurred as result of the increased organic matter decomposition process (Carvalho et al., 2005; Debastiani-Júnior and Nogueira, 2015; Portinho and Nogueira, 2017). Studies show that organic matter in reservoir system under drawdown can be increased by allochthonous derive, as the exposed zone may receive terrestrial debris and organic matter from surroundings (Furey et al, 2004). Here, organic matter may come mainly from the dead plants of the reservoir lateral compartment.

Our results suggest that not only organic matter, but also nutrients and fine sediments were transported from the drawdown exposed sites (i.e. mainly lateral compartment) to deeper areas (i.e. longitudinal one). This transportation process from lateral areas enhances sediment erosion in reservoir system. The re-suspension of these materials that include silt, clay, organic and inorganic matter promotes higher turbidity values found in low water phase, as well as increase in total dissolved solids.

Despite the detected abiotic effects, no significant drawdown alterations in the benthic macroinvertebrates attributes were identified, neither in their community structure distribution. The taxa richness and density increase observed during the low water phase may be a consequence of some species response to water stress (sudden water level diminution), actively dispersing to deeper sites (Wiggins et al., 1980; Marçal, 2014). Also, reduction in macrophyte populations may induce displacement in plant-associated organisms (Grimas, 1965; Wilcox and Meeker, 1992, McEwen and Butler, 2010), increasing their values in sediment. Trade-offs between predation risk, food availability and oxygen concentration in plants bank may determine macroinvertebrates dispersion found here too (Marklund et al., 2001). Our theory of active dispersion was supported by the presence of the exclusive taxa in low water phase, which mostly present high swimming capacity.

Related to diversity and equitability indexes values decrease observed after re-filling, it should be due to the reduction in the relative abundance of rare taxa (contribution less than 10%) and also to the dominance of Oligochaeta, *Corbicula fluminea* and *Melanoides tuberculata*. However, as already mentioned, these differences were not significant between the distinct water level phases.

According to statistical analysis, the differences in benthic macroinvertebrates community structure were related to reservoir compartments. Density was higher in longitudinal compartment, mainly because *Corbicula fluminea*, *Melanoides tuberculata* and Oligochaeta contribution. These most abundant taxa added with the exclusive ones of each compartment compose the main taxa responsible for differences in the community structure (NMDS and SIMPER analysis). We emphasize that the two lateral lagoons, the inner bay and Novo River tributary together exhibited three times more exclusive taxa when compared with the longitudinal compartment. Corroborating other studies, lateral compartments of reservoirs seems to be essential for maintaining the biodiversity of the aquatic system (e.g. Nadai and Henry, 2009; Ferrareze and Nogueira, 2011; Marçal, 2014).

In general, our findings indicate that artificial drawdown over a short timeframe may have no significant impact on benthic macroinvertebrates community of tropical reservoirs. However, the cumulative effects of repeated annual drawdown can result in spatial differences in physical and chemical characteristics of the sediments in the aquatic system (Furay et al., 2004), or else shift in the system steady state (Debastiani-Júnior and Nogueira, 2015), affecting biota communities. Also, there is a potential possibility of organisms mortality events associate to low dissolved oxygen during drawdown, particularly if incoming water is rich in nutrients and organic matter and the remaining system is small in water volumes (Cook, 2006). Thus, continuous water quality and aquatic communities monitoring and evaluation of long-term trends is essential for proper macrophytes management in tropical reservoir using drawdown techniques.

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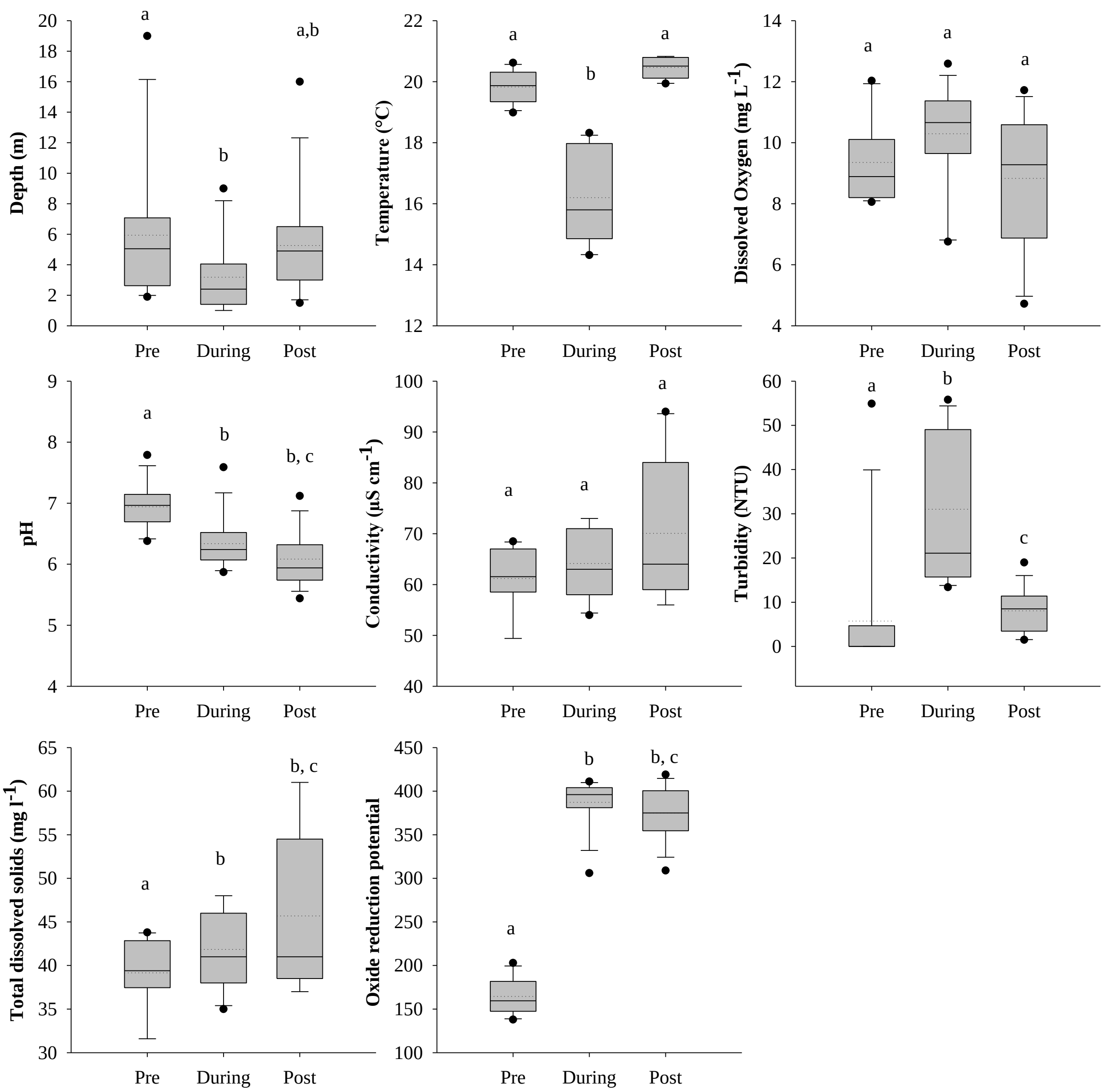
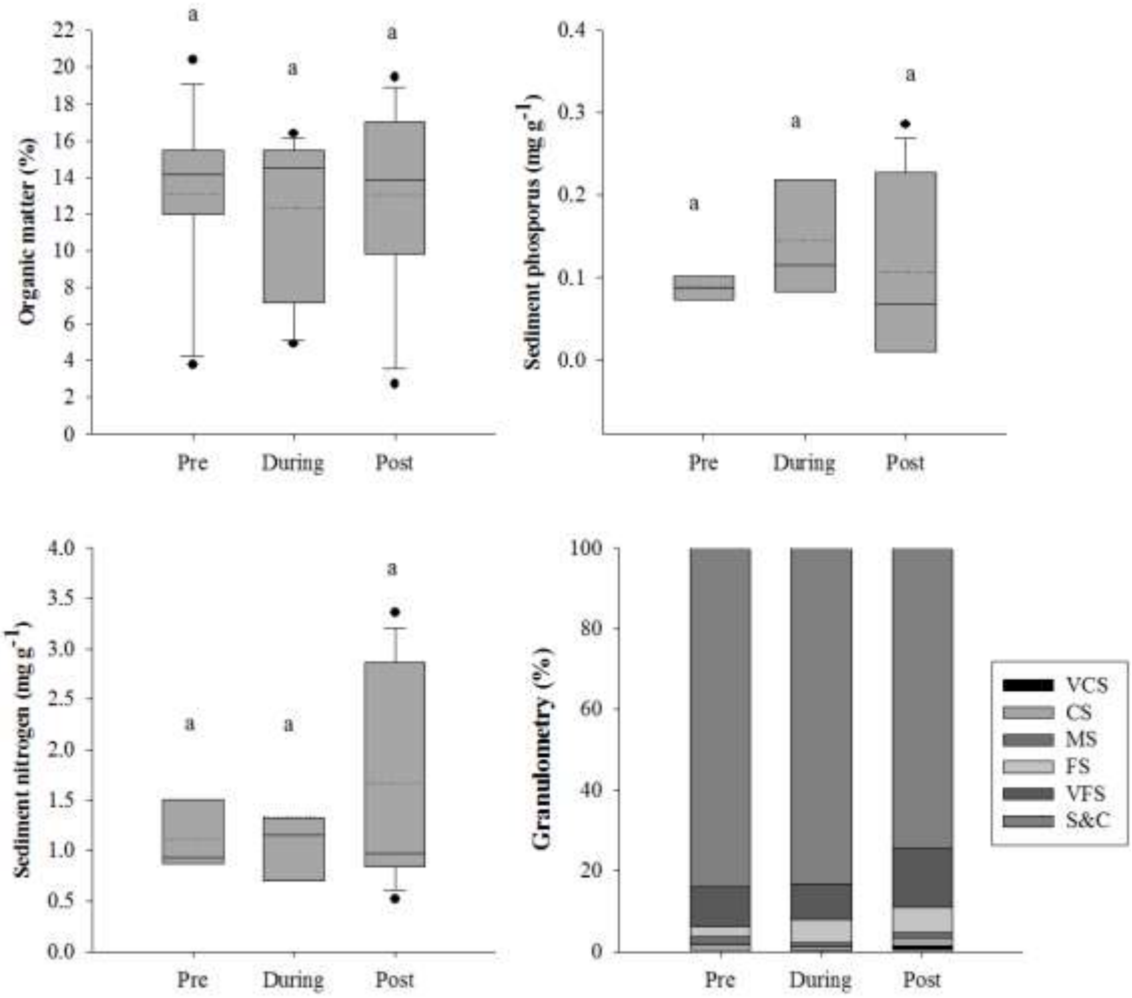
APPENDIX

1. Box plot for water (A) and sediment variables (B) measured in Salto Grande Reservoir during water level phases. Dotted line: mean value; Circle symbol: outliers. Different letters indicate significant differences in values of the same variable.

(A)



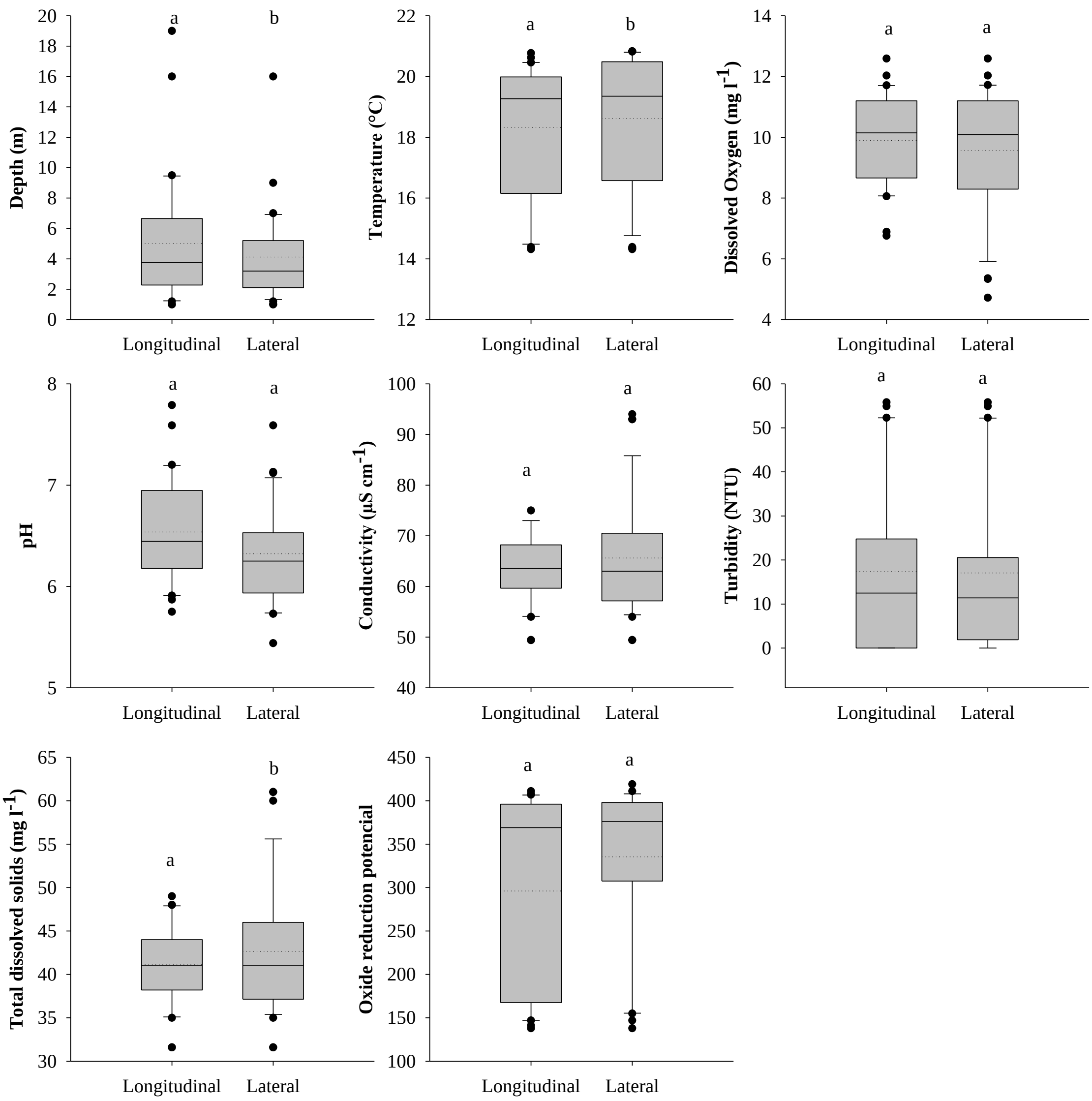
(B)



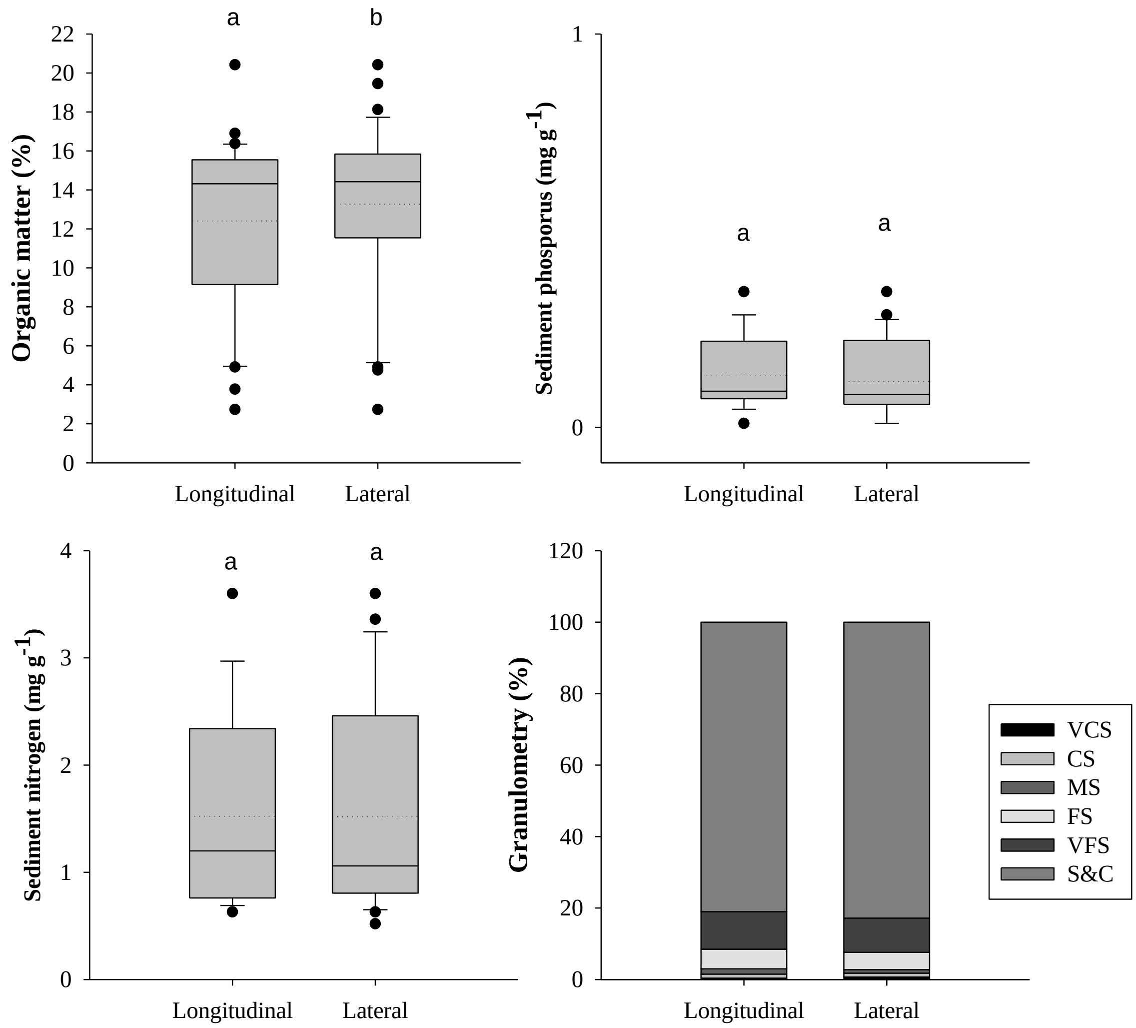
Organic matter (%)
Sediment phosporus (mg g-1)
Sediment nitrogen (mg g-1)
Granulometry (%)
Pre
During
Post
VCS
CS
MS
FS
VFS
S&C

2. Box plot for water (A) and sediment variables (B) measured in Salto Grande Reservoir during the study period, considering the longitudinal and lateral compartments of reservoir. Dotted line: mean value; Circle symbol: outliers. Different letters indicate significant differences in values of the same variable.

(A)



(B)


a
b
Organic matter (%)
22
20
18
16
14
12
10
8
6
4
2
0
Longitudinal
Lateral
Sediment phosporus (mg g-1)
1
0
a
a
Longitudinal
Lateral
Sediment nitrogen (mg g-1)
4
3
2
1
0
a
a
Longitudinal
Lateral
Granulometry (%)
120
100
80
60
40
20
0
Longitudinal
Lateral
VCS
CS
MS
FS
VFS
S&C

3. Taxa scores of RDA analysis.

	RDA1	RDA2
Turbellaria	-0.19	0.24
Nemertea	-0.07	0.08
Nematoda	-0.92	0.65
Limnoperna fortunei	-0.18	-0.44
Corbicula fluminea	-2.71	-2.90
Biomphalaria	0.03	0.04
Texadina	-0.67	-0.12
Melanoides tuberculata	0.94	-4.08
Physa	-0.25	0.23
Pomacea	-0.21	0.00
Ancylidae	-0.78	0.15
Oligochaeta	-3.19	0.11
Glossiphonidae	0.12	0.41
Hyalella	-0.07	0.01
Ostracoda	-4.26	0.43
Hydracarina	-0.19	0.20
Oribatida	0.02	0.11
Tricorythopsis	-0.14	-0.02
Tricorythodes	-0.20	-0.03
Cernotina	-0.67	0.04
Chimarra	-0.20	-0.03
Cyrnellus	-0.35	0.09
Neotrichia	-0.04	0.03
Argia	0.03	0.04
Neocordulia	-0.14	-0.02
Phyllocycla	-0.12	0.01
Progomphus	-0.02	-0.03
Zenithoptera	-0.14	-0.02
Diptera pupae	-0.15	0.13
Chironominae	-1.43	0.13
Orthocladiinae	-0.12	0.02
Tanypodinae	-0.70	0.22
Chaoborus	0.08	0.08
Psychodidae	0.06	-0.11
Cernotina	-0.25	0.12
Veliidae	0.06	-0.11
Hydroscaphidae	-0.01	0.03
Neoelmis	-0.04	0.03
Macrelmis	-0.04	0.03

Capítulo II

“Immediate functional response of littoral benthic macroinvertebrates community to the artificial drawdown employed in a tropical reservoir for macrophytes control”

Capítulo II

"Immediate functional response of littoral benthic macroinvertebrates community to the artificial drawdown employed in a tropical reservoir for macrophytes control"

Abstract

In reservoir systems, the littoral habitat and its invertebrate communities are often expose to water level fluctuation caused by hydropower operational procedures. The aim of this study was examine the effects of the artificial drawdown employed to aquatic macrophytes control on functional diversity of benthic macroinvertebrates fauna in the littoral zone of a tropical reservoir. We analyzed functional diversity changes assessing differences in functional richness (FRic), functional evenness (FEve) and functional divergence (FDiv) among data obtained before water level management (i.e., pre-drawdown phase) and after reservoir re-filling (i.e., post-drawdown phase). The community trait composition (CWM) and traits-environment relationship were also evaluated. Our results indicate shifts in community traits structure that reflected on functional richness decrease. "Body size", "Body form", "Aquatic stage", "Locomotion mode" and "Respiration mode" seems to be promising indicators of littoral impacts related to artificial water level drawdown over benthic macroinvertebrates community. However, the traits selection observed should be more associated with sediment drought and/or habitat losses (i.e.macrophytes substrate) than with the water and sediment characteristics.

Keywords: artificial drought, benthic macroinvertebrates, functional diversity**,** macrophythes control, Salto Grande Reservoir, water level fluctuations.

Introduction

The littoral zone of reservoirs is a transitional ecosystem between land and water (Takeda et al., 1997), described with structural complexity presenting great fauna diversity (Hofmann et al., 2008; Ferrareze and Nogueira, 2011a; 2011b; Liu et al., 2011). Highly susceptible to water level fluctuations, these habitats may be affected by changes in biological, chemical and physical sediment characteristics (Klant et al., 2016), which also impact invertebrate communities (Silva and Petrucio, 2018).

Temporal drying of aquatic sediments can decrease the organic matter content and increase compaction (James et al., 2001; Klant et al., 2016). As the water level decreases significantly, habitat conditions tend to be much more homogeneous; the proportion of sites with fine substrate and low slope can increase, while submerged vegetation and riparian shade coverage disappear (Logez et al., 2016). Benthic animals, in turn, can be indirectly affected by these decreases in food resources or habitat availability (Valdovinos et al., 2007; Evtimova and Donohue, 2016; Silva and Petrucio, 2018) as well as directly by desiccation (McEwen and Butler, 2010).

Sharp declines are observed in littoral macroinvertebrate taxon richness and density with increasing amplitude in water level fluctuation (Aroviita and Hämäläinen, 2008; McEwen and Butler, 2010). Usually, littoral fauna reduction is followed by a period of communities re-structuring, in which new species appear, former ones re-establish themselves and many years may elapse before stabilization is reached (Liu et al., 2011). However, little is known about the functional response of littoral macroinvertebrates to water level fluctuation.

Functional approaches has become increasingly popular due to their ability of provide a mechanistic perspective of the community-environment relationships and functioning of ecosystems (Cadotte et al., 2011; Zhang et al., 2019). This is because species primarily react to the environmental gradients through the specific functional features (i.e. functional traits) and roles they play in an ecosystem (Carmona et al., 2016; Zhang et al., 2019). More generally, a set of morphological, physiological and behavioral traits (e.g., body form and flexibility, parental care, potential for regeneration, food types, feeding habits and respiration mode) determines where the species can live (Schmera et al., 2017), and how enhances ecosystem functions such as productivity, resilience to perturbations or invasion, and regulation in the flux of matter (Villéger et al., 2008).

From a practical point of view, communities under different kinds of environmental changes may present reduced taxonomic and functional diversity if species exhibit more specialized trait combinations (e.g. habitat specialists). Indeed, when considering environmental changes lead to the degradation or even the loss of particular niches, specialist species will be deeply affected (Villéger et al., 2010). Generalists may tolerate a loss of particular habitats as they are supposed to occupy several, and the most common ones (Villéger et al., 2010). Thus, functional composition may exhibit a relatively high correspondence with changes in environmental conditions, reflecting resilience of ecosystems (Laliberté and Legendre, 2010; Göthe et al., 2017; Zhang et al., 2019).

The main objective of this study was to examine the immediate changes in functional benthic macroinvertebrate diversity in the littoral zone of a tropical reservoir under an artificial short-term water level drawdown. The management of water level regimes by artificial drawdown has been used for aquatic macrophytes control in many tropical reservoirs and often occurs much more rapidly than a natural drying event (Portinho and Nogueira, 2017). We assessed the changes in functional indexes comparing data obtained before drawdown (i.e., the pre-drawdown phase) and immediately after re-filling (i.e., the post-drawdown phase). Physical and chemical characteristics of the water and sediment were analyzed to examine the environmental changes in littoral zone that may have been affecting the functional composition of macroinvertebrates community. We believe that artificial drawdown employed to control excessive macrophyte growth results in taxonomic and functional losses for the benthic macroinvertebrate communities in littoral zone of the reservoir through the reduction of the number of taxa.

Material and Methods

Study area

The study was conducted in Salto Grande Reservoir (22°57’S, 49°57’W), located in the Paranapanema River (southeastern Brazil). The reservoir has an area of 12 km^2, a volume of 44.2 hm^3, a mean water retention time of 1.5 days and a mean water discharge of 395 $m^3 s^{-1}$ (Nogueira et al., 2012).

Annually, Salto Grande is artificially drawn-down by ~2.5 m over a period of approximately 15 days as part of a long-term management program carried out by the CTG Brasil hydropower energy company to mitigate the detrimental effects of the excessive growth of *Egeria* spp. stands (Debatiani and Nogueira, 2015; Portinho and Nogueira, 2017). The purpose of the applied technique is to expose the shore plants to dehydration and death, decreasing their biomass in the area (Cook et al., 2006; Portinho and Nogueira, 2017).

The littoral zone of the lentic compartment of the reservoir clearly shows the drought effects of drawdown procedure and a section of it was chosen to represent the impact along the entire perimeter of the reservoir (Figure 1). The selected area is characterized by extreme water level fluctuation in the drawdown periods, presence of piers and embankments along the margins and occurrence of submerged banks of *Egeria* spp. around.

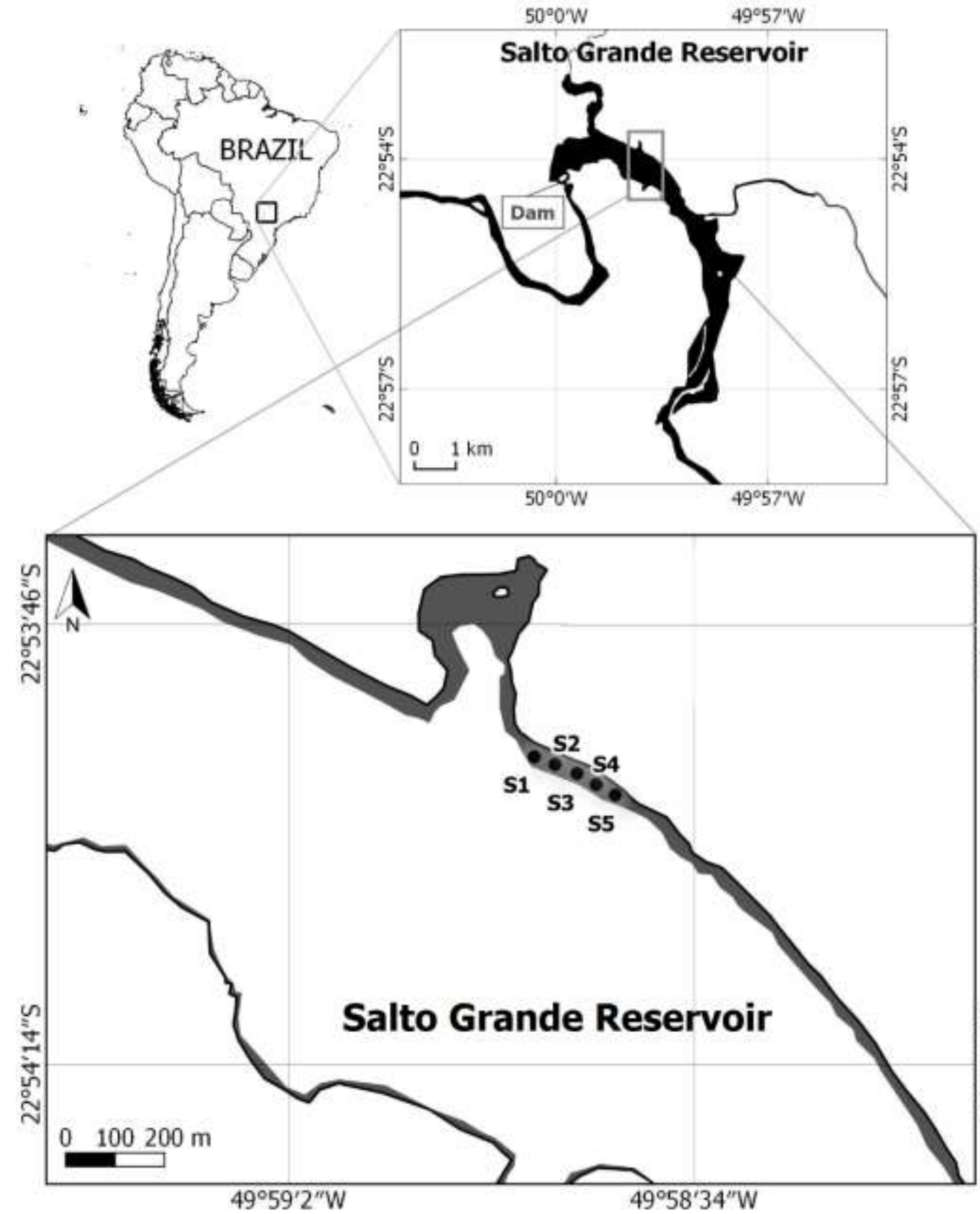


Figure 1. Geographic location of the study area showing the position of littoral sampling sites (S1 to S5) in Salto Grande Reservoir, Paranapanema River, Southeastern Brazil. The grey area represents the water retraction zone, which stay completely exposed during the low water period of drawdown management.

Sampling design

The Salto Grande Reservoir was drawdrown by ~2.3 m over a period of 15 days, between September 17th, 2016 and October 1st, 2016 (Figure 2). Samples were collected on sampling days undertaken during the pre-drawdown phase (September 16th, 2016) and immediately after re-filling (i.e. post-drawdown phase) (October 2nd, 2016) in five sites of the reservoir littoral zone (Figure 1). The sites were approximately 100 m apart from each other.

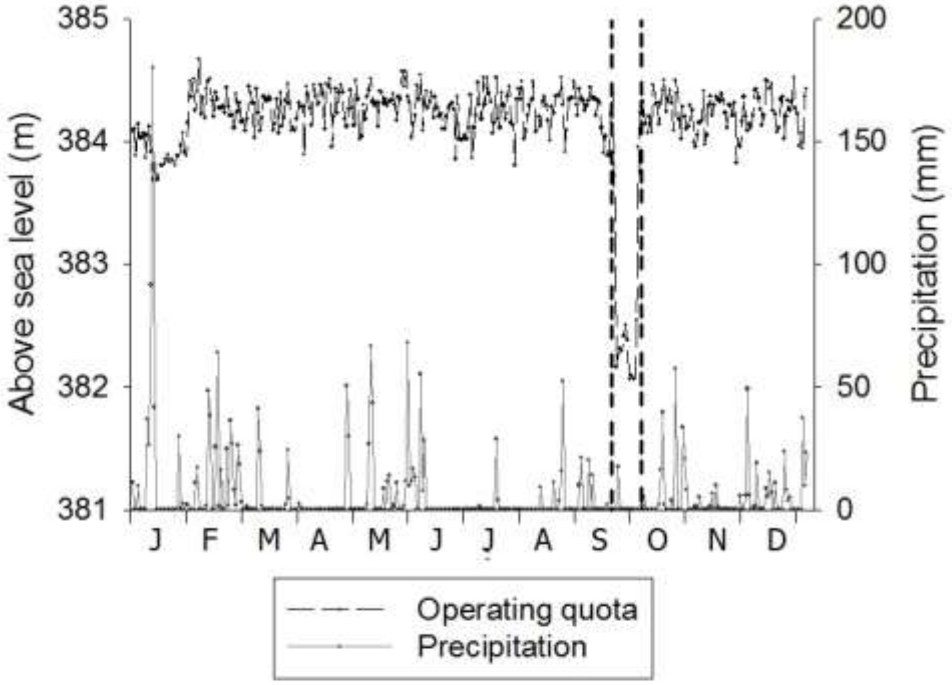


Figure 2. Water level fluctuation in Salto Grande Reservoir and daily precipitation registred in the year 2016. The dotted line indicates the timing of low water in drawdown management of reservoir. Precipitation data source: INMET site.

In each site, the following parameters were measured at the bottom of the water column: temperature (TE), dissolved oxygen (DO), oxygen saturation percentage (DOP), pH, eletric conductivity (K), turbidity (Tb), total dissolved solids (TDS) and oxide-reduction potential (ORP), using a calibrated Horiba probe (U-52). Depth (Dpt) was measured with a Speedtech® sonar and transparency (Tp) with Secchi disc. Sediment samples were also collected for the determination of organic matter content (OM) and particle size analysis (GV: gravel; VCS: very coarse sand; CS: coarse sand; MS: medium sand; FS: fine sand; VFS: very fine sand; SC: silt and clay) (Hakanson and Janson, 1983).

Simultaneously, macroinvertebrates samples were collected in triplicates with a van Veen sampler (0.0198 m²), washed through 250-µm mesh size sieves, fixed in 4% formalin and stored in 70% alcohol. In the laboratory, the organisms were counted and identified to the lowest taxonomic level based on specialized literature (Brinkhurst and Marchese, 1989; Pennak, 1989; Ringuelet and Castellanos, 1991; Lopretto and Tell, 1995; Merritt and Cummins, 1996; Mariano and Froehlich, 2007; Domínguez and Fernández, 2009; Krantz and Walter, 2009; Mugnai et al., 2010).

Data analysis

Environmental variables

A Student's t-test was applied for the detection of environmental differences between pre and post-drawdown phases. Most water data was log(x+1) transformed, except pH. Oxygen saturation percentage and sediment data were arco-sene transformed. Different transformation methods were based on Gotelli and Ellison (2016) recommendations for continuous and percentage data.

Taxonomic diversity

The macroinvertebrates count was converted in density values (individuals per m^2) prior to statistical analyses. To quantify and compare taxonomic diversity between drawdown phases, a Student's t-test was performed using raw taxa richness, Shannon's diversity and Pielou's equitability values. In order to test differences in macroinvertebrates community structure a Permutational Multivariate Analysis of Variance (PERMANOVA) was applied comparing pre and post-drawdown square-root transformed density data. A specific composition analysis (SIMPER) was run to determine the main taxa responsible for the observed differences.

Functional diversity

For functional categorization we used nine traits (Table 1), filled in with information gathered from literature published by McCafferty (1981), Pennak (1989), Ringuelet and Castellanos (1991), Lopretto and Tell (1995), Trivinho-Strixino and Strixino (1995), Merritt and Cummins (1996), Darrigran et al. (1999), Frouz et al. (2003), Bouchard Jr. (2004), Ruppert et al. (2005), Costa et al. (2006), Mansur and Pereira (2006), Domínguez and Fernández (2009), Mugnai et al. (2010), Fransozo and Fransozo (2016), Latini et al. (2016), and online sources (https://ento.psu.edu/extension/factsheets/phorid-flies) (Appendix 1). Trait information was collected at the lowest feasible taxonomic level. That is, when species or genera trait was lacking, family, order or a higher level instead was used. For "body size", it was used the mean values of the sizes found in literature and "aquatic stage" was classified by the author during the identification activities. The traits selected here were cited by Schmera et al. (2017) as some of the most frequently used groups of traits in published papers of macroinvertebrates functional diversiy.

Table 1. Traits, their categories and codes used for analyzes of macroinvertebrates community sampled in littoral zone of Salto Grande Reservoir.

Traits	**Categories**	**Code**
Body size	Mean values (mm)	BS
Body form	Conical	BF1
	Cylindrical	BF2
	Flattened	BF3
	Spherical	BF4
	Spiral-plane	BF5
	Streamlined	BF6
Aquatic stage	Larva	AS1
	Nymph	AS2
	Adult	AS3
Feeding group	Filter-feeders	FG1
	Gathering-collectors	FG2
	Predators	FG3
	Scrapers	FG4
	Herbivores	FG5
	Detritivores	FG6
Locomotion mode	Burrower	LO1
	Crawler	LO2
	Interstitial	LO3
	Swimmer	LO4
Reproduction mode	Asexual	RE1
	Sexual	RE2
Respiration mode	Anal	RP1
	Coloforo	RP2
	Gill	RP3
	Lung	RP4
	Spiracle	RP5
	Tegument	RP6
	Hemoglobin	RP7
Resistance form	Cocoons	RS1
	Diapause/Dormancy	RS2
	Eggs	RS3
	None	RS4
Habitat	Burrowers	HB1
	Clambers	HB2
	Clingers	HB3
	Interstitials	HB4
	Sprawlers	HB5
	Swimmers	HB6

A functional distance matrix based on the dissimilarity version of Gower's formula, modified by Pavoine et al. (2009), was constructed. Functional richness (FRic), functional evenness (FEve) and functional divergence (FDiv) were calculated using dbFD function in FD package (Laliberté and Legendre, 2010) of R Cran software. FD was standardized to vary between 0.0 and 1.0.

FRic measures the overall spread of traits in a particular community (Villéger et al., 2008; Ding et al., 2017). A higher value implies that more niches are filled by taxa (Ding et al., 2017). FEve describes the evenness of abundance distribution in a functional trait space, and lower functional evenness indicates that some parts of niche space, although occupied, are underutilized (Mason et al., 2005; Ding et al., 2017). FDiv represents the highest degree of divergence in abundance spread in trait space (Mason et al., 2005; Ding et al., 2017) and describes species distribution across niche space (Mason et al., 2005, Villéger et al., 2008, Ding et al., 2017). High FDiv entails a high degree of niche differentiation, more efficient are the resource use, and thus low resource competition (Mason et al., 2005; Ding et al., 2017).

To summarize the range and distribution of trait values in the macroinvertebrates community, a trait composition analysis was applied. We choose the 'community-weighted mean trait values' (CWMs) that calculates the average of trait values weighted by the relative abundances of each taxa (Garnier et al., 2004). CWM can be adequately to point shifts in mean trait values due to environmental selection for certain functional traits (Ricotta and Moretti, 2011).

We performed a Student's t-test for each functional diversity index to examine differences between pre and post-drawdown phases. To evaluate differences in the proportion of each trait category between phases a one-way ANOVA was applied. Data of functional structure were compared between both drawdown phases using permutational multivariate analysis of variance (PERMANOVA). Furthermore, a specific composition analysis (SIMPER) was run to determine the main trait responsible for the observed differences.

Traits-environmental link

A RLQ combined with a fourth-corner analysis was performed to test and estimate trait–environment relationships. Both methods are based on the crosses analysis of R (environmental characteristics of samples), L (species distribution across samples) and Q (species traits) matrices. The RLQ is a multivariate technique that provides ordination scores to summarize the join structure among the three tables, whereas the fourth-corner method mainly tests for individual trait-environment relationships (i.e. one trait and one environmental variable at a time), being a complementarity way to exploit ecological data when use combined (Dray et al., 2014).

All abundance data (L matrix) and environmental variables (R matrix), except for pH were transformed prior to the analysis. Correspondence analysis (CA) was applied to R and L tables, and a Hill-Smith analysis for Q table (i.e. mix of qualitative and quantitative variables). For fourth-corner we combined results of model 2 and model 4 (Dray and Legendre, 2008) and the significance was accessed based on 49,999 permutations. The significance level (p-value) was adjusted following recommendations of Dray and Legendre (2008). To perform all RLQ and fourth-corner analysis we followed a tutorial of Dray et al. (2014).

Statistical analyses were conducted in R software (RStudio, v. 1.1.456), using car, vegan, MASS, ade4 and FD packages.

Results

Environmental variables

Half of the environmental variables analyzed presented lower values in post-drawdown phase, but significant decrease was detected in only five of them, being depth, pH, eletric conductivity, total dissolved solids and oxide-reduction potential of water. In general, oxygen content and coarse sediment grains were found in higher percentage in post-drawdown phase, but temperature was the only one significantly higher after re-filling (Table 2; Appendix 2).

Table 2. Mean values and standard deviation (SD) of environmental variables measured in the littoral zone of Salto Grande Reservoir during the pre and post-drawdown phases. Different letters indicate significant differences in values of the same variable. Results from Student's t-test are also shown.

Environmental variables	Pre-drawdown	Post-drawdown	T-test results	
			T	*p*
Depth	1.54 (0.29)	0.95 (0.24)	**-3.38**	**0.01**
Temperature	22.19 (0.12)	22.59 (0.23)	**3.52**	**0.01**
Dissolved oxygen	8.46 (0.23)	8.74 (0.33)	1.60	0.15
Oxygen saturation percentage	99.48 (2.53)	103.50 (3.53)	-0.98	0.38
pH	7.39 (0.14)	7.02 (0.30)	**-2.45**	**0.05**
Eletric conductivity	79.80 (0.45)	74.40 (0.89)	**-11.77**	**0.00**
Transparency	1.26 (0.09)	0.95 (0.24)	-2.39	0.08
Turbidity	19.10 (1.04)	14.35 (6.09)	-1.49	0.21
Total dissolved solids	52.00 (0.00)	48.40 (0.89)	**-8.64**	**0.00**
Oxide-reduction potential	378.00 (9.08)	319.40 (22.35)	**-5.10**	**0.00**
Organic matter	15.70 (0.87)	14.13 (2.22)	-1.47	0.20
Gravel %	0.00 (0.00)	0.07 (0.07)	2.44	0.07
Very coarse sand %	0.02 (0.04)	0.73 (0.70)	2.16	0.09
Coarse sand %	0.04 (0.08)	0.77 (1.06)	1.34	0.24
Medium sand %	0.21 (0.37)	3.36 (4.86)	1.72	0.15
Fine sand %	0.56 (0.38)	5.28 (7.34)	1.50	0.21
Very fine sand %	2.48 (1.57)	4.05 (3.22)	0.88	0.41
Silt and clay %	96.69 (2.41)	85.74 (16.66)	-1.45	0.21

Macroinvertebrates community

Thirty-two taxa belonging to Platyhelminthes, Nemertea, Nematoda, Mollusca, Annelida and Arthropoda were found in the littoral zone of Salto Grande Reservoir during the study period (Table 3).

Turbellaria, Gastropoda *Pomacea,* Bivalvia *Mycetopoda,* Ephemeroptera *Tricorythodes,* Trichoptera *Cernotina*, Coleoptera *Neoelmis,* Chironomidae Orthocladiinae, Tanypodinae and Lepidoptera occurred exclusively in pre-drawdown phase, most with low frequency of occurrence. Collembola Entomobryidae and most Diptera taxa (Empididae, Ephydridae, Phoridae, Muscidae and Tipulidae) were observed only after re-filling and with low frequency of occurrence (except for Muscidae and Phoridae) (Table 3).

Seventeen taxa were recorded in both pre and post-drawdown phases. Nine of them had increased density in post-drawdown phase (Nematoda, 4 Gastropoda, 2 Acari and 2 Diptera), while eight of them, a reduction (Nemertea, 2 Gastropoda, 2 Bivalvia, Oligochaeta, Ostracoda and Odonata) (Table 3). Ostracoda was the most representative taxon in both phases. Taxa with a contribution of less than 10% have higher relative abundance in post-drawdown phase (Table 3).

Table 3. Density (ind.m^{-2}), frequency of occurrence (FO %) and relative abundance (RA %) of benthic macroinvertebrates found in littoral zone of Salto Grande Reservoir during the pre and post-drawdown phases.

		Pre-drawdown			Post-drawdown		
	Code	Density (ind.m^{-2})	FO (%)	RA (%)	Density (ind.m^{-2})	FO (%)	RA (%)
Platyhelminthes – Turbellaria	t1	17	20	0.07	0	0	0.00
Nemertea	t2	1296	100	5.11	34	20	0.20
Nematoda	t3	522	100	2.06	774	100	4.70
Mollusca Gastropoda – *Pomacea*	t4	34	20	0.13	0	0	0.00
Gastropoda – Ancylidae	t5	522	60	2.06	168	60	1.02
Gastropoda – *Biomphalaria*	t6	84	60	0.33	34	40	0.20
Gastropoda – *Physa*	t7	34	20	0.13	84	40	0.51
Gastropoda – *Texadina*	t8	84	60	0.33	455	100	2.76
Gastropoda – *Aylacostoma*	t9	34	20	0.13	67	60	0.41
Gastropoda - *Melanoides tuberculata*	t10	101	40	0.40	236	100	1.43
Bivalvia – *Mycetopoda*	t11	51	20	0.20	0	0	0.00
Bivalvia - *Corbicula fluminea*	t12	3620	100	14.26	3013	100	18.28
Bivalvia - *Limnoperna fortunei*	t13	5960	100	23.47	707	100	4.29
Annelida – Oligochaeta	t14	1835	80	7.23	387	60	2.35
Crustacea – Ostracoda	t15	10387	100	40.92	8569	100	51.99
Acari – Oribatida	t16	303	60	1.19	1162	80	7.05
Acari – Hydrachinidae	t17	34	40	0.13	84	40	0.51
Collembola – Entomobryidae	t18	0	0	0.00	17	20	0.10
Ephemeroptera –*Tricorythodes*	t19	67	60	0.27	0	0	0.00
Trichoptera – *Cernotina*	t20	17	20	0.07	0	0	0.00
Odonata *Phylocycla*	t21	202	100	0.80	34	20	0.20
Coleoptera – *Noelmis*	t22	17	20	0.07	0	0	0.00

Diptera- Empididae	t23	0	0	0.00	51	20	0.31
Diptera – Ephydridae	t24	0	0	0.00	17	20	0.10
Diptera – Phoridae	t25	0	0	0.00	152	40	0.92
Diptera – Muscidae	t26	0	0	0.00	152	80	0.92
Diptera – Tipulidae	t27	0	0	0.00	17	20	0.10
Diptera – Ceratopogonidae	t28	17	20	0.07	51	40	0.31
Diptera – Chironominae	t29	34	40	0.13	219	60	1.33
Diptera – Orthocladiinae	t30	17	20	0.07	0	0	0.00
Diptera – Tanypodinae	t31	84	40	0.33	0	0	0.00
Lepidoptera	t32	17	20	0.07	0	0	0.00

Richness taxa, Shannon's diversity and Pielou's equitability values did not differ between pre and post-drawdown phases (Figure 3; Table 4). However, results of PERMANOVA test show differences among the phases in terms of structure of the macroinvertebrates community ($F=2.52$; $p=0.03$), with Nemertea ($p<0.01$), *Phylocycla* ($p<0.05$) and Muscidae ($p<0.05$) as the main taxa that discriminated it.

The analyses of functional indexes FRic, FEve and FDiv showed significant difference only for FRic when compared the drawdown phases (Figure 3; Table 4). Lower value was detected after the water management (Figure 3).

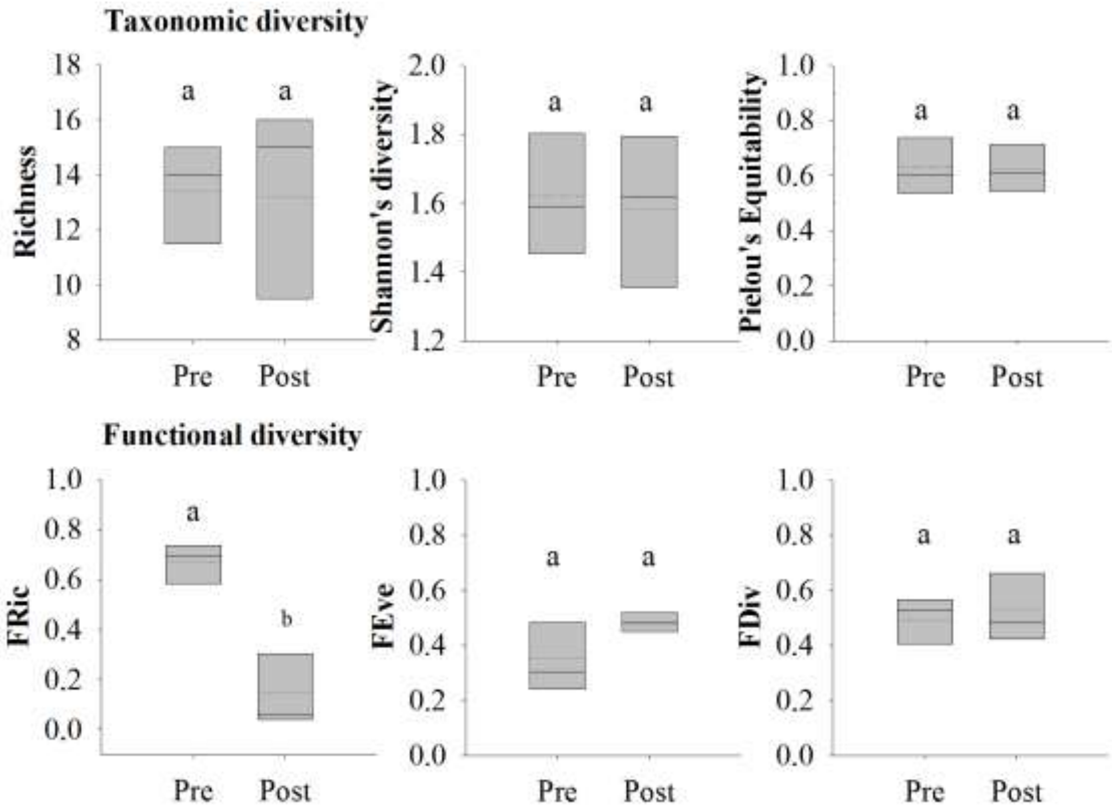


Figure 3. Box plot for taxonomic and functional diversity indexes of the benthic macroinvertebrates community in the littoral zone of Salto Grande Reservoir during the pre and post-drawdown phases. FRic: functional richness; FEve: functional evenness; FDiv: functional divergence. Dotted line: mean values. Letters correspond to comparison test results.

Table 4. Results of Student's t-test applied to taxonomic attributes and functional diversity indexes of the macroinvertebrates community in the littoral zone of Salto Grande Reservoir during pre and post-drawdown phases.

	T-test results	
	T	*p*
<u>Taxonomic diversity indexes</u>		
Richness	-0.11	0.91
Shannon's diversity	-0.29	0.78
Pielou's equitability	-0.12	0.91
<u>Functional diversity indexes</u>		
Functional richness	**-5.14**	**0.00**
Functional eveness	2.11	0.09
Functional divergence	0.47	0.65

A total of five traits categories differed significantly between drawdown phases (Figure 4; Appendix 3). In terms of "Body size", post-drawdown was dominated by smaller organisms (F=21.21, p= 0.00). Regarding "Body form", a significant drastic reduction in abundance of "streamlined" taxa was observed after re-filling (F= 13.57, p=0.01). Likewise for "nymph" of "Aquatic stage" (F=14.48, p=0.01) and "anal" of "Respiration mode" traits (F=8.96, p=0.02). In terms of "Locomotion mode", the post-drawdown phase present a significant higher abundance of taxa characterized by the trait "Swimmer" (F=5.84, p=0.04).

Results of PERMANOVA test point to differences among the phases in terms of structure of the macroinvertebrates traits (F=18.50, p = 0.01), being mean body size (p<0.01), "Herbivores feeding group" (p<0.01), "Streamlined body form" (p<0.05), "Nymph aquatic stage" (p<0.05) and "Anal respiration mode" (p<0.05) the main trait that discriminated it.

The relationships between traits and environmental variables can be summarized by the first two RLQ axes (88.8% and 4.3% of the cross-covariance between traits and environment for axis 1 and 2, respectively). The right (positive) part of the first RLQ axis identifies the taxa (Figure 5a) and the traits (Figure 5c) that were related to post-drawdown phase (Figure 5b). The left part of this axis highlights the taxa and their associated trait attributes of pre-drawdown phase. The fourth-corner statistic allowed a direct analysis of each single trait–environmental variable correlation and pointed no significative relationships.

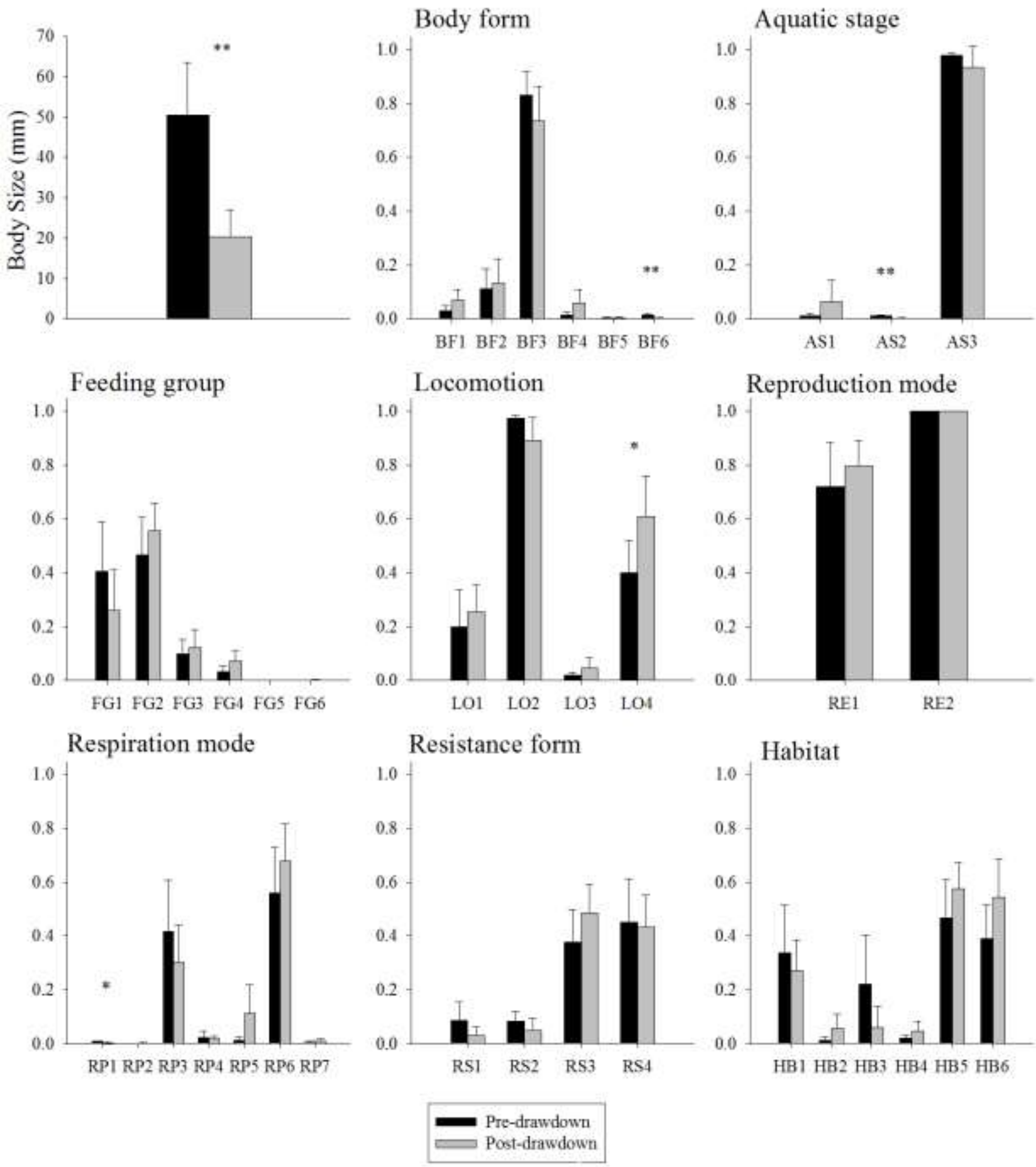


Figure 4. The structure of 39 categories of nine traits of pre-drawdown (black) and post-drawdown (gray) phases. Each bar represents the mean values with standard deviation of each trait category in pre and post-drawdown phases. The ratio is the abundance of taxa with the same trait to the total abundance ratio in a sample. All the category codes in each trait refer to Table 1. * significance level at 0.05, ** significance level at 0.01.

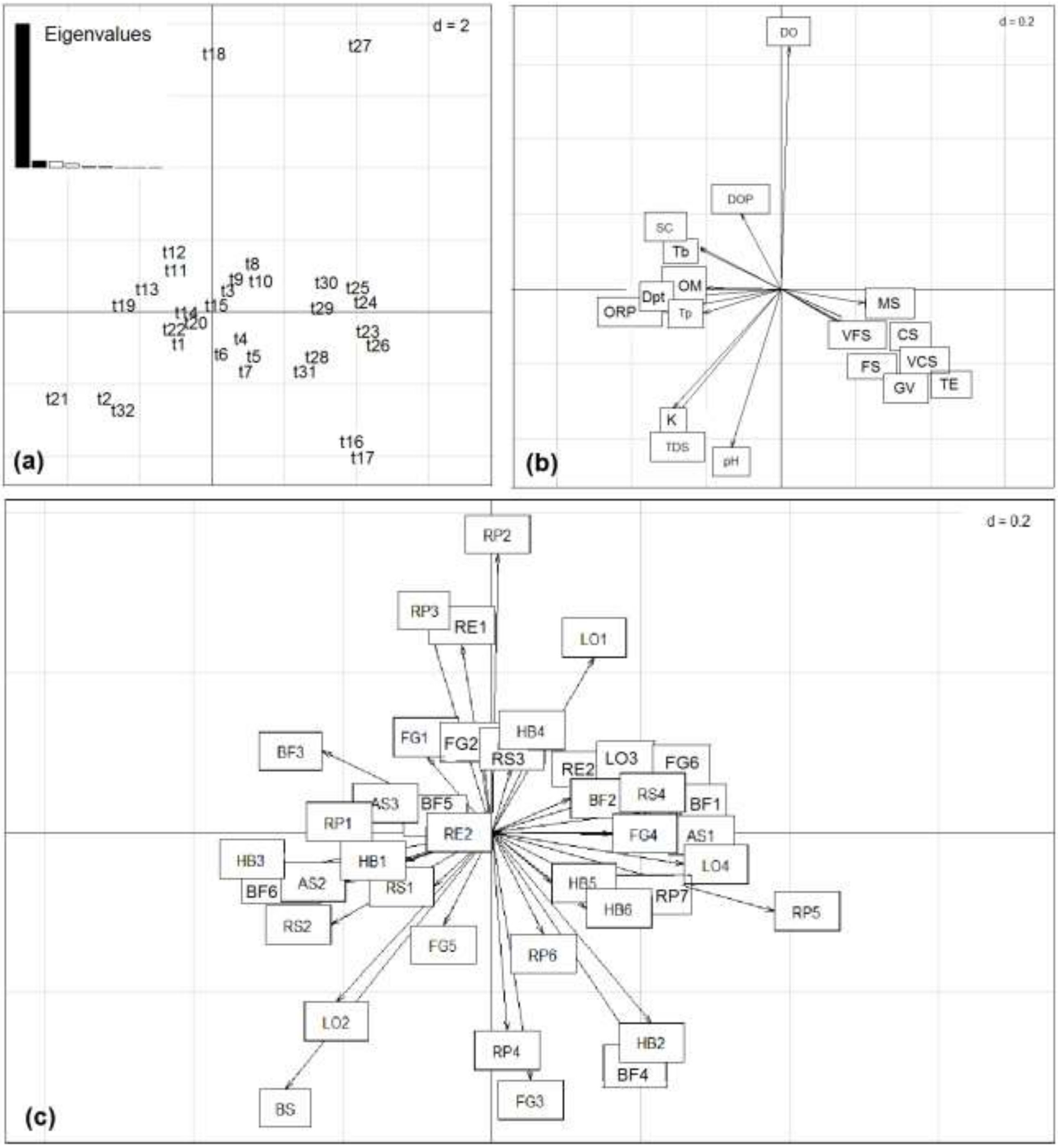


Figure 5. Results of the first two axes of RLQ analysis: (a) eigenvalues and scores of macroinvertebrates taxa, (b) coefficients for environmental variables, and (c) traits. The values of d give the grid size. Codes for traits, environmental variables, and macroinvertebrates taxa are available in Tables 1, 2 and 3.

Discussion

Our results demonstrated that artificial water-level drawdown over a short time period can affect limnological variables of water in the littoral zone of tropical reservoirs, but not the sediment characteristics. The benthic macroinvertebrates community was not negatively impacted if we consider a taxonomic approach, mainly because the fast re-colonization of organisms. However, functional richness decreased in post-drawdown phase due to loss of some traits. “Streamlined body form”, “nymph aquatic stage” and “anal respiration mode” may be considered sensitive traits of macroinvertebrates community to water level management. Besides, “Swimmers locomotion mode” may be classified as a resistance and resiliance trait, while “Small body size” as resilience one. It is important highlight that we were unable to prove the traits-environmental relationship, probably because the choice of the variables assessed here.

The lower depth values found in post-drawdown phase occurred because sampling was done in the first day of re-filling reservoir, when the maximum quota had not been reached yet. Higher temperatures may have occurred as a result of this reduced water volume (Straskraba et al., 1993; Furey et al., 2004) or due to the heat exchange with the sediment that was exposed during low water phase. Lower pH values observed in the post-drawdown phase may be consequence of organic matter degradation in the exposed sediment (James et al., 2001; Klant et al., 2016), being a result of geochemistry processes in sediment-water interface after re-filling. The lower values of organic matter in the sediment in post-drawdown phase support this idea.

Lower total dissolved solids and eletric conductivity values were also found in the post-drawdown phase and may also be related to the lower values of matter content in the sediment of the littoral zone after drying. Moreover, the compaction of exposed sediment contributes to keep elements in the substrata (James et al., 2001; Klant et al., 2016), justifying the eletric conductivity values too. Here, it is important to note that these reductions in sediment variables values were just a trend, not statistically proven. However, these results refer to 15 days of drying in tropical region. A greater drought period may lead to significant differences in sediment characteristics between drawdown phases. In addition, we emphasize the absence of riparian forest and the presence of man-made structures around the studied reservoir. So, further investigations with other surrounding conditions are strongly recommended for a better understanding of sediment dynamics in reservoir systems under water level procedures.

In disagreement with other studies about the effects of water level fluctuations on macroinvertebrate communities of littoral habitats (e.g. Liu et al., 2011; Paschoal et al., 2015; Silva and Petrucio, 2018), no differences in taxonomic diversity indexes were detected between drawdown phases. Changes were observed only in community structure. We attribute these results to the fast re-colonization process of organisms in the littoral zone of the reservoir after the drastic and short time period of drought. We consider oviposition behavior (Harrison and Hildrew, 1998; Johnson and Goedkoop, 2002) and intrinsic factors of habitat choice and life history phenologies (Harrison and

Hildrew, 2001; Johnson and Goedkoop, 2002) to explain it. Besides, also need to be considered a strong influence of water flow action to bring organisms back to littoral areas immediately after re-filling.

Compared to the large research effort in studies of benthos re-colonization in streams, little is known about it in littoral zones of tropical reservoirs after a drawdown management. Taxa that were registered in pre-drawdown phase disappearing after drying period, as Trichoptera and Coleoptera, are considered as late colonizers (Carvalho et al., 2008), whereas in the post-drawdown phase were found most of Diptera, considered as fast and early colonizers (Baumgärtner et al., 2008; Carvalho et al., 2008; Hofmann et al., 2008). Therefore, a long-term colonization and ecological succession study is necessary to explain how the dynamics of this community take place after re-filling phase.

The presence and absence of certain macroinvertebrate groups are also related to their sensibility to environmental conditions (Rosemberg and Resh, 1993). As cited above, some characteristics, or a set of them, will define the tolerance degree of the organisms (Schmera et al., 2017). In our study, "Swimmers locomotion mode" show increased abundance after re-filling (CWM and one-way ANOVA analyses), being related to Acari and Diptera (mainly Empididae, Muscidae and Ceratopogonidae) taxa (RLQ analysis). Therefore, it may reflect a resistance and resilience trait of macroinvertebrates community facing water disturbance. "Small body size" occurred only in post-drawdown phase and may be considered as resilience trait, associated with most of Diptera taxa. Declined traits after water management may be classified as sensitive trait indicators for water level impacts, as "Streamlined body form", "Nhymph aquatic stage" and "Anal respiration mode", which were related to Ephemeroptera, Trichoptera, Odonata, Coleoptera and Lepidoptera taxa. Consequence of this registered defaults in the community traits structure was the lower functional richness observed in post-drawdown phase.

It is important to emphasize that traits-environmental relationship has not been proven by the variables evaluated during water level drawdown in Salto Grande Reservoir (Fourth-corner analysis). That is, none studied environmental variable acted as a filter in the functional traits selection. We believe that other more primary measures related to the procedure, such as sediment moisture content and plant density would bring us this significant relationship. Furthermore, studies show that environmental consequences of an artificial drawdown can appear in very different timescales, ranging from days to seasons or even years (Hellsten et al., 1996; Leira and Cantonati, 2008; Portinho and Nogueira, 2017). As already mentioned by Debastiani-Júnior and Nogueira (2015) and Portinho and Nogueira (2017), all these results support the need for more research on the effects of drawdown on taxonomic and functional response of benthic macroinvertebrates and other aquatic communities, particularly in relation to their extent, frequency, duration and possible of steady-state shifts in these systems.

In general, our study involves the response of macroinvertebrates community to water disturbance and dealt with a paradox when different measures of biodiversity were applied: a loss of functional diversity resulting from a loss of functional traits while taxonomic richness did no change. Some other authors even found loss of functional specialization while species richness increases (Villéger et al., 2010). This result highlights that taxa richness may provide an incomplete signal of ecosystem recovery, and that a multifaceted framework (including functional traits) in the assessment of biodiversity changes is necessary in monitoring or impact reports (Bellwood et al., 2006; Villéger et al., 2010). Anyway, we cannot judge the artificial water level drawdown employed to macrophytes control as negative for the littoral benthic macroinvertebrates community because lack us knowledge of the long-term effects of this management in functional diversity.

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APPENDIX

1. Benthic macroinvertebrates taxa identified in the littoral zone of Salto Grande Reservoir during pre and post-drawdown phases and their respective functional traits. Super scribe letters refer to the literature source. Codes for traits and macroinvertebrates taxa are available in Tables 2 and 3.

Taxa	Traits								
	BS (mm)	BF	AS	FG	LO	RE	RP	RS	HB
t1	155(2)	BF3(2)	AS3(1)	FG3(2)	LO2(2)	RE1, RE2(2)	RP6(2)	RS3(2)	HB5(2)
t2	500.5(2)	BF3(2)	AS3(1)	FG3(2)	LO2(2)	RE1, RE2(2)	RP6(2)	RS2(15)	HB1, HB5(2)
t3	1.75(2)	BF2(2)	AS3(1)	FG3(15)	LO3(2)	RE1, RE2(7)	RP6(7)	RS2(15)	HB4(2)
t4	150(6)	BF4(16)	AS3(1)	FG4(6)	LO1, LO2(6)	RE2(6)	RP3(6)	RS4(19)	HB1, HB5(6)
t5	8.8(16)	BF1(16)	AS3(1)	FG4(6)	LO2(16)	RE2(6)	RP4(6)	RS4(19)	HB5(16)
t6	23.5(6)	BF5(6)	AS3(1)	FG4(6)	LO2(6)	RE2(6)	RP4(6)	RS4(19)	HB5(6)
t7	15.25(16)	BF1(6)	AS3(1)	FG4(6)	LO2(16)	RE2(6)	RP4(6)	RS4(19)	HB5(6)
t8	4.45(16)	BF1(16)	AS3(1)	FG4(6)	LO2(16)	RE1, RE2(6)	RP3(16)	RS4(19)	HB5(6)
t9	32(16)	BF1(16)	AS3(1)	FG4(6)	LO1, LO2(6)	RE2(16)	RP3(6)	RS4(19)	HB1, HB5(6)
t10	32(13)	BF1(13)	AS3(1)	FG4(6)	LO2(13)	RE1, RE2(13)	RP3(6)	RS4(19)	HB5(13)
t11	54.5(10)	BF3(10)	AS3(1)	FG1(14)	LO1, LO2(10)	RE2(6)	RP3(6)	RS4(19)	HB1(10)
t12	48(13)	BF3(6)	AS3(1)	FG1(13)	LO1, LO2(13)	RE1, RE2(13)	RP3(6)	RS4(19)	HB1(13)
t13	38(10)	BF3(10)	AS3(1)	FG1(14)	LO2(10)	RE2(5)	RP3(6)	RS4(19)	HB3(6)
t14	15.5(15)	BF2(7)	AS3(1)	FG2(2)	LO2(2)	RE1, RE2(15)	RP6(2)	RS1(15)	HB1(2)
t15	12.625(2)	BF3(7)	AS3(1)	FG1(2)	LO2, LO4(2)	RE1, RE2(2)	RP6(2)	RS3(7)	HB5, HB6(2)
t16	0.5(2)	BF4(2)	AS3(1)	FG3(2)	LO2, LO4(2)	RE2(2)	RP5, RP6(2)	RS4(19)	HB2, HB6(2)
t17	1.7(15)	BF4(15)	AS3(1)	FG3(15)	LO2, LO4(15)	RE2(15)	RP5, RP6(15)	RS4(19)	HB2, HB6(15)

t18	3[12]	BF3[1]	AS3[1]	FG2[12]	LO4[11]	RE2[12]	RP2, RP6[9]	RS2[12]	HB5[12]
t19	11.5[11]	BF6[11]	AS2[1]	FG2[12]	LO1, LO4[4]	RE2[12]	RP3[12]	RS2[12]	HB3, HB5[12]
t20	21[11]	BF6[11]	AS1[1]	FG3[12]	LO1, LO4[11]	RE2[11]	RP3[12]	RS2[12]	HB3[12]
t21	35[11]	BF6[11]	AS2[1]	FG3[12]	LO2[11]	RE2[11]	RP1, RP6[11]	RS2[12]	HB1[12]
t22	5.5[3]	BF6[11]	AS1[1]	FG2,FG4[12]	LO2, LO4[11]	RE2[11]	RP3[12]	RS2[11]	HB3[12]
t23	4.5[11]	BF2[6]	AS1[1]	FG3[12]	LO1, LO4[12]	RE2[6]	RP5, RP6[9]	RS4[19]	HB1, HB5[12]
t24	7.5[3]	BF2[6]	AS1[1]	FG2[12]	LO1, LO4[12]	RE2[6]	RP5, RP6[9]	RS4[19]	HB1, HB5[12]
t25	3[17]	BF2[6]	AS1[1]	FG2[12]	LO1, LO4[12]	RE2[6]	RP5, RP6[9]	RS4[19]	HB1[12]
t26	10[11]	BF2[6]	AS1[1]	FG3[12]	LO1, LO4[12]	RE2[6]	RP5, RP6[9]	RS4[19]	HB5[12]
t27	17.5[11]	BF2[6]	AS1[1]	FG6[12]	LO1, LO4[12]	RE2[6]	RP5, RP6[9]	RS4[19]	HB1[12]
t28	8.5[11]	BF2[6]	AS1[1]	FG3[12]	LO2, LO4[12]	RE2[6]	RP5, RP6[9]	RS4[19]	HB1[12]
t29	11[11]	BF2[6]	AS1[1]	FG1, FG2[12]	LO1, LO4[18]	RE2[6]	RP6, RP7[18]	RS1[8]	HB1[12]
t30	7[18]	BF2[6]	AS1[1]	FG2, FG4[12]	LO1, LO4[18]	RE2[6]	RP6[18]	RS4[19]	HB1[12]
t31	11[11]	BF2[6]	AS1[1]	FG3[12]	LO2, LO4[18]	RE2[6]	RP6[18]	RS4[19]	HB5, HB6[12]
t32	39[11]	BF6[11]	AS1[1]	FG5[12]	LO2[6]	RE2[6]	RP3[6]	RS4[19]	HB3[6]

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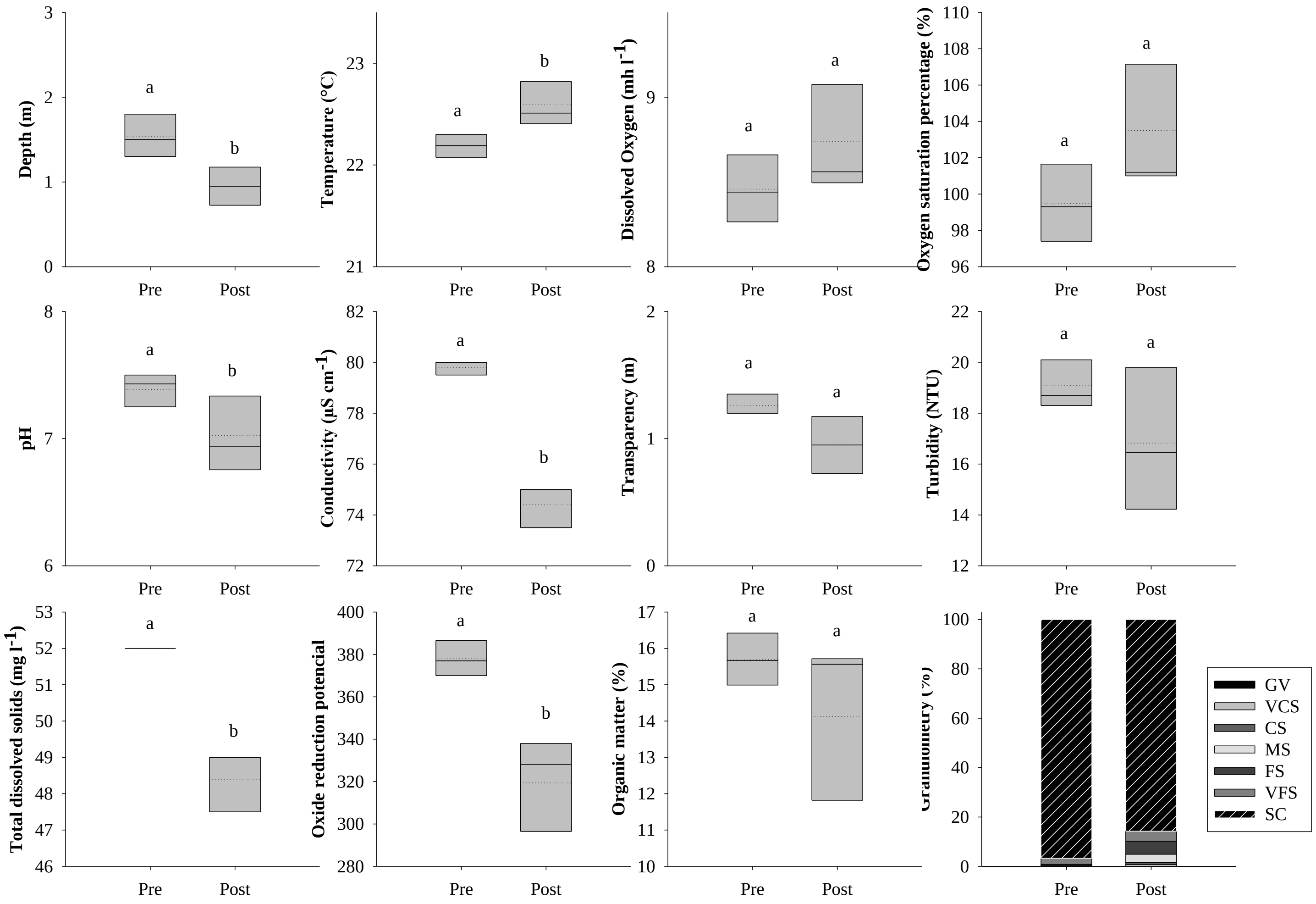
2. Box plot for water and sediment variables measured in the littoral zone of Salto Grande Reservoir during pre and post-drawdown phases. Dotted lines: mean values. Letters correspond to comparison test results.



3. F values and significance level (*p*) results of one-way ANOVA applied to traits categories evaluated in the macroinvertebrates community of littoral zone of Salto Grande Reservoir.

Traits	Categories	F	*p*	Traits	Categories	F	*p*
BS	Mean values	**21.21**	**0.00**	RE	RE1	0.79	0.40
BF	BF1	4.82	0.06		RE2		
	BF2	0.16	0.70	RP	RP1	**8.96**	**0.02**
	BF3	1.88	0.21		RP2	1.00	0.35
	BF4	3.60	0.09		RP3	1.19	0.31
	BF5	0.07	0.79		RP4	0.18	0.68
	BF6	**13.57**	**0.01**		RP5	4.52	0.07
AS	AS1	2.14	0.18		RP6	1.50	0.26
	AS2	**14.48**	**0.01**		RP7	1.75	0.22
	AS3	1.53	0.25	RS	RS1	2.79	0.13
FG	FG1	1.89	0.21		RS2	1.70	0.23
	FG2	1.32	0.28		RS3	2.22	0.17
	FG3	0.42	0.54		RS4	0.04	0.85
	FG4	4.65	0.06	HB	HB1	0.52	0.49
	FG5	1.00	0.35		HB2	3.75	0.09
	FG6	1.00	0.35		HB3	3.27	0.11
LO	LO1	0.53	0.49		HB4	2.19	0.18
	LO2	4.66	0.06		HB5	1.93	0.20
	LO3	2.19	0.18		HB6	3.23	0.11
	LO4	**5.84**	**0.04**				

Considerações finais

De maneira geral, o deplecionamento artificial do nível d'água acarretou alterações na qualidade da água e nas características do sedimento no reservatório de Salto Grande (rio Paranapanema, SP/PR). Não foram observados impactos negativos sobre a diversidade taxonômica de macroinvertebrados bentônicos da região perene do sistema (calha dos rios e região central das lagoas laterias e baía), contudo, houve uma redução na diversidade funcional da comunidade litorânea do reservatório imediatamente após o re-estabelicimento do nível d'água.

Acredita-se que as alterações ambientais relacionadas às características físicas e químicas da água e do sedimento não tenham interferido na dinâmica da biota aquática por se tratar de um sistema do tipo fio d'água, no qual o tempo de residência é muito curto. Assim, ressaltamos a importância de pesquisas que sejam realizadas em outros sistemas (e.g. reservatórios de acumulação) para que tenhamos um diagnóstico de impacto conclusivo. Estudos envolvendo o processo de deplecionamento com diferentes tempos de duração, extensão e frequência também são necessários. Além disso, recomendamos atenção para os efeitos a longo prazo, sendo essencial o monitoramento dos reservatórios que estejam submetidos ao procedimento. Inclusive acompanhar pontos a jusante da barragem, a depender dos efeitos encontrados.

Notamos que a abordagem funcional mostrou-se mais eficaz no apontamento de perda de diversidade frente ao deplecionamento, quando comparada à análise de diversidade taxonômica (e.g. índices de diversidade). Outros trabalhos já vêm destacando a maior sensibilidade dessa medida para detectar as respostas das comunidades às mudanças ambientais. Assim, prevemos que seja tendência a implementação dessa metodologia em avaliações de impactos ambientais, visto que, além de ser capaz de indicar os filtros ambientais que selecionam as espécies, podem fazer leituras preditivas sobre processos de extinção e invasão biológica (competição).

Diante da redução da riqueza funcional na comunidade de macroinvertebrados bentônicos da zona litorânea do reservatório de Salto Grande, é importante conhecermos também o tempo de permanência e as consequências dessa alteração. Por isso, sugerimos a realização de trabalhos que avaliem o processo de re-colonização e sucessão ecológica em zonas litorâneas de reservatórios sujeitas à drástica variação de nível d'água em curto período de tempo para melhor compreensão da dinâmica da comunidade e de suas respostas funcionais após o impacto. Além disso, recomendamos a realização de estudos que englobem a perda de nicho e homogeneização do hábitat para melhor entendimento dos fatores que possam estar atuando na seleção dos traços funcionais.

Vale ressaltar que neste trabalho também ficou evidenciada a importância das áreas laterais dos reservatórios tropicais para manutenção da diversidade regional. Esse tema já é bastante discutido entre pesquisadores da área, no entanto, pouco se fala a respeito de processos de gestão e manejo em sistemas complexos, que apresentam áreas laterais ao corpo principal do reservatório. Assim, em caso de implementação do deplecionamento artificial do nível d’água para controle de macróficas, deve-se ter atenção redobrada com os efeitos sobre esses ambientes.