

UNIVERSIDADE ESTADUAL PAULISTA – UNESP

INSTITUTO DE BIOCÊNCIAS

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**ANÁLISE COMPARATIVA DA DIETA, SELETIVIDADE ALIMENTAR E  
ESTRUTURA DA ICTIOFAUNA, JUVENIS E ESPÉCIES DE PEQUENO PORTE, EM  
LAGOAS MARGINAIS DO RESERVATÓRIO DE ROSANA (RIO PARANAPANEMA,  
SP/PR)**

*Orientador: Dr. Marcos Gomes Nogueira*

Botucatu/SP

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SP/PR)**

Tese apresentada ao Instituto de Biociências da Universidade Estadual Paulista – UNESP, Campus de Botucatu, como parte dos requisitos para a obtenção do Título de Doutor em Ciências Biológicas, Área de concentração: Zoologia.

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*Resumo*

## **I RESUMO GERAL**

**Análise comparativa da dieta, seletividade alimentar e estrutura da ictiofauna, juvenis e espécies de pequeno porte, em lagoas marginais do reservatório de Rosana (rio Paranapanema, SP/PR).** O presente estudo foi conduzido em quatro lagoas marginais da porção superior do reservatório de Rosana, bem como no canal principal do rio Paranapanema. O objetivo do primeiro capítulo foi analisar a composição e os atributos ecológicos das assembléias fitoplanctônicas, recurso trófico primário das cadeias alimentares aquáticas. O segundo capítulo trata da comunidade zooplanctônica (Cladocera e Copepoda) e sua distribuição nos ambientes analisados. O terceiro trabalho procura avaliar se a introdução de uma espécie exótica de peixe (*Cichla kelberi*) pode causar alterações na estrutura da ictiofauna local, com uma possível redução da sua diversidade. Por fim, o quarto capítulo refere-se à alimentação da ictiofauna de pequeno porte, através da análise da dieta e do hábito alimentar das espécies, considerando principalmente a importância da comunidade planctônica para essa fauna. O número total de táxons de fitoplâncton identificados foi de 283. Zygnemaphyta foi o grupo com maior número de espécies, seguido por Chlorophyta e Bacillariophyta. Maior riqueza, abundância e biomassa de fitoplâncton foram observadas nas lagoas, especialmente durante o período chuvoso. O número total de táxons de zooplâncton identificados foi de 72. As lagoas laterais e o período chuvoso apresentaram maior abundância de organismos. Calanoida foi o grupo dominante nas assembléias zooplanctônicas. Os resultados mostraram que no sistema de lagoas laterais as comunidades são controladas por mecanismos ascendentes (“bottom-up”). Um total de 4693 peixes, pertencentes a 43 espécies foram amostrados. A Ordem Characiformes foi a mais abundante, seguida por Perciformes e Siluriformes. Não houve diferenças estatísticas na riqueza, na abundância, na biomassa, na média do comprimento, na composição das assembléias e na diversidade de peixes, comparando-se o período anterior e posterior à introdução da espécie exótica. Os resultados mostraram que a alimentação da ictiofauna amostrada no rio foi diferente das lagoas. No rio, os principais itens foram insetos aquáticos, Cladocera e fitoplâncton, enquanto que nas lagoas os principais itens foram insetos aquáticos, Copepoda e Cladocera. Baixa sobreposição de nicho trófico entre os pares de espécies também foi evidenciada, indicando que as espécies não competem pelos mesmos recursos. Os resultados também mostraram que o maior consumo de zooplâncton pelos peixes acontece quando esses organismos são menores. Os dados indicaram que os peixes se alimentam seletivamente de Cladocera, ao mesmo tempo em que, eles consomem Copepoda como complemento da sua dieta. Finalmente, os resultados indicam que as lagoas laterais têm um importante papel para as comunidades aquáticas, bem como para a alimentação dos peixes de reservatórios, e que o plâncton tem um significativo papel na alimentação da ictiofauna de pequeno porte.

Palavras-chave: Limnologia, fitoplâncton, zooplâncton, ictiofauna, alimentação de peixes, espécies não nativas.

## I.1 ABSTRACT

**Comparative analysis of diet, feeding selectivity and structure of the ichthyofauna, juveniles and small fish, in lateral lagoons of Rosana Reservoir (Paranapanema River, SP/PR).** The study was carried out in four lateral lagoons of the tail region of Rosana reservoir, as well as in the river/reservoir main channel. The aim of the first chapter of the thesis was to analyze the composition and ecological attributes of the phytoplankton assemblages, primordial trophic resource of the aquatic food chains. The second chapter is focused on the zooplankton community (Cladocera and Copepoda) and their distribution in the study environments. The third chapter tries to assess whether the introduction of a non native fish species (*Cichla kelberi*) may promote alterations in the local ichthyofauna, with a possible reduction in its diversity. Finally, the last chapter discusses the ichthyofauna feeding, through the analysis of diet and feeding behavior of fish, considering mainly the importance of plankton organisms as a resource. The total number of phytoplankton taxa identified was of 283. Zygnemaphyta was the most specious group, followed by Chlorophyta and Bacillariophyta. Higher richness, abundance and biomass were observed in the lagoons, especially during the rainy period. The total number of zooplankton taxa was 72. Higher zooplankton abundance was observed in the lateral lagoons and in the rainy period. Calanoids were the dominant group in the zooplankton assemblages. The results indicated that in the lateral lagoons system, the communities are controlled by bottom-up mechanisms. A total of 4,693 fish, belonging to 43 species was sampled between 2004 and 2009. The order Characiformes was the most abundant, followed by Perciformes and Siluriformes. There were no differences in composition, richness, abundance, biomass, mean length and diversity, when compared the periods previous and after the introduction of *Cichla*. The results showed that the feeding of the river fish assemblages was different from the lagoons. In the river, the main consumed items were aquatic insects, Cladocera and phytoplankton while in the lagoons the main items were aquatic insects, Copepoda and Cladocera. Low values of the niche overlap between pairs of species were observed, indicating that species do not compete severely for food resources. The results showed a proportionally higher consume of zooplankton by fish when they are of small size. The data also indicated that fish selected positively on Cladocera species at the same time as they consume Copepod as complementary diet. Thus, the results shows that the lateral lagoons have an important role for the aquatic communities, as well as for the feeding of reservoir fish, and that the plankton has a significant role for the feeding of small fish fauna.

Key-words: Limnology, phytoplankton, zooplankton, ichthyofauna, fish feeding, non native species.

*Apresentação*



## II APRESENTAÇÃO

A água doce é um recurso essencial para todos os ecossistemas e de extrema importância para o consumo humano, tanto para o atendimento de suas funções fisiológicas como para o seu desenvolvimento sócio-econômico. O volume de água doce é de apenas 2,5% do total de água na Terra. Mas nem todo esse volume está prontamente disponível, pois a maior parte se encontra em geleiras e calotas polares e outra grande parte é subterrânea. Apenas 0,3% do total de água doce corresponde aos rios e lagos (Rebouças, 1999), daí a necessidade de se conhecer cada vez melhor esses ambientes, incluindo suas comunidades bióticas, a fim de contribuir com estratégias bem sucedidas de manejo e preservação.

No Brasil os rios das principais bacias hidrográficas, principalmente na região sudeste, foram regulados pela construção de reservatórios. Essas represas são formadas para atender diversos objetivos, tais como: abastecimento de água, regularização de vazão, irrigação, navegação, pesca, recreação e, principalmente, geração de energia elétrica.

Os impactos gerados pela construção de barragens são inúmeros, acarretando na formação de ecossistemas lacustres artificiais e produzindo diferentes alterações, tanto no ambiente aquático como no terrestre adjacente. Segundo Tundisi *et al.* (1999), esses impactos estão relacionados à localização geográfica, ao tamanho, volume e tempo de retenção da água no reservatório, sendo os principais:

- Interferência no transporte de sedimentos, ocorrendo um aumento na taxa de sedimentação a montante e uma maior capacidade de erosão da água a jusante;
- Modificações na fauna do rio;
- Alterações no ciclo hidrológico, com o aumento da capacidade adicional de reserva e alteração do balanço hídrico, modificando os regimes de inundação e as áreas alagadas;
- Modificações nos ciclos biogeoquímicos, com retenção de fósforo e exportação de nitrogênio;

Destacam-se ainda, segundo Esteves (1998):

- Grandes mudanças nos habitats em torno da represa, afetando a fauna e a flora silvestres;
- Inundação de áreas florestais ou agrícolas, que pode levar a alterações físicas e químicas na água;
- Deslocamento de populações que antes habitavam terras inundadas, para o entorno das represas. Estas passam a exercer pressão sobre os recursos naturais e modificam o uso de áreas marginais;
- Mudanças nas condições de reprodução das espécies aquáticas, que podem ocorrer devido à destruição das lagoas marginais e alterações na qualidade física e química da água;
- Aumento no risco de deslizamento e tremores de terra devido ao peso das águas represadas e/ou da barragem (Paiva, 1982 apud Esteves, 1998);
- Possível aumento das comunidades de macrófitas aquáticas, principalmente de espécies flutuantes;

Os reservatórios em cascata, como no caso do rio Paranapanema, causam efeitos e impactos cumulativos, transformando completamente as condições biogeofísicas, econômicas e sociais na bacia de drenagem (Tundisi *et al.*, 1999, Nogueira *et al.*, 2006).

As barragens construídas sobre os cursos d'água para a formação dos reservatórios acabam por transformar sistemas lóticos em lênticos, ou semi-lênticos, promovendo atenuações significativas na velocidade de corrente. Os contornos irregulares dos reservatórios, associados a determinadas características morfométricas, levam à formação de regiões de remanso, onde as condições limnológicas (velocidade de circulação, profundidade média e variáveis físicas, químicas e biológicas) geralmente diferem daquelas observadas no corpo central. É comum encontrar nestas regiões de remanso, o desenvolvimento acentuado de comunidades de macrófitas aquáticas.

Compartimentos laterais diferenciados, representados principalmente pelas lagoas marginais e áreas de várzea, podem ser formados ou ampliados com a construção de represas.

A presença de áreas alagadas, como lagoas e várzeas permanentes e temporárias, sobretudo nas regiões de cabeceira dos reservatórios, é importante para os fluxos de nutrientes, manutenção dos recursos tróficos e biodiversidade do sistema como um todo. Tais atributos estão intimamente associados ao fato destes ambientes funcionarem como zonas de interação (ecótonos) com os ecossistemas terrestres da bacia de drenagem. O grande interesse científico nestas áreas se deve ao fato das mesmas serem consideradas altamente produtivas (Wetzel & Likens, 1991), recebendo aportes significativos de detritos que variam com a época do ano, inclusive devido aos ciclos fenológicos da vegetação marginal (Henry, 2003). No caso do reservatório de Rosana, objeto do presente estudo, a interação com a vegetação terrestre tem uma grande importância, devido a presença de uma extensa área de mata na margem direita do reservatório – maior área de floresta nativa do interior de São Paulo onde se localiza o Parque Estadual do Morro do Diabo.

A ecologia das populações animais e vegetais de lagoas rasas é ainda pouco conhecida, não só por haver uma grande heterogeneidade de microhabitats, como também pelo difícil acesso até elas. Tais lagoas são intensamente afetadas pelas condições climáticas, já que geralmente são rasas e podem ser classificadas como temporárias se desaparecem/secam completamente em épocas de estiagem prolongada, o que dificulta ainda mais o seu estudo e a compreensão da dinâmica destes ambientes.

A presença de compartimentos laterais aos rios e reservatórios favorece o desenvolvimento de macrófitas aquáticas, pois elas encontram condições adequadas para sua fixação e sua nutrição (Bianchini Jr., 1999). Estas plantas, por sua vez, interferem na composição das demais comunidades aquáticas e semi-aquáticas (Panarelli *et al.*, 2003). Dessa forma, a existência de lagoas laterais é um fator que contribui para maior riqueza de espécies no ambiente lótico, pois tais sistemas são partes integrantes da paisagem nas zonas de transição entre o ambiente aquático e o terrestre, formando uma área de ecótono (Sendacz & Monteiro Júnior, 2003).

Ecótonos são considerados áreas de tensão, onde comunidades interferem umas sobre as outras, por competição direta, resultando em diferentes taxas de reprodução e de crescimento, tolerância e capacidade de recuperação aos distúrbios, que intervêm para determinar a preponderância de uma ou outra população (Neiff, 2003).

Segundo Pieczynska (1995) e Esteves (1998), a zona litoral desempenha importante papel no funcionamento lacustre, sendo colonizada por uma comunidade muito rica de plantas e animais, pois nessa

região os organismos aquáticos encontram numerosos tipos de habitats. Desta forma, o ecótono água – terra é uma região muito produtiva e de extrema importância para a conservação das comunidades de peixes de água doce (Schiemer *et al.*, 1995).

De acordo com Thomaz *et al.* (1997) a ocorrência de habitats distintos, aquáticos e transicionais, em áreas sujeitas à inundação pelo rio, proporcionam a manutenção de uma considerável biodiversidade. Portanto, a investigação e a preservação dessas áreas devem ser consideradas como prioritárias (Sendacz & Monteiro Júnior, 2003).

As lagoas marginais têm um importante papel como área de reprodução e desenvolvimento dos peixes. Esses ambientes são considerados berçários naturais da ictiofauna (Meschiatti *et al.*, 2000), sendo essenciais para que diversas espécies de peixes executem as estratégias e táticas de seu ciclo de vida (refúgio, reprodução, alimentação, crescimento, entre outras) (Agostinho & Zalewski, 1995; Silva, 1997).

Estudos feitos em planícies de inundação de rios neotropicais demonstraram a importância das macrófitas aquáticas que crescem nestas áreas para a fauna de peixes, com um amplo domínio de espécies de pequeno porte e juvenis de espécies maiores (Cordiviola de Yuan *et al.*, 1984; Araújo Lima *et al.*, 1986; Junk, 1973; Meschiatti *et al.*, 2000).

Delariva *et al.* (1994) registraram, em banco de macrófitas de diferentes áreas de várzea, juvenis de 90% das espécies de peixes capturadas no alto rio Paraná. Os dois principais fatores que explicam a alta densidade de peixes em habitats com vegetação são: disponibilidade de alimentos e abrigo contra a predação (Rozas & Odum, 1988).

A criação de um novo ecossistema, que passa a ser lântico pela formação do reservatório, representa em um grande impacto na comunidade de peixes que permanece a montante do barramento (Beaumord, 1991; Beaumord & Petrere Jr., 1994). Essa comunidade sofre modificações, envolvendo a redução da abundância de determinadas espécies, como as reofílicas, e aumento de espécies melhor adaptadas aos ambientes lânticos, como é o caso dos curimatídeos (Castro & Arcifa, 1987; Rodrigues *et al.*, 1990). Em geral ocorre uma redução da riqueza específica e de bioformas de peixes (Smith *et al.*, 2003).

Reconhecendo o fato de que os compartimentos espaciais são de extrema importância no ciclo de vida dos peixes, torna-se fundamental estudar a influência dos diferentes tipos de áreas (lateral e longitudinal) sobre a biologia e ecologia das espécies, incluindo dieta e atividade alimentar. O conhecimento das interações tróficas gera subsídios para o melhor entendimento entre os componentes da ictiofauna e os demais organismos da comunidade aquática. Hahn *et al.* (1997), ressaltam que o conhecimento das fontes de alimento utilizadas pelos peixes pode fornecer dados sobre condições do habitat, disponibilidade de recursos e evidenciar aspectos do comportamento das espécies. Windell & Bowen (1978) relatam que estudos baseados na análise de conteúdo gástrico têm servido de base para o entendimento ecológico do papel desempenhado pelas espécies de peixes.

A maioria dos estudos sobre ecologia dos peixes nas regiões tropicais, especificamente de ecologia trófica, enfoca as espécies de maior porte. Embora essas análises tenham produzido informações relevantes,

outras abordagens são necessárias para a complementação das pesquisas e o melhor entendimento do papel peixes nas comunidades aquáticas (Zavala-Camin, 1996).

Em base às considerações anteriores, foram estabelecidos os temas de estudo dessa tese. Os dados foram obtidos em lagoas marginais e trecho lótico da porção superior do reservatório de Rosana, rio Paranapanema (SP/PR).

Em termos de estrutura do texto, optou-se pela organização na forma de capítulos, os quais foram redigidos nos moldes de um de artigo científico (segundo as normas do periódico *Brazilian Journal of Biology*).

O objetivo do primeiro capítulo foi analisar a composição e os atributos ecológicos das assembléias fitoplanctônicas, recurso trófico primário das cadeias alimentares aquáticas, em quatro lagoas marginais da porção superior do reservatório de Rosana, bem como no canal principal do rio Paranapanema. O segundo capítulo trata da comunidade zooplancônica (Cladocera e Copépoda) e sua distribuição nos ambientes de estudo. O terceiro trabalho procura avaliar se a introdução de uma espécie exótica de peixe pode causar alterações na estrutura da ictiofauna local, com uma possível redução da sua diversidade. Finalmente, o quarto capítulo refere-se à alimentação da ictiofauna de pequeno porte, através da análise da dieta e do hábito alimentar das espécies, considerando a importância da comunidade planctônica para essa fauna.

Por fim, cabe ressaltar que o desenvolvimento desse estudo foi importante para dar continuidade ao projeto iniciado durante o mestrado do aluno (Ferrareze, 2007), no qual foi avaliada a distribuição espaço-temporal dos juvenis e espécies de peixes de pequeno porte (Ferrareze & Nogueira, 2011) na região de montante do reservatório de Rosana (lagoas e canal do rio), bem como feita a caracterização limnológica dos ambientes (Ferrareze *et al.*, no prelo). Nessa segunda etapa do estudo, deu-se ênfase ao estudo da dieta dos peixes e o possível impacto da invasão de *Cichla kelberi* Spix & Agassiz, 1831. Procurou-se ainda analisar detalhadamente as assembléias planctônicas (fito e zooplâncton) no ambiente de estudo, simultaneamente amostradas, principalmente pelo fato destes organismos constituírem recursos potencialmente importantes para o desenvolvimento da fauna de peixes de pequeno porte.

## **II.1 ÁREA DE ESTUDO**

O reservatório de Rosana está localizado na região oeste do estado de São Paulo, na bacia hidrográfica do rio Paranapanema (Figura 01).

A bacia hidrográfica do rio Paranapanema localiza-se entre as coordenadas 22° - 26° S e 47° - 54°W, estendendo-se pelo sudoeste do estado de São Paulo e norte do estado do Paraná. A área drenada é de 100.800 km<sup>2</sup>, sendo 47% no território paulista e 53% no Paraná. O curso principal do rio, em direção leste - oeste, tem uma extensão de 929 km, com 570 m de desnível, desenvolvendo-se entre as altitudes de 809 e 239 m (Figura 02).

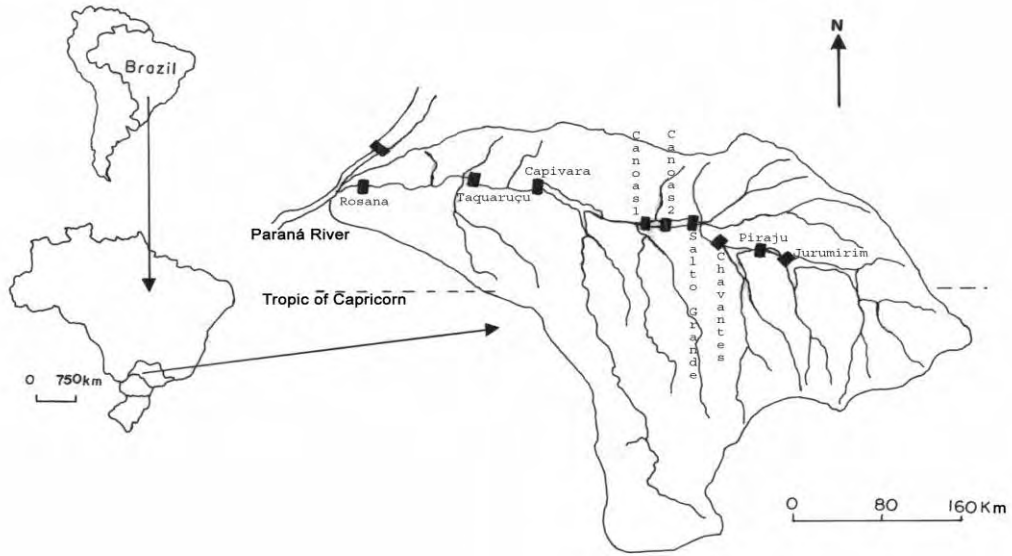
O reservatório de Rosana (Figura 03) é o último de uma série de 11 reservatórios construídos no rio Paranapanema, estando sua barragem localizada a 22° 36'S e 52° 52'W. Sua área de drenagem é de 11.000

km<sup>2</sup>, com superfície do espelho d'água de 276,14 km<sup>2</sup> (CESP, 1987). Trata-se de um reservatório do tipo “fio d'água” com tempo médio de residência da água calculado em 18,5 dias (CESP- USP, 1994). O tempo de residência teórico foi calculado em 21,3 dias (média para 2000) e 18 dias (média para 2001) por Nogueira *et al.* (2002a). Neste reservatório não ocorrem estratificações térmicas estáveis e a temperatura da superfície da água pode atingir valores muito elevados (32 °C) (Nogueira *et al.*, 2002a). A vazão média defluente freqüentemente ultrapassa o valor de 1000 m<sup>3</sup>/s sendo a média para 2000 e 2001 de 1054,8 e 1255,1 m<sup>3</sup>/s, respectivamente (Nogueira *et al.*, 2006). A utilização de dados de transparência da água, da concentração de clorofila e de fósforo tem levado a classificação do reservatório como sendo oligotrófico, eventualmente mesotrófico na sua zona superior (Nogueira *et al.*, 2002b). Pagioro *et al.* (2003) classificam o reservatório de Rosana como mesotrófico. Por sua vez, Train *et al.* (2003) consideram Rosana oligotrófico, pelos valores muito baixos de biomassa fitoplanctônica, mostrando controvérsias e necessidade de um aprofundamento do estudo limnológico desta represa.

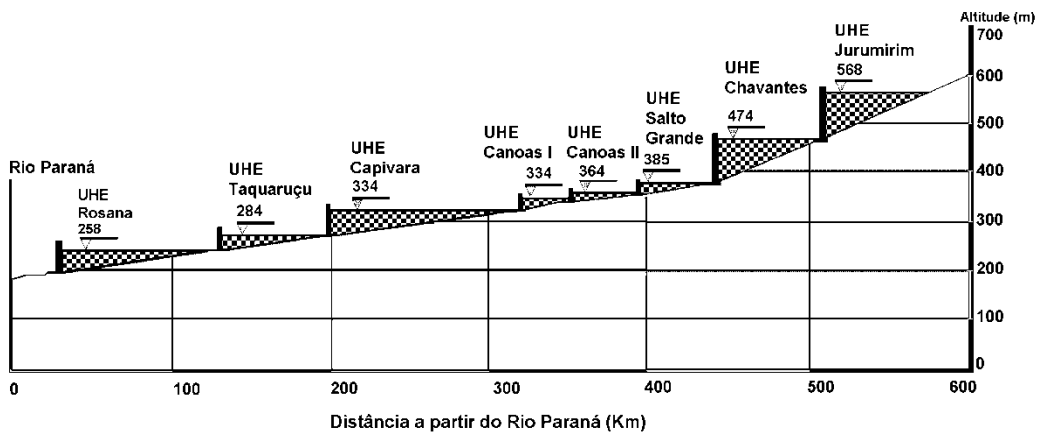
A região proposta para o estudo está compreendida em um grande grupo climático: clima temperado quente. A temperatura atmosférica média anual é de 21°C, com valores mais baixos entre maio e agosto (média mínima de 13°C) e mais altos entre janeiro e março (média máxima de 32°C). Esta região possui duas estações climáticas definidas pelo regime pluviométrico: estação chuvosa e de seca. A pluviosidade na bacia apresenta variações regionais, entre 1100 e 1300 mm na margem paulista e de 1500 a 1600 mm no lado paranaense (Duke Energy, 2001).

A vegetação original, Floresta estacional semidecídua (mata seca do interior), ocupava a maior parte das áreas de “terra firme” do oeste paulista e norte paranaense. Ocorriam também manchas de cerrado na região nordeste do reservatório. Nas áreas associadas a terrenos permanente ou temporariamente inundados ao longo do rio Paranapanema e afluentes eram encontradas várzeas, campos úmidos e matas ciliares.

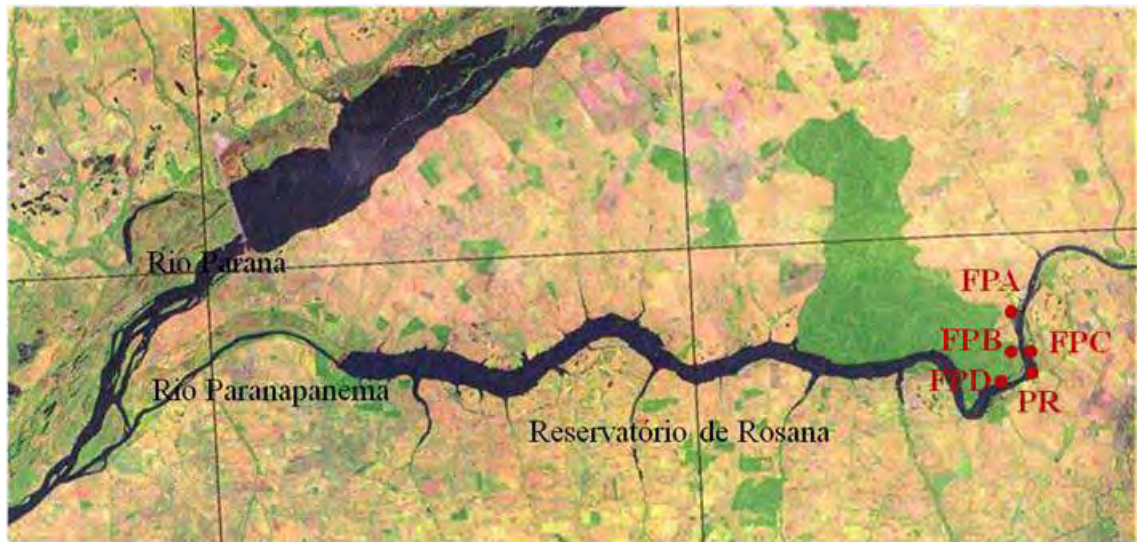
Hoje, em ambos os estados (SP e PR), o diagnóstico da situação ambiental para a bacia do Paranapanema indica a quase inexistência de matas ciliares na região, restando somente poucos fragmentos florestais em alguns municípios (Rosana, Teodoro Sampaio e Euclides da Cunha) (Duke Energy, 2001).



**Figura 01:** Localização da bacia hidrográfica do rio Paranapanema.



**Figura 02.** Distância entre reservatórios do rio Paranapanema a partir do rio Paraná e cotas altimétricas em relação ao nível do mar (Fonte: Duke Energy International – Geração Paranapanema).



**Figura 03:** Imagem TM/LandSat do reservatório de Rosana, com a indicação dos pontos de coleta, e foz do rio Paranapanema junto ao rio Paraná.

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## *Capítulo 1*

**Phytoplankton assemblages in lateral lagoons of a large tropical reservoir**

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Running title: Phytoplankton in reservoir lateral lagoons.

## **Abstract**

This study aimed to analyze the composition and ecological attributes of the phytoplankton assemblages in four lateral lagoons and in the main channel of Rosana Reservoir (Parapanema River, SE Brazil). Fieldwork was carried out in September and November/2004 and January, March, May and August/2005. The total number of taxa identified was of 283. Zygnemaphyta was the most specious group, followed by Chlorophyta and Bacillariophyta. Higher richness, abundance and biomass were observed in the lagoons, especially during the rainy period. Cryptophyceae and Bacillariophyceae dominated numerically. *Cryptomonas brasiliensis* Castro, Bicudo and Bicudo was the main species of the phytoplankton. The results showed that the phytoplankton assemblages are mainly influenced by the meteorological factors and by some important nutrient sources. Correlation analyses indicated that the assemblage abundance was limited by total nitrogen and by the total dissolved phosphorus. The phytoplankton abundance influenced positively the zooplankton abundance. This pattern indicates that in the lateral lagoons system, the communities are controlled by bottom-up mechanisms. The results validate the hypotheses that lateral lagoons have a prominent ecological role on the phytoplankton diversity, and also evidenced the main driving forces influencing the assemblage composition and ecological attributes. The incorporation of lateral lagoons in environmental programs should be a target strategy for the conservation of the regional aquatic biota, minimizing the negative impact of the dam.

*Keywords:* Parapanema River, Rosana Reservoir, Chlorophyceae, Bacillariophyceae, Cryptophyceae.

## **Assembléias fitoplanctônicas em lagoas laterais de um reservatório tropical de grande porte**

### **Resumo**

O objetivo deste estudo foi analisar a composição e os atributos ecológicos das assembléias fitoplanctônicas de quatro lagoas marginais e canal principal do reservatório de Rosana (SE, Brasil). Os trabalhos de campo foram realizados em setembro e setembro de 2004 e janeiro, março, maio e agosto de 2005. O número total de táxons identificados foi de 283. Zygnemaphyta foi o grupo com maior número de espécies, seguido por Chlorophyta e Bacillariophyta. Maior riqueza, abundância e biomassa foram observadas nas lagoas, especialmente durante o período chuvoso. Cryptophyceae e Bacillariophyceae dominaram numericamente as assembléias. *Cryptomonas brasiliensis* Castro, Bicudo e Bicudo foi a principal espécie do fitoplâncton nesse estudo. Os resultados mostraram que as assembléias fitoplanctônicas são influenciadas pelos fatores meteorológicos e determinados nutrientes. Análises de correlação mostraram que a abundância do fitoplâncton foi limitada pelo nitrogênio total e pelo fósforo total dissolvido. Por sua vez a abundância fitoplanctônica influenciou positivamente a abundância do zooplâncton. Esse padrão indica que no sistema de lagoas laterais as comunidades são controladas por mecanismos ascendentes. Os resultados validaram a hipótese de que as lagoas laterais têm um proeminente papel na diversidade do fitoplâncton e também mostraram quais são as principais forças que influenciam a composição e os atributos ecológicos das assembléias de organismos. A incorporação das lagoas laterais em programas ambientais seria uma boa estratégia para conservação da biota aquática regional, minimizando o impacto negativo do represamento.

*Palavras-chave:* Rio Paranapanema, Reservatório de Rosana, Chlorophyceae, Bacillariophyceae e Cryptophyceae.

## 1. Introduction

The construction of reservoirs causes physical, chemical and biological changes along the longitudinal axis of the impounded rivers (Straškraba, 1990; Barbosa *et al.* 1999).

During the last years intensive efforts have been undertaken in order to systematize the studies on reservoirs in Brazil, generating significant advances in the limnological knowledge of this kind of ecosystem (e.g. Tundisi, 1988; Henry, 1999; Tundisi and Straškraba, 1999; Nogueira *et al.*, 2006). The accumulated limnological knowledge on reservoirs has provided a growing understanding of these systems as a unique class of lakes. However the comprehension of the structure and functioning of reservoirs is still incomplete (Kennedy *et al.*, 2003). For example, integrated approaches of the interactions between these water bodies and lateral lagoons are still scarce (Bicudo *et al.*, 2008).

The reservoir filling up can increase the connectivity between river and floodplain habitats, or even take to the formation of artificial lagoons (Henry *et al.*, 2006b). The lateral lagoons are highly productive, exhibit numerous microhabitats and are colonized by rich assemblages of plants, invertebrate and vertebrate fauna (Pieczynska, 1995). Therefore, these environments have an important role for the biodiversity maintenance of the entire fluvial ecosystem (Baumgartner *et al.*, 2004).

Among the numerous habitats colonized by algae, the lateral lagoons are peculiar as a consequence of the strong interaction with the fluvial and semi-terrestrial ecosystems (Huszar, 1996; Henry *et al.*, 2006c). Regionally, these environments have also a prominent role in the nutrient flow and in the maintenance of the trophic resources and biodiversity (Naiman *et al.*, 1988; Pieczynska, 1990; Wetzel and Likens, 1991; Mitsch, 1996; Thomaz *et al.*, 1997; Straškraba and Tundisi, 2000).

Assemblages of phytoplankton are important for the primary productivity of freshwater ecosystems and certain taxa are also considered as good indicators of different environment conditions (e.g. hydrodynamics and trophic state) (Rosén, 1981; Vincent and Dryden, 1989; Sommer, 1984; Reynolds, 1992, 1999; Padisak *et al.*, 1999; Nogueira *et al.*, 2010). The structure of algae assemblages, indicated by some attributes such as specific composition and richness, population densities, dominance and uniformity, can be used to evaluate the aquatic system quality, and the specific diversity measurements could constitute an appropriate index to compare different environment conditions (Rosa *et al.*, 1988). Besides, the phytoplankton constitutes the

basis of the aquatic food chain and, consequently, human alterations in aquatic environments promote changes in structure and dynamics of these assemblages, as well as the in other trophic levels (Odum, 2004).

Variations in the composition, abundance, and biomass of phytoplanktonic assemblages are strongly influenced by meteorological factors, such as precipitation, winds and temperature (Harris, 1986; Dos Santos and Calijuri, 1998; Melo and Huszar, 2000; Calijuri *et al.*, 2002), chemical nutrients and the abundance of other aquatic communities (Odum, 2004; Tundisi, 2008).

In the present study the composition and the ecological attributes of phytoplankton assemblages in four lateral lagoons and in the main channel of Rosana Reservoir was analysed. The specific objectives were to determine the spatial and temporal variation in the composition, richness, abundance and diversity, as well as to correlate the abundance of phytoplankton with the limnological variables (transparency, temperature, pH, electric conductivity of water, turbidity and concentrations of dissolved oxygen, total suspended solids, dissolved silicate and total nutrients), precipitation and zooplankton abundance.

The main hypothesis is that the lateral lagoons have a significant contribution for the phytoplankton diversity of Rosana Reservoir. It was also intended to determine the main driving forces influencing on the spatial and temporal variation of the composition and ecological attributes of the phytoplankton assemblages in the lateral lagoons system.

## **2. Material and Methods**

### *2.1. Study area*

The study area is in the upstream (tail) zone of Rosana Reservoir, approximately 80 km above dam (Figure 1), which is located at 22°36'S and 52°52'W. The reservoir is the last one of a series of eleven along the Paranapanema River (SP/PR, Brazil), with a surface area of 276 km<sup>2</sup> (watershed of 11,000 km<sup>2</sup>), water retention time of 21 days (annual mean value), relatively shallow (maximum of 26 m close to the dam) and oligo-mesotrophic (Nogueira *et al.*, 2006).

The climate is subtropical humid (average temperature of 21°C) with two pronounced seasons: dry and rainy (Duke Energy, 2001). During the studied period, the rainy season ranged from September/2004 to January/2005 (month average of 157 mm), while the dry period ranged from February to August of 2005 (month average of 70.7 mm). The accumulated rain precipitation in the study period was 1,207.5 mm. The

rain precipitation data was provided by the meteorological station of the State Park of “Morro do Diabo”, municipality of Teodoro Sampaio (State of São Paulo).

## *2.2. Samplings and laboratory analyses*

The study was carried out in 4 lagoons and one sampling station in the Paranapanema River (PR), close to the river bank (Figure 1; Table 1). Samplings were carried out in September and November of 2004 and January, March, May and August of 2005.

Two kinds of lagoons were assessed: 3 natural systems (FPB, FPC and FPD) and one originated by the flood of mining digging (FPA). The natural lagoons (FPB and FPD) are located inside the State Park of Morro do Diabo, while the last one (FPC) is located in an area influenced by human activities (agriculture and cattle breeding). The dominant macrophytes of each lagoon, in terms of stand area, were registered (Table 1). Identification of these plants was performed at the genus level, with help of taxonomists of Botany Department from Biosciences Institute of UNESP/Botucatu. The main limnological characteristics of each point are showed in Table 2.

The sampling stations positioning, the area of each lagoon (integration of geometric distances), as well as their connectivity (transversal section of the lagoon mouth) with the river-reservoir main channel, were determined using a Garmin E-Trex GPS.

For the quantitative analysis of the phytoplankton, unfiltered samples were collected at the subsurface (ca. 0.5 m). The samples were fixed and preserved with Lugol solution. After sedimentation (Margalef, 1983), the organisms (cell, colony, and filament) were counted using inverted microscopy (Utermöhl, 1958) at a magnification of 400x. At least 120 optical fields distributed in parallel transects were examined, and the minimum number of organisms counted per sample was 150.

Filtered samples were also collected through vertical net hauls (20  $\mu$ m of mesh size) from near bottom (ca. 0.5m) to surface and preserved in 4% formalin. These samples were analyzed in optical microscope (maximum magnification of 1000x) for the identification of the phytoplankton organisms (Bicudo and Menezes, 2005). New taxa that appeared during the quantitative analyzes were also considered for qualitative purpose (richness).



As an indicator of the phytoplankton biomass, chlorophyll *a* (total) concentration was determined after filtration (Millipore AP40 membranes) of 1000 mL of water from each sampling point. For pigments extraction, it was used cold acetone (90%) and manual maceration (Talling and Driver, 1963; Golterman *et al.*, 1978).

Phytoplankton diversity was estimated using the Shannon-Weaver Index ( $\log_2$ ). In order to compare the sampling sites, using the phytoplankton structure assemblages, a cluster analysis (r-Pearson similarity) (Pcordwin) was performed. The organism abundance per class was used. Despite the high taxonomical level, in general each phytoplankton class constitutes a well defined ecological group indicating distinct environmental conditions.

The mean values of the assemblages attributes were calculated in order to synthesize the information and facilitate the identification of patterns. Two periods were considered in the analysis: rainy and dry periods. The representativeness of the means was assumed based on the normal data distribution (Shapiro-Wilk's *W* test) (Underwood, 1997; Statistica TM 6.0).

A one-way ANOVA test was performed to detect differences among sampling sites. When differences were detected, the Tukey test was applied to determine the level of significance (Underwood, 1997). Differences between periods were verified by the test *t*-student, using the mean of the variables for each season (dry and rainy). Significant differences were considered when  $p < 0.05$  (Underwood, 1997), which were mentioned in the results. The analyses were performed using StatisticaTM 6.0 software (Statsoft, 2001).

Finally, two different analyses were used in order to validate the postulated hypothesis and for identification of the main factors influencing on the phytoplankton biomass/abundance. The canonic correspondence analysis, CCA (Pcordwin) (McCune and Mefford, 1999), was used to verify correlations between the phytoplankton classes and the limnological variables, per sampling site and period. The correlation analyses (Pearson product-moment) (Sokal and Rohlf, 1979) were performed to show how the different environmental variables (total nitrogen and phosphorus, chlorophyll *a*, transparency, dissolved phosphorus and zooplankton abundance) influence the phytoplankton assemblages. The environmental variables (Ferrareze and Nogueira, *in press*) and zooplankton abundance (Ferrareze and Nogueira, *in preparation*) were simultaneously measured.

### 3. Results

A total of 283 taxa were registered, distributed in 103 different genera. Zygnemaphyta was the most specious group (94 taxa), followed by Chlorophyta (77 taxa), Bacillariophyta (71 taxa), Cyanophyta (20 taxa), Euglenophyta (12 taxa), Chrysophyta (5 taxa), Dinophyta (2 taxa), Cryptophyta (1 taxa) and Xanthophyta (1 taxa).

Significant higher phytoplankton richness was observed in the lateral lagoons when compared with the river-reservoir sampling station ( $p=0.000021$ ;  $F=236.84$ ; Figure 2). The FPD exhibited the highest phytoplankton richness (varying from 70 to 100 species per period). Seasonally, significant higher richness was observed during rainy season (93 taxa) compared to the dry period (76 taxa) ( $p=0.004$ ).

The lateral lagoons showed significant higher phytoplankton abundance when compared with the reservoir ( $p=0.0000$ ;  $F=117.86$ ; Figure 3). However, in two lagoons (FPB and FPC) it was found the lowest number of individuals during November of 2004 (values of 46,992 and 63,694, respectively). Seasonally, significant higher abundance was observed in rainy (mean of 135,760 individual  $L^{-1}$ ) compared to the dry period (mean of 93,623 individual  $L^{-1}$ ) ( $p=0.041$ ).

The phytoplankton abundance was positively correlated with the total dissolved phosphorus ( $r=0.45$ ;  $p=0.003$ ; Figure 4), total nitrogen ( $r=0.58$ ;  $p=0.001$ ; Figure 5) and zooplankton abundance ( $r=0.8$ ;  $p=0.000$ ; Figure 6), but the phytoplankton abundance did not show a good correlation with the total phosphorus ( $r=0.18$ ;  $p=0.04$ ).

The phytoplankton biomass had the same variation pattern exhibited by the abundance. Highest values of biomass occurred in the lateral lagoons ( $p=0.00$ ;  $F=94.02$ ; Figure 7), although the lowest average values for chlorophyll were measured at FPB and FPC stations. Seasonally, significant higher biomass was also observed in the rainy (mean of 3.21  $\mu g L^{-1}$ ) compared to the dry period (mean of 2.15  $\mu g L^{-1}$ ) ( $p=0.049$ ).

A positive linear correlation between chlorophyll and phytoplankton numerical abundance ( $r=0.98$ ;  $p=0.001$ ; Figure 8), as expected. The chlorophyll *a* was negatively correlated with transparency ( $r = 0.6$ ;  $p=0.0011$ ; Figure 9).

The relative abundance among the main phytoplankton groups, for the whole study period, is shown in Figure 10. The Zygnemaphyceae, despite having a larger number of species, were not numerically dominant.

Cryptophyceae was the most abundant group (41.9%), followed by Bacillariophyceae (28.1%). Cryptophyceae exhibited higher dominance during rainy period, mainly in November of 2004, when the mean dominance was around 55% of the population. A conspicuous presence of Bacillariophyta occurred during dry period, reaching 48.3% of population on August of 2005. Chlorophyta had a relatively higher contribution only in the autumn (May of 2005). In this sampling period, the abundance distribution among the different main phytoplankton groups was more homogeneous. Cyanophyta had higher density during summer (January of 2005). The highest percentage of this group occurred in the FPA station.

*Cryptomonas brasiliensis* Castro, Bicudo and Bicudo can be considered as the main species of the phytoplankton in this study. The specie was observed in all samples and its abundance ranged from 21%, in FPA (September of 2004), to 62.3%, in FPC (November of 2004).

Despite of the higher phytoplankton diversity mean values in the lateral lagoons, when compared with the reservoir, there was no significant difference among the sampling stations ( $p=0.683$ ;  $F=0.575$ ; Figure 11). There was also no significant difference between the seasonal periods ( $p=0.07$ ) for this attribute.

The cluster analysis (Figure 12), on the basis of the phytoplankton assemblage structure of each sampling station, showed a higher similarity between FPC and PR. The analysis also evidenced that the most distinctive environments were the FPB and FPD, which are located inside the State Park of Morro do Diabo and they are the most preserved lagoons.

Finally, the results of the CCA (Figure 13 and Table 3) explained 67% of the data variability ( $p=0.02$ ), considering the three first ordination axes (axis 1 = 45%, axis 2 = 15% and axis 3 = 7%). The classes Bacillariophyceae and Chrysophyceae were better correlated with the positive side of the axis 1, associated to low values of total nitrogen, total phosphorus, precipitation, temperature, turbidity and suspended solids and with high values of pH, transparency and dissolved oxygen. The classes Chlorophyceae, Zygnemaphyceae, Cyanophyceae and Cryptophyceae were better positioned on the negative side of the axis 1, associated with high values of total nitrogen, total phosphorus, precipitation, temperature, turbidity and suspended solids.

Chlorophyceae was located on the negative side of the axis 2, associated with low precipitation and with high concentrations of total phosphorus and dissolved silicate.

Some associations among the periods and the phytoplankton assemblages could be observed through the CCA analysis. Bacillariophyceae and Chrysophyceae were more representative during the dry period

(September/2004, May and August of 2005). Cyanophyceae were more representative during November/2004 and January/2005, and Chlorophyceae, Zignemaphyceae and Euglenophyceae during March/2005. Cryptophyceae were not associated with any period, exhibiting a high abundance during the whole study.

#### **4. Discussion**

Studies indicate that the contribution of lateral habitats such as lagoons, floodplains and oxbow lakes is of great importance for the whole river watershed biodiversity (Naiman *et al.*, 1988; Pieczynska, 1990; Wetzel and Likens, 1991; Mitsch, 1996; Thomaz *et al.*, 1997; Straškraba and Tundisi, 2000). This assumption is verified in the present investigation. The richness registered in the Rosana reservoir lateral lagoons (283 taxa/103 genera) is higher than the ones verified in other studies carried out in lotic and lentic (reservoirs) stretches of the whole Paranapanema basin (Ferrareze and Nogueira, 2006; Nogueira *et al.*, 2010). Our phytoplankton richness data is also higher when compared to other studies on phytoplankton assemblages carried out in particular aquatic environments of the basin with similar number of analyzed samples (Nogueira, 2000; Bittencourt-Oliveira, 2002; Bicudo *et al.*, 2006; Henry *et al.*, 2006c). The same pattern is verified for the zooplankton (Ferrareze and Nogueira, *in preparation*) and fish (Ferrareze and Nogueira, 2011) assemblages, which were simultaneously sampled in the same environments of this study. These results demonstrate the importance of considering the lateral lagoons and other kinds of wetland habitats in order to assess the biodiversity status of inland water basins.

The results also showed that the phytoplankton assemblages exhibited considerable seasonal changes. Variations in the composition, abundance, and biomass of phytoplankton assemblages were influenced by meteorological factors, such as precipitation and temperature and by some important nutrients, such as total nitrogen and dissolved phosphorus. Similar tendencies were also observed in reservoirs and fluvial systems of the high Paraná River basin (Santos and Calijuri, 1998; Nogueira, 2000; Miranda and Gomes, 2001; Calijuri *et al.*, 2002; Matsumura-Tundisi and Tundisi, 2005).

The CCA analysis clearly separated the sampling stations along the studied periods, showing the dominance of different phytoplankton classes under influence of some limnological variables. Through the results of the

CCA and the regression analyses, it could be supposed the main driving forces influencing the composition and the ecological attributes of phytoplankton assemblages in the lateral lagoons system.

The Zygnemaphyceae was the most specious phytoplankton group, followed by Bacillariophyceae and Chlorophyceae. This structural characteristic seems to be a consistent pattern for the phytoplankton assemblages in the floodplain lagoons of high Paraná River basin (Rodrigues and Bicudo, 2001). High richness of Bacillariophyceae and Chlorophyceae has also been observed for three lateral lagoons of the upper Paranapanema River (Jurimirim Reservoir) (Henry *et al.*, 2006a), and for the Paranapanema River reservoir cascade (Nogueira *et al.*, 2010). Another factor influencing the high richness of Zygnemaphyceae in the lateral lagoons is the contribution of the periphyton assemblages, as the lateral lagoons exhibit a high amount of different species of aquatic macrophytes, microhabitats highly propitious for the development of periphyton algae (Tundisi, 2008).

Higher abundance and biomass (chlorophyll *a*) of phytoplankton assemblages were observed in the lateral lagoons, compared to the reservoir. This is a result of a high nutrient availability verified in these environments, especially during the rainy period (late spring and summer) (Ferrareze *et al.*, *in press*). The seasonal input of nutrients associated to the instability of water column (strong rains; raising of lotic conditions) resulted assemblages dominated by C-strategist species, such as *Cryptomonas* and *Discotella*, or even r-strategists, *Aulacoseira* spp. for instance, which are typical of the initial phase of succession (Reynolds, 1984).

Positive correlation among phytoplankton assemblages and nutrient concentration and high water period was also observed by other authors in the upper Paraná River basin (Train and Rodrigues, 1998; Rodrigues and Bicudo, 2001) and in the Paranapanema River Basin (Nogueira, 2000; Bittencourt-Oliveira, 2002; Henry *et al.*, 2006a; Ferrareze and Nogueira, 2006; Bicudo *et al.*, 2006; Nogueira *et al.*, 2010).

Different from natural lakes, the phytoplankton dynamics in rivers is dominated by physical interactions, and those biotic interactions traditionally believed to regulate limnetic communities are suppressed and rarely are well-expressed (Reynolds *et al.*, 1994).

The results of the correlation analysis indicate that the phytoplankton abundance in Rosana Reservoir and lateral lagoons can be limited by nitrogen and dissolved phosphorus. It was also shown, and the same was found by Nogueira *et al.* (2010) for the Paranapanema reservoirs cascade, that the zooplankton does not

control the phytoplankton abundance. These results indicated that in the studied lateral lagoon system the communities are mainly controlled by bottom-up mechanisms (Townsend *et al.*, 2006).

In general, the chlorophyll concentrations in the studied areas were low. According to Miranda and Gomes (2001), an important factor responsible for the recurrent low values of chlorophyll in the upper Paraná basin reservoirs is the predominant high flow, besides the scarcity of some important mineral nutrients, other than N and P, and minor essential ions such as carbon, potassium, calcium, magnesium and iron

The increase in the chlorophyll concentration and in the water transparency during the dry period is an ordinary variation pattern for large tropical rivers and lagoons (Schmidt, 1970; Rai and Hill, 1982; Bonetto *et al.*, 1983; Bonetto, 1986; Welcome, 1986; Garcia de Emiliani, 1990; Neiff, 1990; Carvalho *et al.*, 2001). In the present study, despite of a drastic reduction of the water transparency in the rainy period, there was an increase in the chlorophyll concentrations. The same pattern was verified for other reservoirs and fluvial stretches in the Paranapanema River Basin (Ferrareze and Nogueira, 2006; Nogueira *et al.*, 2010). This fact occurred due to the growth of phytoplankton groups tolerant to the low light penetration, such as Cryptophyceae and some species of diatoms. Besides, the increase in chlorophyll was determined by higher nutrient concentrations in the lagoons (Ferrareze and Nogueira, *in press*) and by the enhancement in the water flux, favoring some species of Bacillariophyceae, such as the ones of the genus *Aulacoseira*, and Cryptophyceae (functional group Y, C-strategist, *sensu* Reynolds *et al.*, 2002) able to develop under more turbulent conditions (Haphey-Wood, 1988; Tundisi, 1990).

Therefore, the negative correlation between water transparency and chlorophyll shows that the light conditions in the Rosana Reservoir seems not to be a limiting factor for the phytoplankton development.

These results demonstrate that these assemblages responded quickly to the environmental variations (Reynolds, 1984).

The instability of the water column promoted by the rainfall, relatively low water retention time of the reservoir and high input of nutrients could explain the small changes in the phytoplankton assemblages dominance during the period studied. These conditions are not propitious for a wide number of phytoplankton species. This scenario allowed the Cryptophyceae (C-strategist) to be dominant during most of time. Only during few periods, probably associated to a relative higher stability of the water column, some genera, such as *Aulacoseira* and *Discotella*, were able to experience a higher growth, abundance.

*Discotella* is dominant in oligotrophic environments with great availability of light and a low Si:P ratio, if compared to other diatoms groups, such as the Pennales. The *Aulacoseira* populations tend to be dominant in conditions of total circulation, due to the fact that your heavy frustules has high sedimentation rate and need to be continuously resuspended to remain in the water column (Wollin and Duthie, 1999). According to Reynolds (1984) and Sommer (1988), diatoms occur during periods with high availability of nutrients and good light conditions and they grow quickly, mainly in the presence of high concentrations of nitrogen, being opportunists and colonizers (r-strategists and C-strategists). These assumptions helped to explain the high density of Bacillariophyceae in the river/reservoir sampling station when compared to the lateral lagoons.

The relative increase of Cyanophyceae during summer is mainly related to the growth of *Microcystis aeruginosa* (Kutzing) Lemmermannin. This specie is an S-strategist, and apparently characteristic of waters with phosphate oscillations, being a specialist in phosphate storage and able to regulate efficiently its (ability to float). *Microcystis* requires high temperatures, it is tolerating to variation in light intensity and it is not subject to predation by herbivores (Kilham and Hecky, 1988; Kromkamp *et al.*, 1989).

The increase of Euglenophyceae during summer, mainly in the lateral lagoons, is probably due to the organic matter carried by the rainfall, typical of this period, from the terrestrial system to the aquatic system. This group of organism can facultative use dissolved organic matter in nutritious processes (Reynolds, 1984).

The variation of the phytoplankton diversity was not significantly different among the sampling stations and periods. This result was influenced by the *Cryptomonas* numerical dominance during the whole study in all sampling stations. The diversity values were similar to the ones calculated in other studies carried out in the Paranapanema Basin (Nogueira, 2000; Bittencourt-Oliveira, 2002; Bicudo *et al.*, 2006; Ferrareze and Nogueira, 2006; Henry *et al.*, 2006c; Nogueira *et al.*, 2010).

Floristic similarity among phytoplankton assemblages, as observed through the cluster analysis, shows the importance of the interaction between the surrounding landscape and aquatic environments (Huszar, 1996; Henry, 2003). The lateral lagoons located inside the environmental protection area (State Park of Morro do Diabo) exhibited more distinct assemblages than the other lagoons. Additionally, the analysis also evidenced the influence of the river assemblages on the assemblages of the wider connected lateral lagoon, FPC. The same pattern is observed for other communities – fish (Ferrareze and Nogueira, 2011) and zooplankton

(Ferrareze and Nogueira, *in preparation*), as well as in the nutrients dynamics (Ferrareze and Nogueira, *in press*).

The results validate the hypothesis that lateral lagoons have a prominent ecological role for the phytoplankton of Rosana Reservoir, adding diversity to the system, and evidenced the main driving forces influencing the composition and the ecological attributes of the assemblages in the lateral lagoons system. The results also indicate that the incorporation of lateral lagoons in environmental programs should be a good strategy for the conservation of the regional aquatic biota, minimizing the negative impact of the dam.

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**Table 1.** Denomination of the sampling stations, geographical positioning, lagoons surface area, main aquatic macrophytes and estimated area of connectivity of lagoons with the river/reservoir main channel.

Sampling station	Geographical coordinates	Area (km <sup>2</sup> )	Dominant macrophytes	Connectivity (m <sup>2</sup> )
Lateral lagoon A (FPA)	22° 34' 03.3''S / 52° 09' 11.4''W	0.110	<i>Typha</i> , <i>Eichhornia</i> , <i>Brachiaria</i> , <i>Pontederia</i> and <i>Salvinia</i>	50
Lateral lagoon B (FPB)	22° 36' 56.5''S / 52° 09' 47.3''W	0.024	<i>Eichhornia</i> , <i>Brachiaria</i> , <i>Pontederia</i> , <i>Salvinia</i> , <i>Pistia</i> , <i>Egeria</i> and <i>Nymphaea</i>	6.5
Lateral lagoon C (FPC)	22° 37' 28.9''S / 52° 09' 21.1''W	0.721	<i>Eichhornia</i> , <i>Brachiaria</i> , <i>Pontederia</i> , <i>Salvinia</i> and <i>Egeria</i>	525
Parapananema River Bank (PR)	22° 37' 51.6''S / 52° 09' 30.5''W	-	<i>Typha</i> , <i>Eichhornia</i> , <i>Brachiaria</i> , <i>Pontederia</i> , <i>Salvinia</i> and <i>Pistia</i>	-
Lateral lagoon D (FPD)	22° 38' 22.0''S / 52° 09' 29.0''W	0.063	<i>Eichhornia</i> , <i>Brachiaria</i> , <i>Pontederia</i> , <i>Salvinia</i> , <i>Pistia</i> and <i>Nymphaea</i>	60.2

**Table 2.** Mean values (among depths) (except transparency) for the limnological variables measured at the different sampling stations and periods. Source Ferrareze and Nogueira (in press).

	pH					Dissolved oxygen (mg L <sup>-1</sup> )					Temperature (°C)							
	set-04	nov-04	jan-05	mar-05	mai-05	ago-05	set-04	nov-04	jan-05	mar-05	mai-05	ago-05	set-04	nov-04	jan-05	mar-05	mai-05	ago-05
FPA	7.2	7.5	6.2	6.6	7.3	6.1	8.7	6.5	6.2	8.4	6.2	8.0	23.0	25.5	27.2	27.6	25.4	22.2
FPB	7.3	6.6	6.3	6.6	7.3	7.6	8.6	7.7	6.3	5.0	9.5	8.3	22.1	25.5	27.1	27.4	25.3	22.4
FPC	7.2	6.3	5.9	6.5	7.2	7.6	9.7	8.0	5.9	5.2	10.0	9.0	20.8	25.7	26.9	27.2	25.2	22.1
PR	7.2	6.2	5.2	6.4	6.9	7.2	9.6	7.8	6.0	6.4	9.2	12.0	20.5	25.2	27.1	26.9	24.6	22.4
FPD	7.4	6.2	5.5	5.9	7.0	7.1	8.8	7.6	5.4	9.2	13.2	12.0	21.0	25.6	27.0	27.3	25.2	22.5

	Conductivity (µS cm <sup>-1</sup> )					Transparency (m)					Turbidity (NTU)							
	set-04	nov-04	jan-05	mar-05	mai-05	ago-05	set-04	nov-04	jan-05	mar-05	mai-05	ago-05	set-04	nov-04	jan-05	mar-05	mai-05	ago-05
FPA	46	70	70	70	48	64	2.8	1.5	0.4	1	2	3.5*	8.2	36.7	52.4	17.3	15.1	9.0
FPB	70	70	70	70	44	64	2.3	1.6	0.1	0.8	2.2	2.8*	4.5	33.4	40.2	12.3	7.4	4.2
FPC	90	80	90	80	80	65	2.2	1	0.2	1	2.7	3*	5.1	55.1	83.4	14.0	7.8	6.0
PR	60	70	70	70	52	65	2.1	1.3	0.1	0.7	2.2	5.8*	5.1	98.0	135.5	20.3	6.5	5.7
FPD	60	70	90	80	85	65	2.7	1.9	0.2	1	2.5	3.5*	5.0	94.7	140.0	21.0	6.9	5.8

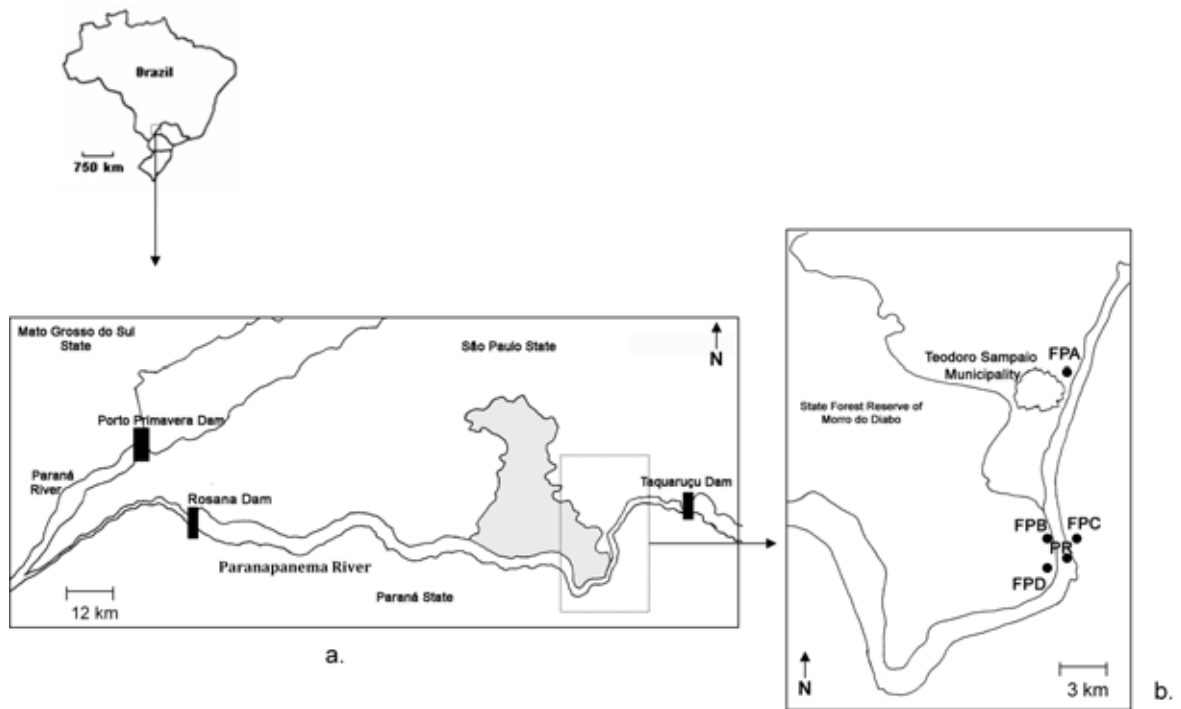
  

	Suspended Solids (mg L <sup>-1</sup> )					Total Nitrogen (µg L <sup>-1</sup> )					Total Phosphorus (µg L <sup>-1</sup> )							
	set-04	nov-04	jan-05	mar-05	mai-05	ago-05	set-04	nov-04	jan-05	mar-05	mai-05	ago-05	set-04	nov-04	jan-05	mar-05	mai-05	ago-05
FPA	4.1	5.8	9.2	4.1	2.2	1.7	193	366	533	321	241	252	14.1	21.7	19.2	33.0	31.6	25.8
FPB	2.2	7.2	18.4	4.3	2.7	2.0	236	361	587	363	301	320	9.5	36.7	53.8	45.6	30.4	26.0
FPC	4.2	13.0	14.8	3.4	2.4	2.0	242	418	662	373	296	466	9.9	28.7	32.4	38.4	39.8	30.2
PR	2.5	5.3	31.9	5.3	3.4	1.8	306	329	659	340	288	306	7.9	32.8	52.8	50.1	34.5	30.6
FPD	2.4	3.2	16.0	3.6	2.0	2.4	224	316	555	364	306	289	5.9	31.6	39.0	38.4	28.7	24.2

\*bottom

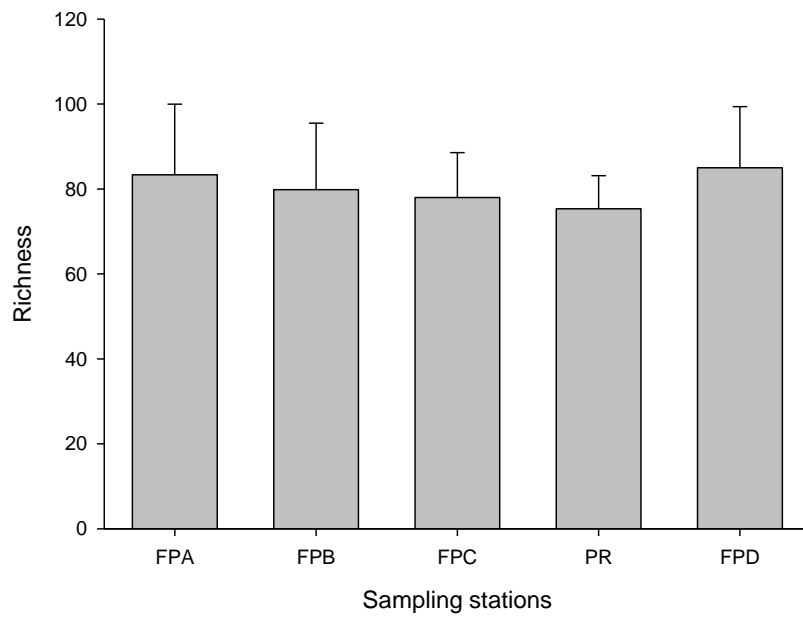
**Table 3.** Significant ( $r > 0.4$ ) correlations of the biotic and abiotic variables with the main components 1 e 2 (CCA analysis).

	<b>Abbreviation</b>	<b>r (Axis 1)</b>	<b>r (Axis 2)</b>
<b>Biotic</b>			
Bacillariophyceae	Bacil	0.9	-0.03
Chlorophyceae	Chloro	-0.5	-0.7
Chrysophyceae	Chryso	0.4	0.06
Zygnemaphyceae	Zygne	-0.4	-0.2
Cyanophyceae	Cyano	-0.5	0.7
Cryptophyceae	Crypto	-0.4	0.01
<b>Abiotic</b>			
Total Nitrogenous	TN	-0.5	0.1
Total Phosphorus	TP	-0.4	-0.4
Dissolved silicate	Silicate	0.3	-0.6
Rain precipitation	Pluvio	-0.6	0.4
pH	pH	0.7	0.03
Dissolved oxygen	DO	0.4	-0.2
Temperature	T	-0.8	-0.3
Transparency	Transp	0.8	-0.03
Turbidity	Turb	-0.7	0.3
Total Suspended Solids	SSt	-0.5	0.4

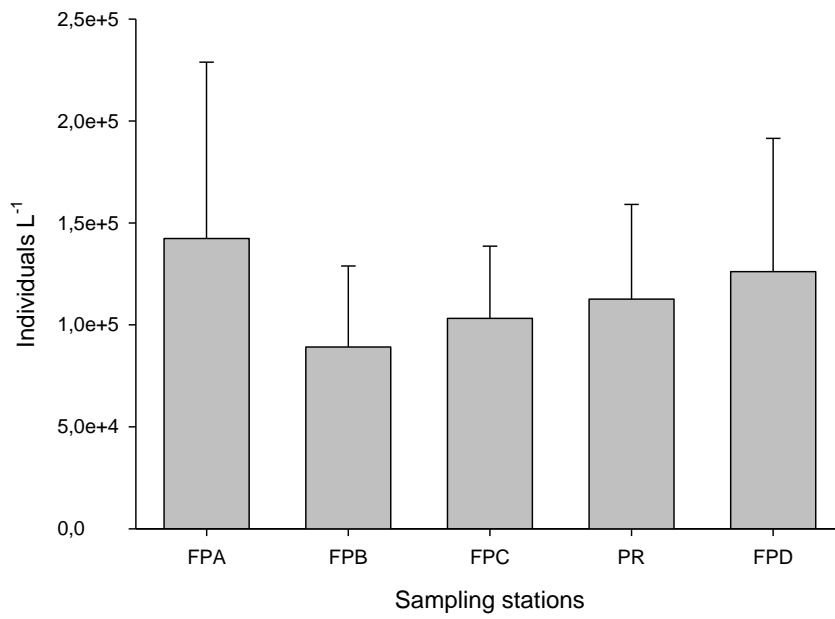


**Figure 1** – Study area in the region of the confluence of Paraná and Paranapanema Rivers (States of São Paulo – SP, Paraná – PR and Mato Grosso do Sul – MS) showing the positioning of Rosana, Taquaruçu and Porto Primavera dams and the State Forest of “Morro do Diabo” (gray area) (a.). On the right (detail) the location of the sampling stations and the municipality of Teodoro Sampaio (b.).

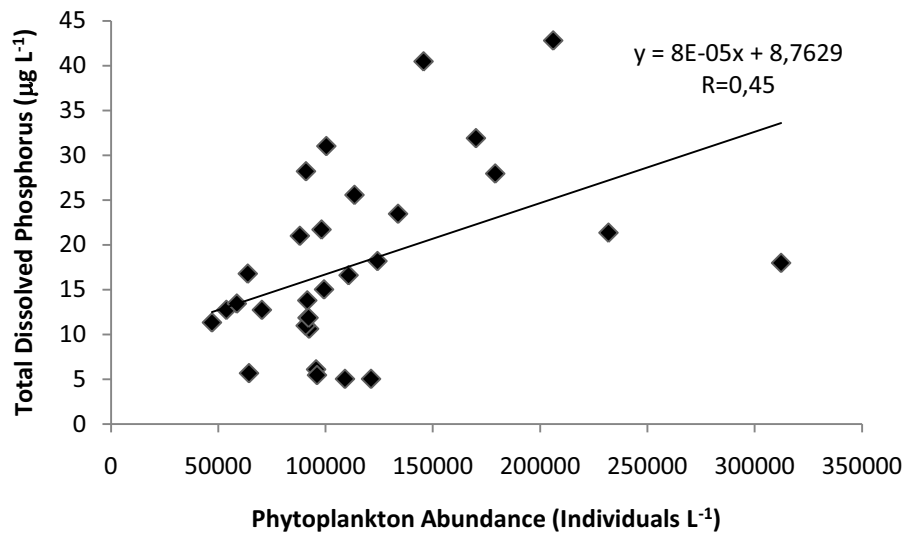




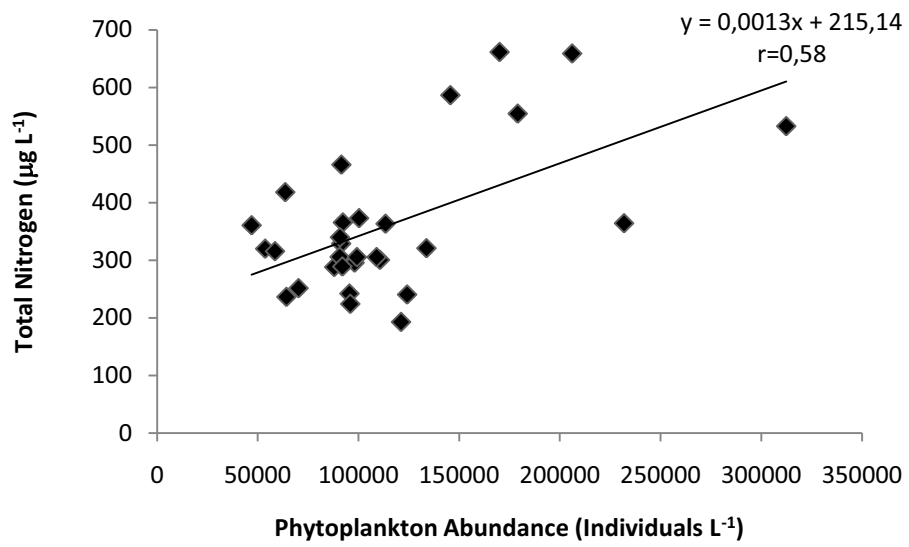
**Figure 2** – Phytoplankton richness (mean values and standard deviation) at the different sampling stations.



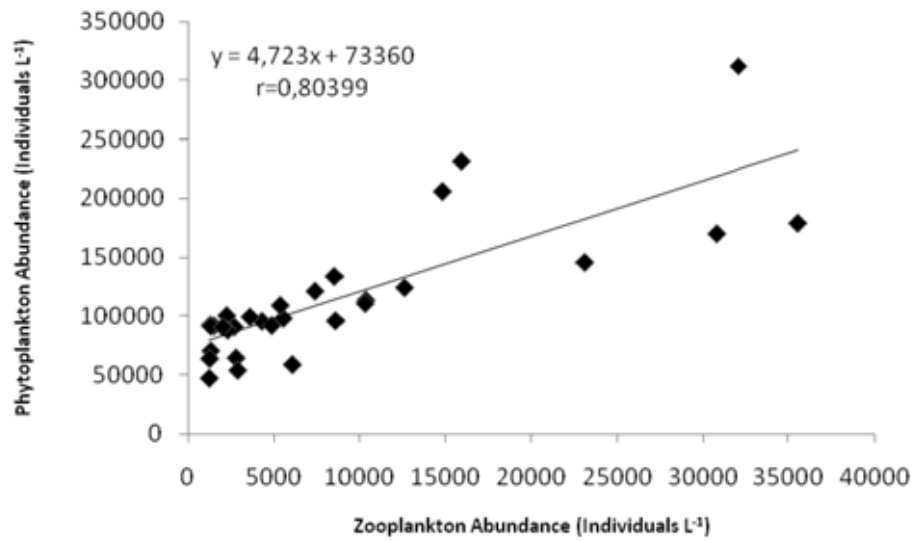
**Figure 3** – Phytoplankton abundance (mean values and standard deviation) at the sampling stations, considering the different study periods.



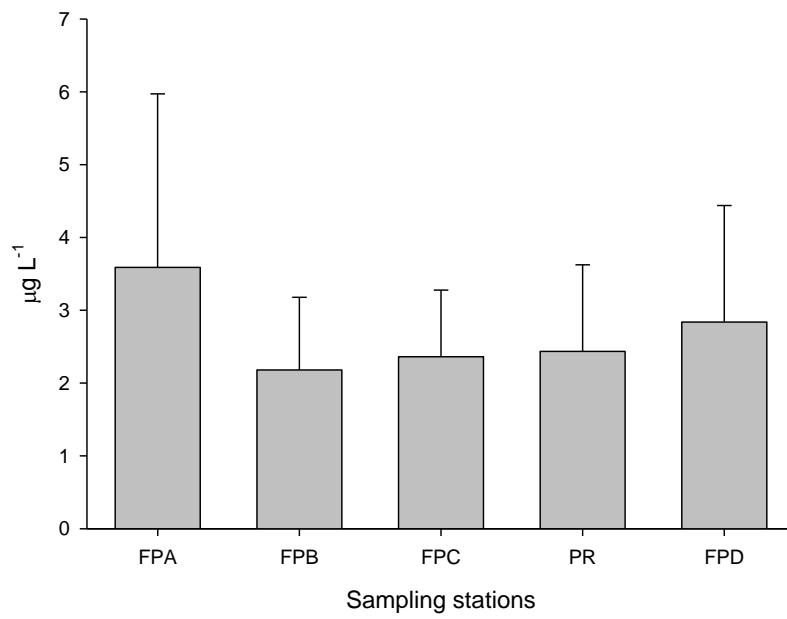
**Figure 4** – Linear correlation between total dissolved phosphorus and phytoplankton abundance at the sampling stations.



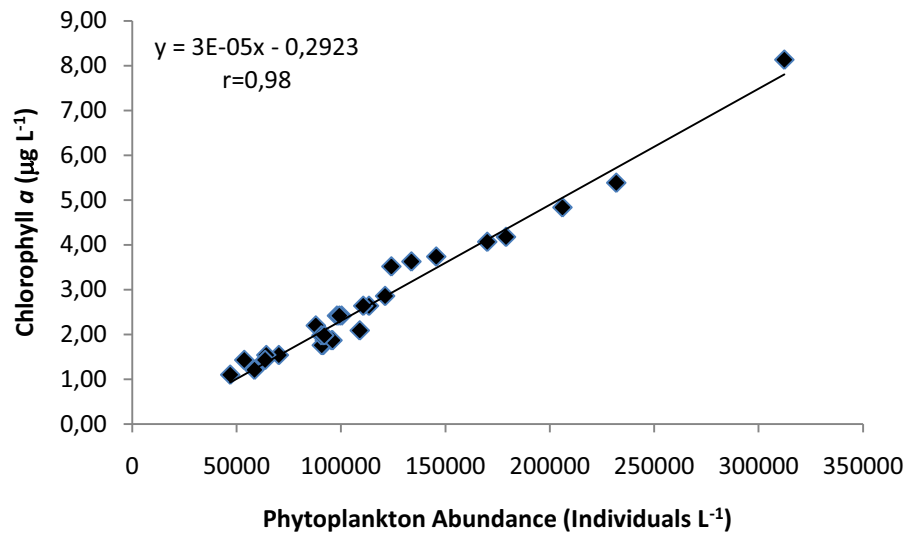
**Figure 5** – Linear correlation between total nitrogen and phytoplankton abundance at the sampling stations.



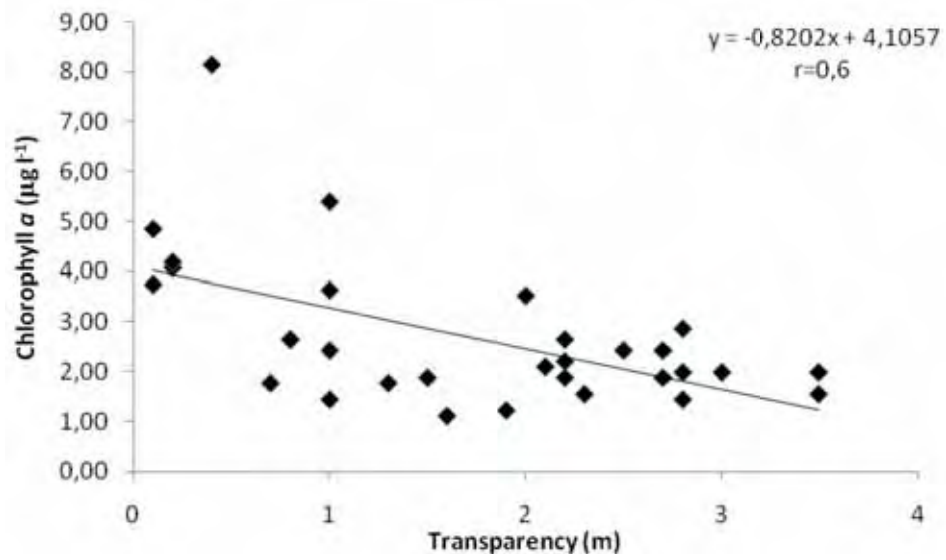
**Figure 6** – Linear correlation between zooplankton abundance and phytoplankton abundance at the sampling stations.



**Figure 7** – Phytoplankton biomass (chlorophyll *a*) (mean values and standard deviation) at the sampling stations, considering the different study periods.

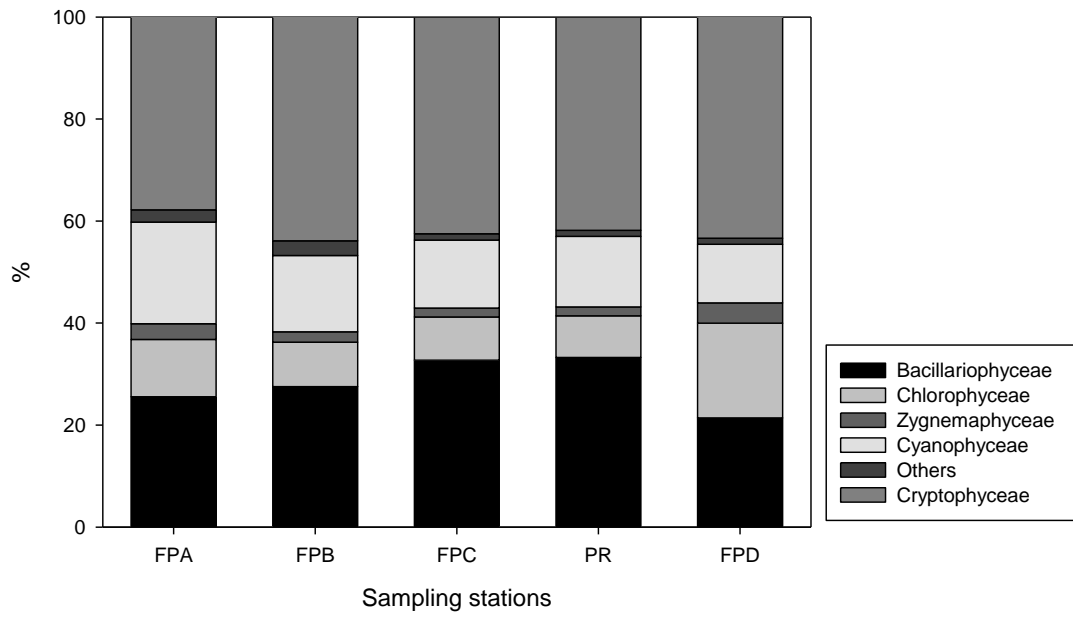


**Figure 8** – Linear correlation between chlorophyll *a* and phytoplankton abundance at the sampling stations.

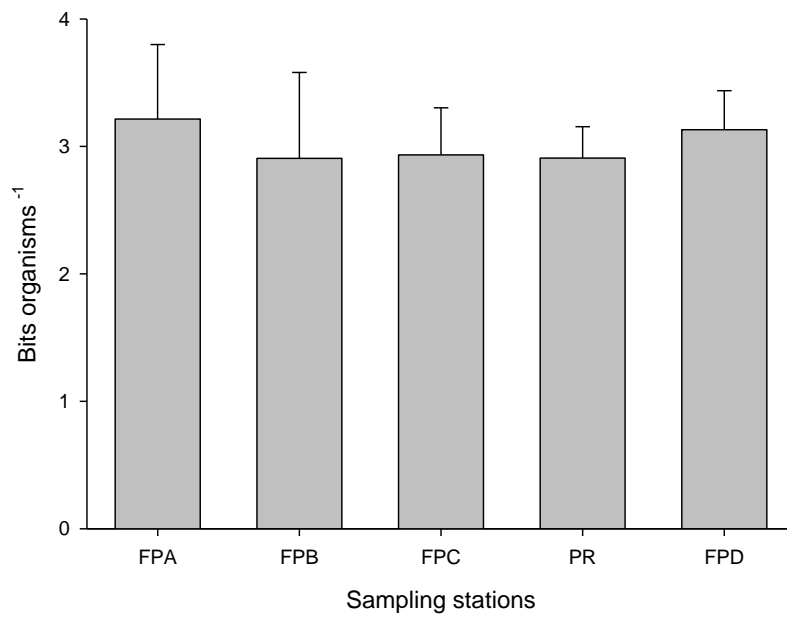


**Figure 9** – Linear correlation between chlorophyll *a* and transparency at the sampling stations.

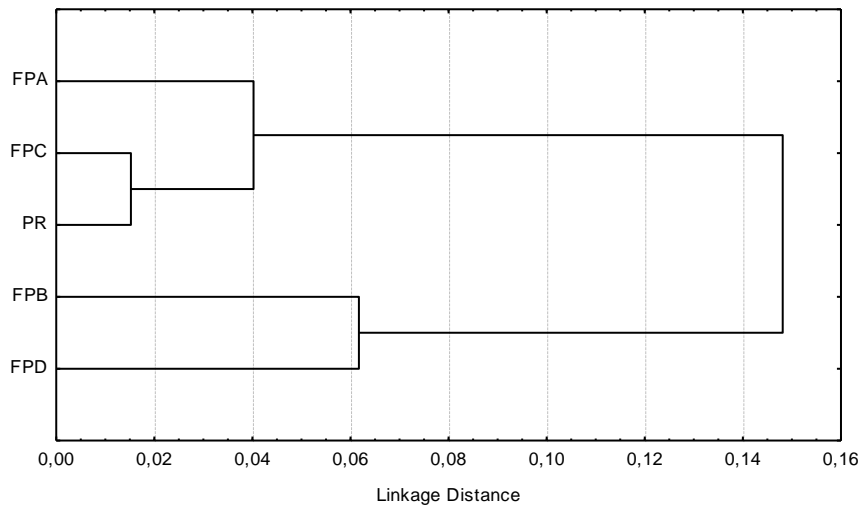




**Figure 10** – Relative abundance among the phytoplankton groups at the different sampling stations, considering the different study periods.



**Figure 11** – Diversity of the phytoplankton assemblages (mean values and standard deviation) at the sampling stations, during the different study periods.



**Figure 12** - Similarity analysis among the sampling stations based on the abundance of the phytoplankton classes.



## *Capítulo 2*

**Importance of lateral lagoons for the zooplankton assemblages (Cladocera and Copepoda) in a large tropical reservoir**

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Running title: Zooplankton in reservoir lateral lagoons.

## **Abstract**

This study aimed to analyze the composition and the ecological attributes of zooplankton assemblages (Cladocera and Copepoda), in four marginal lagoons and in the main channel of Rosana Reservoir (SE Brazil). Fieldwork was carried out in September and November/2004 and January, March, May and August/2005. A total of 72 taxa was identified (55 cladocerans and 17 copepods). Seasonally, a significant higher richness was observed during the rainy period. The lateral lagoons, compared to the reservoir, and the rainy period, compared to the dry one, showed higher zooplankton abundance. Copepods exhibited higher abundance than cladocerans. Among the copepods, there was a higher abundance of nauplii forms in the lateral lagoons and in the dry period. Calanoida dominated in relation to Cyclopoida. The most numerous cladoceran family was Bosminidae, followed by Daphniidae. The results showed that the zooplankton assemblages are influenced by the meteorological factors, by some important nutrients (indirectly) and by the phytoplankton abundance. This pattern indicated that in the lateral lagoon system the communities are controlled by bottom-up mechanisms. The results validate the hypotheses that lateral lagoons have a prominent ecological role on the zooplankton of Rosana Reservoir and also evidenced the main driving forces influencing the composition and the ecological attributes of the assemblages in the lateral lagoons system. The incorporation of lateral lagoons in regional environmental programs should be a target strategy for the conservation of the aquatic biota, minimizing the negative impact of the dam.

*Keywords:* Paranapanema River, Rosana Reservoir, floodplain, microcrustaceans, spatial variation, temporal variation.

## **Importância das lagoas laterais para as assembléias zooplanctônicas (Cladocera e Copepoda) em um reservatório tropical de grande porte**

### **Resumo**

O objetivo deste estudo foi analisar a composição e os atributos ecológicos das assembléias zooplanctônicas (Cladocera e Copepoda) de quatro lagoas marginais e do canal principal do reservatório de Rosana (SE, Brasil). Os trabalhos de campo foram realizados em setembro e novembro de 2004 e janeiro, março, maio e agosto de 2005. O número total de táxons identificados foi de 72 (55 cladóceros e 17 copépodes). Sazonalmente, maior riqueza foi observada durante o período chuvoso. As lagoas laterais, em relação ao reservatório, e o período chuvoso, em relação ao seco, apresentaram maior abundância de organismos. Os copépodes foram mais numerosos que os cladóceros. As lagoas marginais e o período seco apresentaram maior abundância de náuplios. Calanoida foi dominante em relação aos Cyclopoida. Entre os cladóceros, Bosminidae foi a família mais numerosa, seguida por Daphniidae. Os resultados mostraram que as assembléias zooplanctônicas são influenciadas pelos fatores meteorológicos, por alguns nutrientes (indiretamente) e pela abundância do fitoplâncton. Esse padrão indicou que no sistema de lagoas laterais, o funcionamento das comunidades é determinado por mecanismos de controle ascendente. Os resultados validaram a hipótese de que as lagoas laterais têm um proeminente papel ecológico para o zooplâncton do reservatório de Rosana e mostraram quais são as principais forças que influenciam a composição e os atributos ecológicos das assembléias nesses ambientes. A incorporação das lagoas laterais em programas regionais de conservação ambiental pode ser uma boa estratégia para conservação da biodiversidade aquática, minimizando o impacto negativo da construção da barragem.

*Palavras-chave:* Rio Paranapanema, reservatório de Rosana, lagoas marginais, microcrustáceos, variação espacial, variação temporal.



## 1. Introduction

A large number of reservoirs have been constructed in the last decades in Brazil, mainly in order to supply the increasing energetic demand. Nowadays, the main Brazilian rivers, especially in the Southeast region, were regulated by dams. Besides providing electric power, these reservoirs are also used for water supply, irrigation, aquaculture, recreation, tourism and navigation (Tundisi, 2005; Tundisi *et al.*, 2008). As a consequence of the intensive damming, the regional riverine systems have been transformed in large lentic (or semi-lentic) ecosystems (Nogueira *et al.*, 1999; Soares *et al.*, 2008).

As a consequence of the reservoir filling up, there is an increase of the connectivity between river and floodplain habitats, or even the formation of artificial lagoons (Henry *et al.*, 2006). Lateral lagoons form a complex gradient between the river channel and adjacent terrestrial ecosystems, resulting in a variety of secondary and tertiary ecotones (Ward *et al.*, 1999). These systems are characterized by remarkable environmental interactions between surface water, groundwater and riparian vegetation, and usually they sustain a very high biodiversity (Ward and Tockner, 2001). The degree of connectivity of lateral lagoons with the main rivers has also been considered as an important controlling factor of floodplain aquatic communities (Thomaz *et al.*, 2007; José de Paggi and Paggi, 2008; Bonecker *et al.*, 2009; Guntzel *et al.*, 2010).

Studies based on zooplankton assemblages contributed for the increasing knowledge of reservoirs structure and functioning (e.g. Rocha *et al.*, 1995; Matsumura-Tundisi, 1999; Matsumura-Tundisi and Tundisi, 2003; Sendacz *et al.*, 2003; Velho *et al.*, 2001; Bezerra-Neto and Pinto-Coelho, 2007; Nogueira *et al.* 2008). Nevertheless, studies focusing on the importance of the lateral compartments for the zooplankton are restricted to a few reservoirs (Panarelli *et al.*, 2001; Casanova and Henry, 2004; Panarelli *et al.*, 2008; Casanova *et al.*, 2009; Nadai and Henry, 2009; Panarelli *et al.*, 2010).

There are evidences that changes in the structure and dynamic of zooplankton assemblages produce alterations in all trophic levels of a reservoir ecosystem (Rocha *et al.*, 1995). These modifications can determine some undesirable processes, such as algae blooms, which cause a deterioration of the water quality condition (Pinto-Coelho *et al.*, 1999). It happens due to the fact that the zooplankton has an important role in the energy transfer between primary producers and consumers of higher trophic levels (Odum, 2004). Additionally, some zooplankton species, or even information of the assemblage structure, have been used as

bio-indicators of spatial and seasonal variability (Matsumura-Tundisi *et al.*, 1990; Pinto Coelho *et al.*, 1999; Sendacz and Kubo, 1999; Nogueira, 2001).

In the present study, it was analyzed the composition and ecological attributes of zooplankton assemblages in four lateral lagoons and in the main channel of Rosana Reservoir, Paranapanema River. The specific objectives were to determine the spatial and temporal variation in the composition, richness, abundance and diversity of cladocerans and copepods and to correlate their distribution with the limnological variables (transparency, temperature, pH, electric conductivity of water, turbidity and concentrations of dissolved oxygen, suspended solids, total nitrogen, total phosphorus and dissolved silicate), precipitation and phytoplankton abundance.

The main hypothesis is that the lateral lagoons have a significant contribution for the zooplankton diversity of Rosana Reservoir. It was also intended to determine the main driving forces influencing on the spatial and temporal variation of the composition and ecological attributes of the zooplankton assemblages in the lateral lagoons system.

## **2. Material and Methods**

### *2.1. Study area*

The study area is in the upstream (tail) zone of Rosana Reservoir, approximately 80 km above dam (Figure 1), which is located at 22° 36'S and 52° 52'W. The reservoir is the last one of a series of eleven along the Paranapanema River (SP/PR, Brazil), with a surface area of 276 km<sup>2</sup> (watershed of 11,000 km<sup>2</sup>), water retention time of 21 days (annual mean value), relatively shallow (maximum of 26 m close to the dam) and oligo-mesotrophic (Nogueira *et al.*, 2006).

The climate is subtropical humid (average temperature of 21°C) with two pronounced seasons: rainy and dry (Duke Energy, 2001). During the studied period, the rainy season ranged from September/2004 to January/2005 (month average of 157 mm), while the dry period ranged from February to August of 2005 (month average of 70.7 mm). The accumulated rain precipitation in the study period was 1,207.5 mm. The rain precipitation data was provided by the meteorological station of the State Park of “Morro do Diabo”, municipality of Teodoro Sampaio (State of São Paulo).

## 2.2. Samplings and laboratory analyses

The study was carried out in 4 lagoons and one sampling station in the Paranapanema River (PR), close to the river bank (Figure 1; Table 1). Samplings were carried out in September and November of 2004 and January, March, May and August of 2005.

Two kinds of lagoons were assessed: 3 natural systems (FPB, FPC and FPD) and one originated by the flood of mining digging (FPA). The natural lagoons (FPB and FPD) are located inside the State Park of Morro do Diabo, while the last one (FPC) is located in an area influenced by human activities (agriculture and cattle breeding). The dominant macrophytes of each lagoon, in terms of stand area, were registered (Table 1). Identification of these plants was performed at the genus level, with help of taxonomists of Botany Department from Biosciences Institute of UNESP/Botucatu. The main limnological characteristics of each point are showed in Table 2.

The sampling stations positioning, the area of each lagoon (integration of geometric distances), as well as their connectivity (transversal section of the lagoon mouth) with the river-reservoir main channel, were determined using a Garmin E-Trex GPS.

The zooplankton samples were collected using a conical net (30 cm mouth diameter and 50  $\mu\text{m}$  mesh size) through vertical hauls from near bottom (ca. 0.5 m) to surface. In each point/period it was obtained an additional sample for qualitative analysis. For the quantitative analysis a minimum of 150 individuals was counted per sample and in case of low abundance the entire sample was analyzed. Microcrustaceans were identified by specialized literature (Sendacz and Kubo, 1982; Reid, 1985, Matsumura-Tundisi, 1986; Elmoor-Loureiro, 1997; Rocha, 1998 and Silva, 2003). Among cladocerans, the Sididae, Ilyocryptidae and Macrothricidae were grouped as Others (for graphical representation), due to their low representativeness.

Samples were fixed and preserved in 4% formaldehyde and they are deposited in the Freshwater Invertebrate Collection of the Department of Zoology, Biosciences Institute of the State University of São Paulo (campus of Botucatu).

Zooplankton diversity was estimated using the Shannon-Weaver Index ( $\log_2$ ). In order to compare the sampling sites on the basis of the zooplankton assemblages structure a cluster analysis (r-Pearson similarity) (Pcordwin) was performed, using the abundance per group.

The mean values of the measured assemblages attributes were calculated to in order to synthesize the information and facilitate the identification of patterns. Two periods were considered in the analysis: rainy and dry periods. The representativeness of the means was assumed based on the normal data distribution (Shapiro-Wilk's W test) (Underwood, 1997; Statistica™ 6.0).

A one-way ANOVA test was performed to detect differences among sampling sites. When differences were detected, the Tukey test was applied to determine the level of significance (Underwood, 1997). Differences between the periods were tested by the test t-student, using the mean of the variables for each season (dry and rainy). Significant different values were considered when  $p < 0.05$  (Underwood, 1997), which are mentioned in the results. The analyses were performed using Statistica™ 6.0 software (Statsoft, 2001).

Finally, a canonic correspondence analysis, CCA (Pcordwin) (McCune and Mefford, 1999) was used to validate the second hypothesis and identify the main limnological factors influencing the zooplankton abundance. The environmental variables (Ferrareze and Nogueira, *in press*) and phytoplankton abundance (Ferrareze and Nogueira, *in preparation*) were simultaneously measured.

### 3. Results

A total of 72 taxa was found in the zooplankton samples. Cladocera was represented by 55 species (3 Moinidae, 3 Bosminidae, 6 Sididae, 8 Daphniidae, 2 Ilyocryptidae, 4 Macrothricidae, 9 Chydorinae and 20 Aloninae) and Copepoda by 17 species (6 Diaptomidae and 11 Cyclopidae).

An increasing tendency of the zooplankton richness towards the dam was observed. The number of species was significantly higher at the FPD sampling station ( $p=0.00$ ;  $F=524.59$ ; Fig. 2). Seasonally, significant higher richness was observed during rainy period (mean of 23 taxa) and lower in dry period (mean of 20 taxa) ( $p=0.035$ ).

The lateral lagoons exhibited significant higher zooplankton abundance when compared with the reservoir ( $p=0.000066$ ;  $F=22.86$ ; Fig. 3). Seasonally, significant higher abundance was observed in the rainy (mean of 12,475 individual  $m^{-3}$ ) compared to the dry period (mean of 5,228 individual  $m^{-3}$ ) ( $p=0.033$ ). The zooplankton abundance was positively correlated with the phytoplankton abundance ( $r=0.8$ ;  $p=0.000$ ; Fig. 4).

Copepods showed higher abundance than Cladocerans, 79.5% and 20.5% of the total number of organisms, respectively ( $p=0.000$ ). An exception was observed at the FPB on January of 2005, where Cladocerans reached 51.6% of the total number of organism. Among the copepods, nauplii of Calanoida (mean of 2,505 individual  $m^{-3}$ ) were more abundant than the nauplii of Cyclopoida (mean of 1,873 individual  $m^{-3}$ ) ( $p=0.026$ ). Higher number of naupli forms were observed in the lateral lagoons compared to the reservoir ( $p=0.001$ ). Seasonally, there were high nauplii abundance in the dry period (66.2% of the population) than the rainy period (55.5% of the population) ( $p=0.023$ ).

The Calanoida/Cyclopoida relative abundance (Fig. 5) showed a higher proportion of calanoids.

Among the copepods the main species, in terms of abundance and frequency of occurrence, were the diaptomidae *Notodiaptomus henseni* Dahl, 1894 and *N. iheringi* Wright, 1935 as well as the cyclopidae *Thermocyclops decipiens* (Kiefer, 1929), *T. minutus* (Lowndes, 1934) and *Mesocyclops ogunnus* Onabamiro, 1957.

The relative abundance among cladocerans (Fig. 6) showed that the Chydoridae, despite having a larger number of species, were not numerically dominant. Bosminidae was the most abundant group (43.6%), followed by Daphniidae (38.2%). Bosminidae exhibited higher dominance in the lagoons FPA, FPB and FPD. Daphniidae were more abundant at the reservoir sampling stations and Chydoridae, typical from littoral habitats, were proportionally more abundant in FPB and FPC lagoons.

The main cladoceran species were the Daphniidae *Daphnia gessneri* Herbst, 1967 and *Ceriodaphnia silvestrii* Daday, 1902; the Moinidae *Moina minuta* Hansen, 1899 and the Bosminidae *Bosmina freyi* De Melo and Hebert, 1994 and *Bosminopsis deitersi* Richard, 1895.

Despite a tendency of richness increase towards the dam, there was no significant difference among the sampling station diversity ( $p=0.553$ ;  $F=1.77$ ; Fig. 7). There was also no significant difference between the season periods ( $p=0.07$ ).

The cluster analysis (Fig. 8), on the basis of the zooplankton assemblage structure of each sampling station, showed a higher similarity between the stations FPA and FPD. Similarity analyses also evidenced that the reservoir sampling station (PR) has a distinct zooplankton assemblage compared to the lateral lagoons.

Finally, the results of the CCA (Fig. 9 and Table 3) explained 73% of the data variability ( $p=0.01$ ), considering the three first ordination axes (axis 1 = 48.8%, axis 2 = 14.9% and axis 3 = 9.3%). The groups

Sididae, Daphniidae and Moinidae were better correlated with the positive side of the axis 1, associated to higher values of total nitrogen, total phosphorus, precipitation, temperature, turbidity, suspended solids and conductivity and also with higher phytoplankton abundance. The groups Bosminidae, Calanoida and Cyclopoida positioned on the negative side of the axis 1, associated to higher values of pH, dissolved silicate and transparency.

Bosminidae and Moinidae were located on the positive side of the axis 2, associated to lower values of conductivity as well as to higher concentrations of dissolved silicate.

Some associations among the periods and the phytoplankton assemblages could be observed through the CCA analysis. Sididae, Daphniidae and Moinidae were more representative during the rainy period (January of 2005). Calanoida, Chydoridae and Ilyocryptidae were more representative during November/2004 and March/2005, while, Bosminidae, Cyclopoidae and Macrothricidae were more representative during the dry period.

#### **4. Discussion**

Studies carried out in the upper Paranapanema basin evidenced that the lateral lagoons have a major importance for the zooplankton diversity of Jurumirim Reservoir (Panarelli *et al.*, 2001; Casanova and Henry, 2004; Panarelli *et al.*, 2008; Casanova *et al.*, 2009; Nadai and Henry, 2009; Panarelli *et al.*, 2010). In the present investigation, in the lower Paranapanema basin, the microcrustacean found in the lateral lagoons of Rosana Reservoir, 72, is much higher when compared to previous analyses of the zooplankton assemblages sampled along the reservoir main channel (46 taxa) (Sartori, 2008). The amount of species is also higher than the ones found in other reservoirs and lagoons of the Paranapanema River basin (Nogueira, 2001; Sampaio *et al.*, 2002; Panarelli *et al.*, 2003; Martins and Henry, 2004; Nadai and Henry, 2009; Panarelli *et al.*, 2010) and comparable to the microcrustacean richness determined for the whole basin (limnetic habitats), 75 species (Nogueira *et al.*, 2008).

The zooplankton of the lateral lagoons/reservoir system exhibited remarkable seasonal changes, with dominance of different groups under particular limnological conditions. It was possible to recognize, through the statistical analyses (CCA and regression analyses), a clear separation of the sampling stations along the

study periods. These analyses also indicated what are the main driving forces influencing on the composition and the ecological attributes of the assemblages. Variations in composition and abundance were influenced by meteorological factors, such as precipitation and temperature, indirectly by some important nutrients (nitrogen and phosphorus) and also by the phytoplankton abundance. Similar correlations have been reported for other environments of the upper Paraná basin (Bonecker and Lansac-Tôha, 1996; Aoyagui and Bonecker, 2004; Lansac-Tôha *et al.*, 2005; Nogueira *et al.*, 2008).

The Cladocera and Copepoda species found during this study have already been reported in other zooplankton studies carried out in the Paranapanema River (Henry and Nogueira, 1999; Nogueira, 2001; Sampaio, *et al.*, 2002, Panarelli *et al.*, 2003; Gralhóz, 2005; Nogueira *et al.*, 2006; Sartori, 2008; Nogueira *et al.*, 2008; Nadai and Henry, 2009; Perbiche-Neves and Nogueira, 2010).

The higher proportion of Cladocera (55 species) in relation to Copepoda (17 species) follows the tendency observed in other regional studies on planktonic microcrustaceans (Rocha *et al.*, 2002; Nogueira *et al.*, 2008). However, it is important to note that this is not an exclusive pattern for the neotropics and studies in the Amazonian region (Robertson and Hardy, 1984) and middle Paraná (Paggi and José de Paggi, 1990) have demonstrated that Copepoda can also be of a major importance in terms of richness (about 40 to 50 species).

Higher richness during the rainy period, probably due to the transport and homogenization of different water masses, was also observed in other studies in the upper Paraná basin (Bonecker and Lansaca-Tôha, 1996; Aoyagui and Bonecker, 2004).

Another possible recurrent tendency is the longitudinal (towards the dam) increase in the zooplankton richness. In our research the highest number of species occurred in the most downstream located lagoon (FDP). This pattern was observed in Rosana (Sartori, 2008; Naliato *et al.*, 2009) and other reservoirs in the Paranapanema basin (Mitsuka and Henry, 2002; Nogueira *et al.*, 2006; Nogueira *et al.*, 2008), as well as in other river basins (Velho *et al.*, 2001). Another contributing factor for zooplankton richness in FDP is the high transparency and low values of suspended matter. Oligotrophic environments tend to exhibit high number of zooplankton species (Maitland, 1978).

The high abundance verified in the lagoons demonstrated that these lateral environments contributed for the exportation of organisms (Aoyagui and Bonecker, 2004). The zooplankton development in the lagoons (composition, abundance and diversity) is succeeded due to the habitat complexity (macrophytes stands)

(Maia-Barbosa *et al.*, 2008), high water retention time and low flow conditions. In an study carried out in floodplain habitats (water meadow and lagoons) Paranapanema Basin a very high number of cladoceran species was registered, 70, most belonging to Chydoridae (Gralhóz, 2005), including rare species (Debastiani Junior *et al.*, 2009). In the Danube River, the main channel with high flow velocity showed lower density of zooplankton, while in the lateral environments, a higher density was found. This region was considered center for the zooplankton development in the river (Reckendorfer *et al.*, 1999).

The increase of zooplankton abundance verified during the rainy period was directly related with the phytoplankton abundance. The phytoplankton growth is a response to the higher nutrient availability during the late spring and summer (Ferrareze and Nogueira, *in preparation*). When the phytoplankton abundance declined the zooplankton also reduced. This pattern indicated that in the lateral lagoon system, the communities are controlled by the bottom-up mechanisms (*sensu* Townsend *et al.*, 2006).

The present composition and dominance among Diaptomidae in the studied sampling stations, when compared with previous studies, indicates the occurrence of important long-term structural changes in the zooplankton assemblages of the Paranapanema basin. In this study, *Notodiaptomus iheringi* and *N. henseni* were the main species and *N. conifer* was found in low abundance in the FDP lagoon. This last species used to be abundant in the Paranapanema reservoirs during the late 1970s (Sampaio *et al.*, 2002), and was still found in relative high numbers in the end of 1990s and beginning of 2000s (Nogueira, 2001; Mitsuka and Henry, 2002). Another important Diatomidade species in the past, *Argyrodiaptomus furcatus*, has presently a minor contribution. Changes in the composition of Calanoida fauna along the last three decades in the reservoirs of the State of São Paulo are discussed by Matsumura-Tundisi and Tundisi (2003). The authors consider that the substitution of species may be related to the progressive increase of the electric conductivity and alterations in the ionic composition of the water, reflecting the advance of eutrophication.

In this study, adults of Copepoda and copepodits were more abundant in summer, when Calanoida was dominant. In the other hand, during winter, when Cyclopoida increased their proportion in the zooplankton assemblages, the nauplii and the copepodits were found in high number. This discrepancy of abundance among the several phases of Calanoida and Cyclopoids development could be related to their different reproductive strategies (Casanova, and Henry, 2004; Sartori *et al.*, 2009; Nogueira *et al.*, 2008). The Cyclopoids can be considered r-strategists (colonist) with high reproductive rate, but with low rate of survival



during larval phases. The Calanoida (k-strategists) eggs are generally bigger than the ones of Cyclopoids, generating larvae in a better nutritional condition and with higher survivor rate (Nogueira *et al.*, 2008).

Higher abundance of nauplii observed in the lateral lagoons indicates that these lateral environments can have an important role for the recruitment of copepod populations. This hypothesis was also considered for the lagoons of Jurumirim Reservoir by Casanova and Henry (2004).

In relation to the adults of Copepoda, *N. henseni* showed the high abundance among the copepods. This species was also found in high abundance in other studies in the Paranapanema River (Oliveira, 2004; Nogueira *et al.*, 2008) and other reservoirs of the upper Paraná region (Lopes *et al.*, 1997; Nogueira, 2001; Bonecker *et al.*, 2001; Serafim Júnior *et al.*, 2005; Nogueira *et al.*, 2006; Santos Wisniewski and Rocha, 2007). Among the Cyclopoida, the genus *Thermocyclops* and *Mesocyclops* showed high abundance. These genera are also commonly found in Brazilian reservoirs (Sendacz *et al.*, 1982; Pinto Coelho, 2002; Lopes *et al.*, 1997).

The Calanoids and Cyclopoids co-existed in the whole study. Temporally, there was a decrease of Calanoids in relation to the Cyclopoids during the dry period. A higher abundance of Cyclopoids during the dry period, mainly due to the contribution of *Thermocyclops*, has already been documented by Panarelli *et al.* (2001) and Mitsuka and Henry (2002) for the Jurumirim Reservoir. The changes in the proportion between the zooplankton Orders could be indicating the occurrence of a high mortality rate during the larval phases of Cyclopoids, as previously mentioned.

Among the Cladocera, Bosminidae was the dominant family, mainly in the lagoons, represented by *Bosmina*. The presence in high abundance of this genus can be an indicative of the trophic condition, as the individuals feed on bacterium and detritus (Sendacz *et al.*, 1985). Daphniidae was also abundant, mainly in the reservoir sampling station. The rains in the watershed promote the introduction of alloctone material into the lagoons, increasing the eutrophication and stimulate the development of some species and decrease of others (Sartori, 2008).

High abundance of *Bosmina* and *Daphnia* has already verified in other studies in the Paranapanema River by Nogueira (2001), Panarelli *et al.* (2003), Nogueira *et al.* (2008) and Sartori (2008). Some genera considered rare in limnetic samples, and observed in our study, are frequent when the hauls are carried out together or

close the vegetation, as the case of *Chydorus*, *Ephemeroporus*, *Ilyocriptus*, *Leydigia* (Elmoor-Loureiro, 1997; Gralhóz, 2005; Maia-Barbosa *et al.*, 2008).

The diversity did not show a clear difference among the different sampling stations and periods. This is due to the fact that some taxa of *Bosmina*, *Daphnia*, *Thermocyclops* and *Notodiaptomus* were abundant in the whole study. In general the diversity values were similar to the ones found in other studies in the Paranapanema basin (Henry and Nogueira, 1999; Nogueira, 2001; Sampaio, *et al.*, 2002, Panarelli *et al.*, 2003; Gralhóz, 2005; Nogueira *et al.*, 2006; Sartori, 2008; Nogueira *et al.*, 2008).

The similarity on the basis of zooplankton structure showed that the connectivity with the river/reservoir influences on the composition and abundance of the lagoons assemblages. The analysis also demonstrated the importance of the interaction of the surrounding landscape with the aquatic environments. The lateral lagoons located inside the environmental protection area and with the narrowest connectivity exhibited more distinctive assemblages than the other lagoons. The cluster analysis also evidenced the influence of the river assemblages on the assemblages of the lateral lagoon FPC. The same pattern is observed in other communities, ichthyofauna (Ferrareze and Nogueira, 2011) and phytoplankton (Ferrareze and Nogueira, *in preparation*) and even in the nutrients dynamics (Ferrareze and Nogueira, *in press*). Other studies which investigated the influence of connectivity on the zooplankton assemblages showed that higher the connectivity among the river and the lagoon, determine higher similarity among local communities and lower the regional richness (Forbes and Chase, 2002).

The results validated the hypotheses that lateral lagoons have a prominent ecological role on the zooplankton assemblages, in terms of richness and abundance. It was also evidenced the main driving forces influencing the composition and the ecological attributes of zooplankton assemblages in the lateral lagoons system.

The incorporation of lateral lagoons in environmental programs should be a good strategy for the conservation of the regional aquatic biota, minimizing the negative impact of the dam.

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**Table 1.** Denomination of the sampling stations, geographical positioning, lagoons surface area, main aquatic macrophytes and estimated area of connectivity of lagoons with the river/reservoir main channel.

<b>Sampling station</b>	<b>Geographical coordinates</b>	<b>Area (km<sup>2</sup>)</b>	<b>Dominant macrophytes</b>	<b>Connectivity (m<sup>2</sup>)</b>
Lateral lagoon A (FPA)	22° 34' 03.3''S / 52° 09' 11.4''W	0.110	<i>Typha, Eichhornia, Brachiaria, Pontederia and Salvinia</i>	50
Lateral lagoon B (FPB)	22° 36' 56.5''S / 52° 09' 47.3''W	0.024	<i>Eichhornia, Brachiaria, Pontederia, Salvinia, Pistia, Egeria and Nymphaea</i>	6.5
Lateral lagoon C (FPC)	22° 37' 28.9''S / 52° 09' 21.1''W	0.721	<i>Eichhornia, Brachiaria, Pontederia, Salvinia and Egeria</i>	525
Parapanama River Bank (PR)	22° 37' 51.6''S / 52° 09' 30.5''W	-	<i>Typha, Eichhornia, Brachiaria, Pontederia, Salvinia and Pistia</i>	-
Lateral lagoon D (FPD)	22° 38' 22.0''S / 52° 09' 29.0''W	0.063	<i>Eichhornia, Brachiaria, Pontederia, Salvinia, Pistia and Nymphaea</i>	60.2

**Table 2.** Mean values (among depths) (except transparency) for the limnological variables measured at the different sampling stations and periods.

	pH					Dissolved oxygen (mg L <sup>-1</sup> )					Temperature (°C)							
	set-04	nov-04	jan-05	mar-05	mai-05	ago-05	set-04	nov-04	jan-05	mar-05	mai-05	ago-05	set-04	nov-04	jan-05	mar-05	mai-05	ago-05
FPA	7.2	7.5	6.2	6.6	7.3	6.1	8.7	6.5	6.2	8.4	6.2	8.0	23.0	25.5	27.2	27.6	25.4	22.2
FPB	7.3	6.6	6.3	6.6	7.3	7.6	8.6	7.7	6.3	5.0	9.5	8.3	22.1	25.5	27.1	27.4	25.3	22.4
FPC	7.2	6.3	5.9	6.5	7.2	7.6	9.7	8.0	5.9	5.2	10.0	9.0	20.8	25.7	26.9	27.2	25.2	22.1
PR	7.2	6.2	5.2	6.4	6.9	7.2	9.6	7.8	6.0	6.4	9.2	12.0	20.5	25.2	27.1	26.9	24.6	22.4
FPD	7.4	6.2	5.5	5.9	7.0	7.1	8.8	7.6	5.4	9.2	13.2	12.0	21.0	25.6	27.0	27.3	25.2	22.5

	Conductivity (µS cm <sup>-1</sup> )					Transparency (m)					Turbidity (NTU)							
	set-04	nov-04	jan-05	mar-05	mai-05	ago-05	set-04	nov-04	jan-05	mar-05	mai-05	ago-05	set-04	nov-04	jan-05	mar-05	mai-05	ago-05
FPA	46	70	70	70	48	64	2.8	1.5	0.4	1	2	3.5*	8.2	36.7	52.4	17.3	15.1	9.0
FPB	70	70	70	70	44	64	2.3	1.6	0.1	0.8	2.2	2.8*	4.5	33.4	40.2	12.3	7.4	4.2
FPC	90	80	90	80	80	65	2.2	1	0.2	1	2.7	3*	5.1	55.1	83.4	14.0	7.8	6.0
PR	60	70	70	70	52	65	2.1	1.3	0.1	0.7	2.2	5.8*	5.1	98.0	135.5	20.3	6.5	5.7
FPD	60	70	90	80	85	65	2.7	1.9	0.2	1	2.5	3.5*	5.0	94.7	140.0	21.0	6.9	5.8

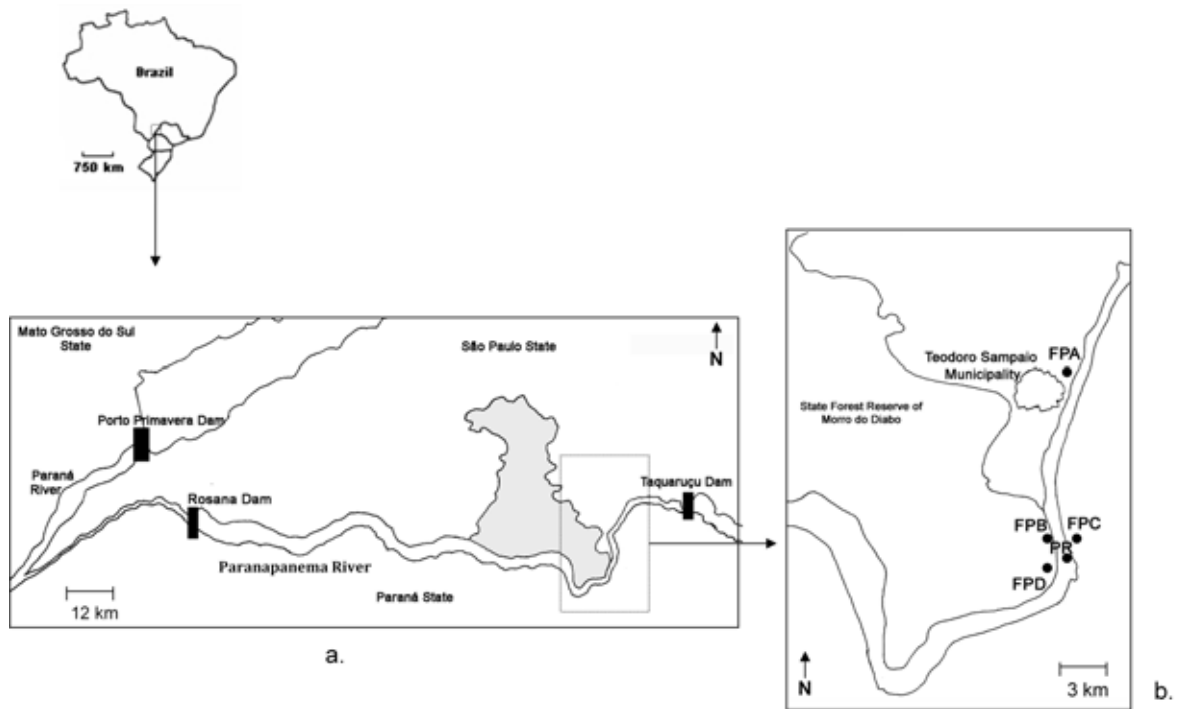
	Suspended Solids (mg L <sup>-1</sup> )					Total Nitrogenous (µg L <sup>-1</sup> )					Total Phosphorus (µg L <sup>-1</sup> )							
	set-04	nov-04	jan-05	mar-05	mai-05	ago-05	set-04	nov-04	jan-05	mar-05	mai-05	ago-05	set-04	nov-04	jan-05	mar-05	mai-05	ago-05
FPA	4.1	5.8	9.2	4.1	2.2	1.7	193	366	533	321	241	252	14.1	21.7	19.2	33.0	31.6	25.8
FPB	2.2	7.2	18.4	4.3	2.7	2.0	236	361	587	363	301	320	9.5	36.7	53.8	45.6	30.4	26.0
FPC	4.2	13.0	14.8	3.4	2.4	2.0	242	418	662	373	296	466	9.9	28.7	32.4	38.4	39.8	30.2
PR	2.5	5.3	31.9	5.3	3.4	1.8	306	329	659	340	288	306	7.9	32.8	52.8	50.1	34.5	30.6
FPD	2.4	3.2	16.0	3.6	2.0	2.4	224	316	555	364	306	289	5.9	31.6	39.0	38.4	28.7	24.2

\*bottom

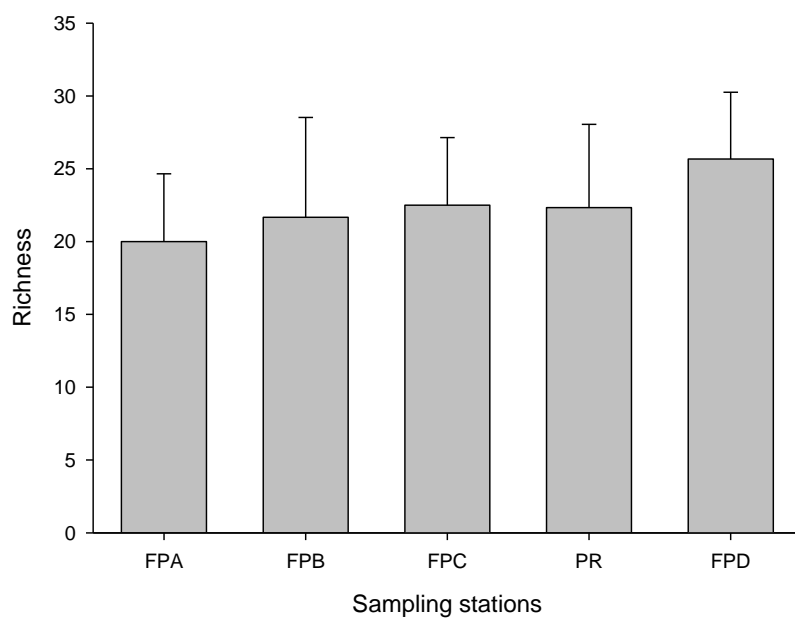


**Table 3.** Significant ( $r > 0.4$ ) correlations of the biotic and abiotic variables with the main components 1 e 2 (CCA analysis).

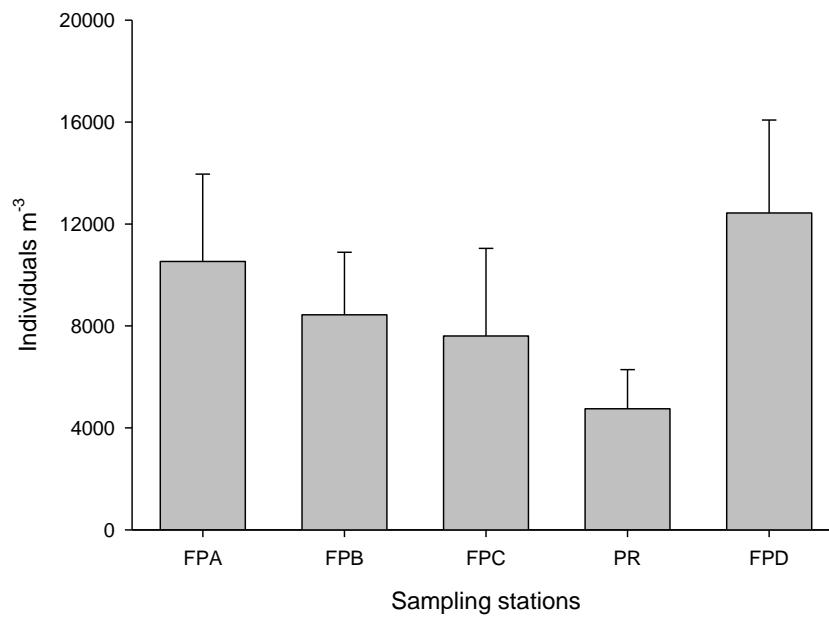
	<b>Abbreviation</b>	<b>r (Axis 1)</b>	<b>r (Axis 2)</b>
<b>Biotic</b>			
Sididae	Sididae	0.7	-0.01
Daphniidae	Daphn	0.9	0.2
Moinidae	Moinidae	0.6	0.5
Bosminidae	Bosmi	-0.5	0.5
Calanoidae	Calano	-0.6	-0.1
Cyclopoidae	Cyclo	-0.2	0.4
<b>Abiotic</b>			
Total Nitrogenous	Nt	0.8	-0.2
Total Phosphorus	Pt	0.5	-0.2
Dissolved Silicate	Silica	-0.1	0.4
Rain precipitation	Pluvio	0.9	0.1
pH	pH	-0.8	0.3
Temperature	T	0.6	-0.2
Conductivity	K	0.4	-0.5
Transparency	Transp	-0.7	0.2
Turbidity	Turb	0.8	-0.2
Phytoplankton abundance	Phyto	0.5	0.3
Total Suspended Solids	SSt	0.9	-0.1



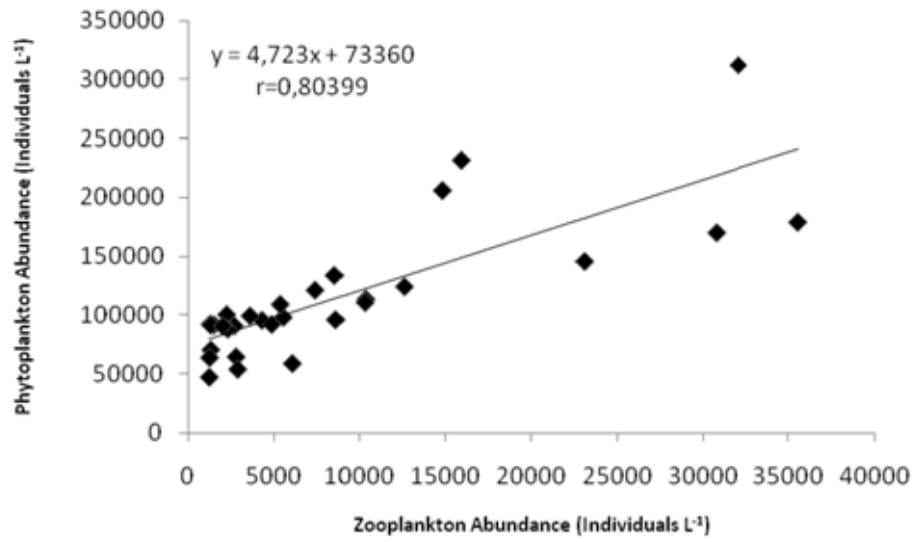
**Figure 1** – Study area in the region of the confluence of Paraná and Paranapanema Rivers (States of São Paulo – SP, Paraná – PR and Mato Grosso do Sul – MS) showing the positioning of Rosana, Taquaruçu and Porto Primavera dams and the State Park of “Morro do Diabo” (gray area) (a.). On the right (detail) the location of the sampling stations and the municipality of Teodoro Sampaio (b.).



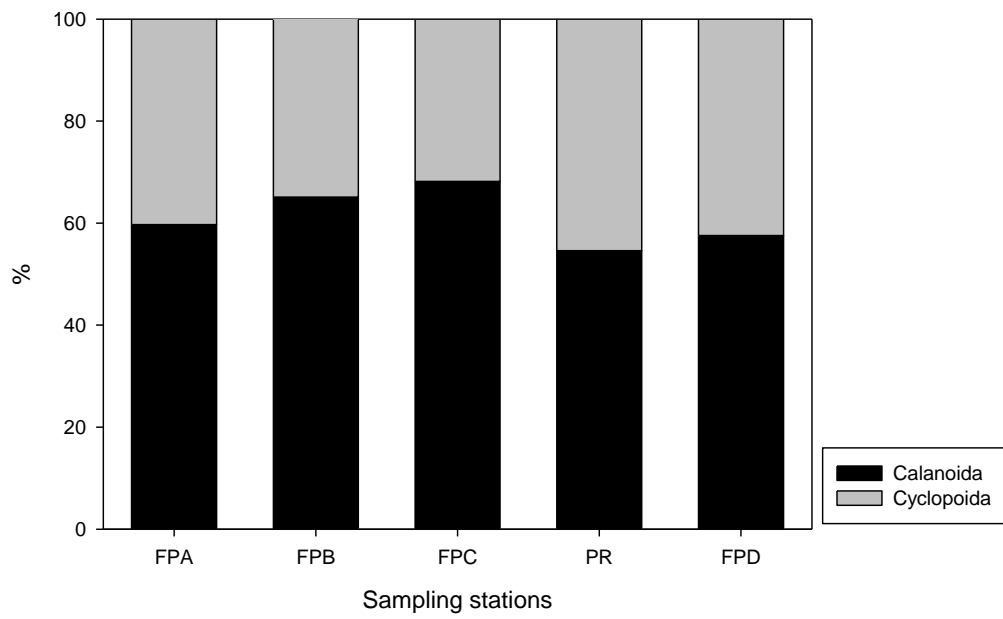
**Figure 2** – Zooplankton richness (mean values and standard deviation) at the different sampling stations.



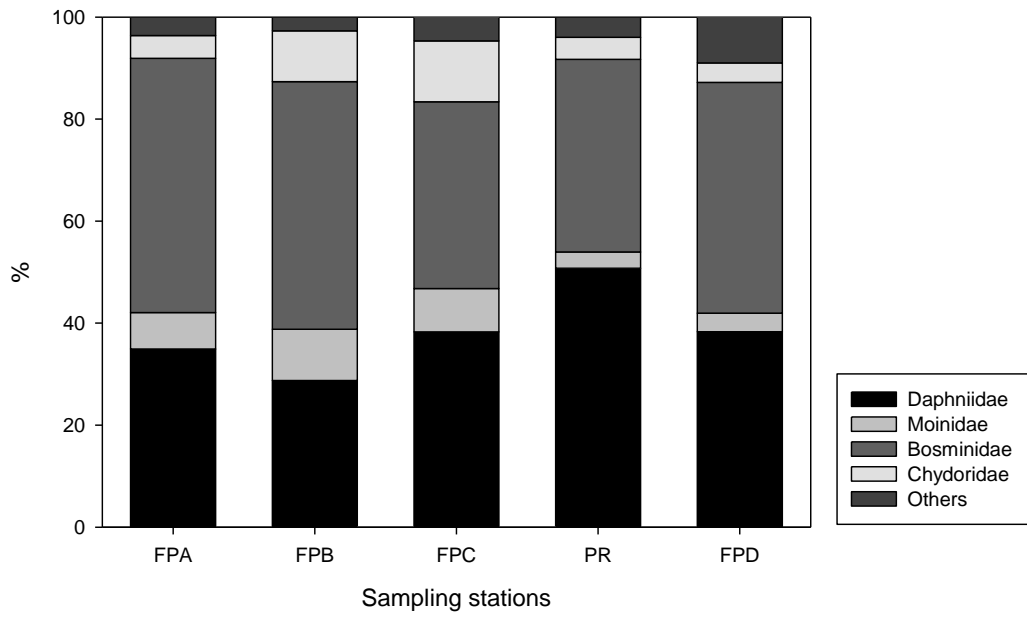
**Figure 3** – Zooplankton abundance (mean values and standard deviation) at the sampling stations, considering the different study periods.



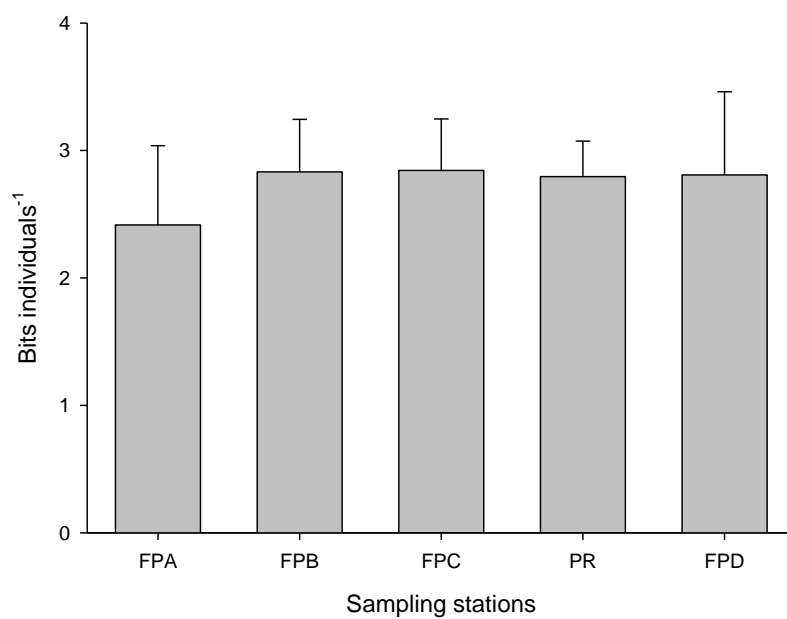
**Figure 4** – Linear correlation between zooplankton abundance and phytoplankton abundance at the sampling stations.



**Figure 5** – Relative abundance among the Copepod groups at the different sampling stations, considering the different study periods.

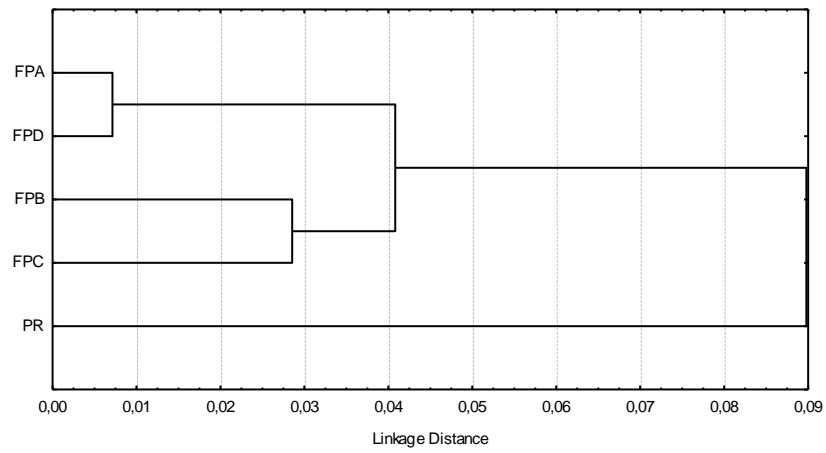


**Figure 6** – Relative abundance among the Cladocera groups at the different sampling stations, considering the different study periods.

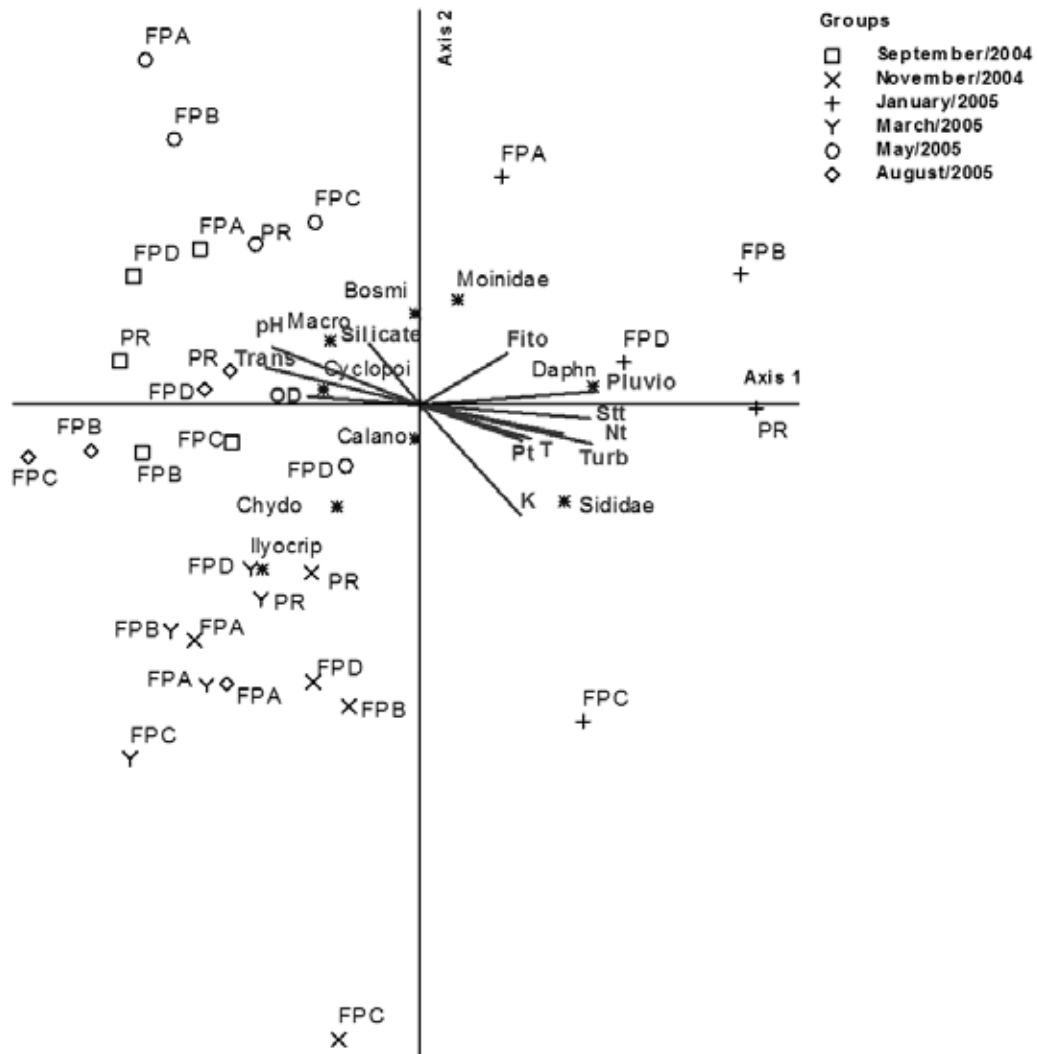


**Figure 7** – Diversity of zooplankton assemblages (mean values and standard deviation) at the sampling stations, during the different study periods.





**Figure 8** - Similarity analysis among the sampling stations based on the abundance of the zooplankton groups.



**Figure 9** – Canonical correspondence analysis (CCA) showing the distribution of the zooplankton species in relation to the limnological variables. See Table 3 for abbreviations.

## *Capítulo 3*

**Impact assessment of the introduction of *Cichla kelberi* in a large Neotropical reservoir**

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Running title: Impacts of *Cichla* on the Fish fauna.

## **Abstract**

This study aimed to understand how the introduction of *Cichla kelberi* in Rosana Reservoir (Paranapanema River) affected the native ichthyofauna. Data on the structure of the small fish fauna assemblage were obtained before and after the introduction of this carnivorous species. Samplings were carried out in February and September of 2004, previously to the register of *Cichla kelberi* in the reservoir, and after its introduction, November of 2004, January, March, May and August of 2005, February and June of 2006, February and July of 2007, February and October of 2008 and February of 2009. A total of 4,693 fish, belonging to 43 different species was sampled between 2004 and 2009. The order Characiformes was the most abundant, followed by Perciformes and Siluriformes. Comparative analyses, before and after the introduction, could not demonstrate significant changes in composition, richness, abundance, biomass, mean length and diversity. Aquatic insects were the main feeding item of *C. kelberi*, followed by tetragonopterinae fish. Cannibalism was recorded during the whole study period. The results showed that *Cichla* cannot deeply affect the ichthyofauna assemblages of a large Neotropical reservoir, at least in a short or medium term period after its introduction. The results also allowed concluding that the introduction of *C. kelberi* in the reservoir is in the phase 3. In this phase, the species can survive and reproduce in the new environment; however it is not totally established and disseminated. The reasons for the fact that *Cichla* is still not dominant in Rosana Reservoir could be related to feeding competition, high rate of cannibalism and the presence of large amount of aquatic macrophytes (refuge zones). In spite of the results, the continuous monitoring of the role of non native species on the local fish fauna is absolutely necessary. The impacts caused by colonization of this undesirable species can be magnified by complex processes, usually correlated with other environmental disturbances, especially the negative effects of damming.

*Keywords:* Paranapanema River, Rosana Reservoir, non native fish, impact, long term study.

## **Avaliação do impacto da introdução da *Cichla kelberi* em um reservatório Neotropical de grande porte**

### **Resumo**

O objetivo deste estudo foi entender como a introdução da *Cichla* no reservatório de Rosana (rio Paranapanema) afeta em longo prazo as assembleias de peixes. Dados da estrutura da ictiofauna de pequeno porte foram obtidos antes e após a introdução. As coletas foram realizadas em Fevereiro e Setembro de 2004, quando *Cichla kelberi*, ainda não havia sido registrado no reservatório, e após sua presença, em novembro de 2004, janeiro, março, maio e agosto de 2005, fevereiro e junho de 2006, fevereiro e julho de 2007, fevereiro e outubro de 2008 e fevereiro de 2009. Um total de 4693 peixes, pertencentes a 43 espécies foi amostrado entre 2004 e 2009. A Ordem Characiformes foi a mais abundante, seguida por Perciformes e Siluriformes. Análises comparativas, antes e depois da introdução, não demonstraram mudanças significativas na composição, riqueza, abundância, biomassa, comprimento médio e diversidade. Insetos aquáticos constituíram no principal item da alimentação de *Cichla kelberi*, seguido por peixes tetragonopterídeos. Canibalismo foi registrado durante todo o período de estudo. Os resultados mostraram que *Cichla* não afeta substancialmente a ictiofauna dos reservatórios neotropicais, pelo menos no curto e médio prazo após sua introdução. Os resultados também permitiram concluir que a introdução de *Cichla kelberi* se encontra na fase 3. Nessa fase, a espécie pode sobreviver e reproduzir no novo ambiente, contudo ela não está totalmente estabelecida e disseminada. As razões que explicam a ausência de dominância de *Cichla* no reservatório de Rosana podem estar relacionadas à competição alimentar, a alta taxa de canibalismo e grande quantidade de macrófitas aquáticas (zonas de refúgio). Apesar dos resultados, o monitoramento contínuo do papel das espécies não nativas sobre a ictiofauna local é de extrema importância, pelo fato de que os impactos causados por essas espécies podem ser amplificados, geralmente correlacionados com outros distúrbios ambientais, principalmente efeitos negativos do barramento.

*Palavras-chave:* Rio Paranapanema, reservatório de Rosana, peixes não nativos, impacto, estudo em longo prazo.

## 1. Introduction

River regulation represents one of the major impacts on fish fauna and can drastically change the species composition and abundance. Some species cannot survive to the newly created environment while others can become excessively abundant (Ahearn *et al.*, 2005; Agostinho *et al.*, 2008).

Another serious damage for the ichthyofauna is the introduction of non-native species. The introduction of non-native fish species has can cause the decline or even the extinction of native fish populations, the biotic homogenization - the replacement of endemic native species by widespread distributed exotic species (Gido and Brown, 1999; Olden and Poff, 2004; Marchetti *et al.*, 2006; McKinney, 2006; Smith, 2006; Light and Marchetti, 2007).

Biotic invasion, as a consequence of human activities, is an over century phenomenon (Simberloff, 2003). Since the Roman Empire, introduction of fish into alien environments have been mediated by boat displacement, importation of aquarium fish, aquaculture activities based on exotic species, releases for biological control, releases for fisheries improvement, construction of inter-catchment canals for water transportation, pipes and tunnels (Ruesink, 2005; Brasher *et al.*, 2006; Jeschke and Strayer, 2006; Stohlgren *et al.*, 2006). Exotic fishes are positively associated with man-made reservoirs, generally due to stocking for sport fishing and inundation of natural barriers, such large waterfalls (Pringle *et al.*, 2000; Leprieur *et al.*, 2006). Above dam populations of exotics usually have higher abundance than the ones living below dam (Holmquist *et al.*, 1998).

In the last years the introduction of peacock-bass species (*Cichla* spp.) in Neotropical reservoirs has been considered as a major problem (Kullander and Ferreira, 2006). *Cichla* is an exceptionally voracious predator and studies showed that its introduction may seriously threat the native fish, compromising the assemblage diversity or even causing the complete regional extinction of several species (Zaret and Paine, 1973; Godinho *et al.*, 1994; Santos *et al.*, 1994; Latini and Petrere, 2004; Pelicice and Agostinho, 2009).

Nevertheless, quantitative analysis of the dispersion and establishment of non-native fish in a wide spatial and temporal scale is still rare. The complete understanding of the process is crucial for

prediction, and maybe the avoidance, of further expansion of invasive species and biotic homogenization in aquatic ecosystems (Han *et al.*, 2008).

The proposal of the present study is to evaluate the potential negative impact of the introduction of *Cichla kelberi* Spix and Agassiz, 1831 in Rosana Reservoir, Paranapanema River. The aim is to understand how *Cichla* affects the small size ichthyofauna, comparing the assemblage structure before and after (in a relatively long term period) the introduction.

Additional information on the small size fish assemblage distribution and ecological attributes and limnological characteristic of the study environment is provided by Ferrareze and Nogueira (2011) and Ferrareze and Nogueira (*in press*), respectively.

## **2. Material and Methods**

### *2.1. Study area*

The study area is located in the upstream (tail) zone of Rosana Reservoir, approximately 80 km above dam (Figure 1), which is located at 22° 36'S and 52° 52'W. The reservoir is the last one, from a series of eleven along the Paranapanema River (SP/PR, Brazil), with a surface area of 276 km<sup>2</sup> (watershed of 11,000 km<sup>2</sup>), water retention time of 21 days (annual mean values), shallow (maximum of 26 m close to the dam) and oligo-mesotrophic (Nogueira *et al.*, 2006).

The climate is subtropical humid (average temperature of 21°C) with two pronounced seasons, a dry weather predominates from April to August (autumn/winter), and the rains are concentrated in late spring and summer (from November to March) (Ferrareze and Nogueira, *in press*).

### *2.2. Samplings and laboratory analyses*

The samplings were carried out in February and September of 2004, previously to the register of *Cichla kelberi* in the Rosana Reservoir (Casatti *et al.*, 2003; Pelicice *et al.*, 2005), and in November of 2004 (register of the first occurrence of this species) (Pelicice and Agostinho, 2009), January,



March, May and August of 2005, February and June of 2006, February and July of 2007, February and October of 2008 and February of 2009.

The study was carried out in 4 lagoons and one sampling station in Paranapanema River (PR), close to the river bank (Figure 1; Table 1). Two kinds of lagoons were assessed: 3 natural lagoons and one originated by the flood of mining digging (FPA). The natural lagoons (FPB and FPD) are located inside the State Park of Morro do Diabo, while the last one (FPC) is located in an area influenced by human activities (agriculture and cattle breeding). The dominant macrophytes of each lagoon, in terms of stand area, were registered (Table 1). Identification of these plants was performed at the genus level, with help of taxonomists of Botany Department from Biosciences Institute of UNESP/Botucatu.

Small fish were sampled with a net of 7.5m<sup>2</sup> (1.5x5m; 0.3 cm of mesh size). In each point/period five manual throws were performed towards to the aquatic macrophyte stands and in the limnetic zone.

In the laboratory, the organisms were transferred to ethanol 70% for permanent storage. Voucher specimens are deposited in the Freshwater Fish Collection of the Department of Zoology, State University of São Paulo, Campus of Botucatu.

The biometry of the collected organisms was obtained through measurements of weigh (biomass in g; Mettler Toledo PB 3002 scale, 0.01g accuracy) and length (paquimeter, 0.1 mm) – standard (except for Gymnotiformes and Synbranchiformes) and total.

For taxonomical identification of the fish species it was used specialized literature (Britsk, 1972; Britsk et al., 1986; Britsk et al., 1999; Reis et al., 2003; Nelson, 2006; Graça and Pavanelli, 2007) and the scientific collections of the State University of São Paulo (Campus S. J. R. Preto) and University of São Paulo Museum (MZUSP) were also consulted.

Numerical richness, abundance and biomass were calculated for the communities, while the Index of Importance (Nataragam and Jhingian, 1961, *apud* Beaumord and Petrere, 1994) was calculated for each species. The Shannon-Wiener index was calculated to estimate the fish assemblage

diversity of each lagoon for the distinct sampling periods. This index is widely used in analyses of communities structure (Magurran, 2004).

In order to describe the feeding preference of *C. kelberi*, its diet was determined through stomach content analysis. The items were identified under a stereoscopic microscope and microscope, trying to attain the most detailed taxonomic level.

The mean values of the community variables were calculated to synthesize the information and facilitate the identification of patterns. The data were grouped by sampling year. The representativeness of the means was assumed based on the normal data distribution (Shapiro-Wilk's W test) (Underwood, 1997; Statistica™ 6.0), after previously standardization ( $\text{Log}_x+1$ ).

Finally, a one-way ANOVA test was performed to detect differences among periods. When differences were detected, the Tukey test was applied to determine the level of significance (Underwood, 1997). It was considered significant difference values of  $p < 0.05$  (Underwood, 1997), which were mentioned in the results. The analyses were performed using Statistica™ 6.0 software (Statsoft, 2001).

### **3. Results**

A total of 4,693 fish, belonging to 43 species was sampled between 2004 and 2009 (Table 2). The assemblages were primarily composed by small-size species, due to the chosen methodology. The order Characiformes was the most abundant, totalizing 95.4% of the individuals, followed by Perciformes, 2.5%, and Siluriformes, 1.2%. Other orders represented only 0.9% of the individuals.

In terms of Species Importance, the main species was *Hemigrammus marginatus* Ellis, 1911, which represented about 37% of the total captures. Other abundant species were *Hyphessobrycon eques* (Steindachner, 1882), *Bryconamericus stramineus* Eigenmann, 1908 and *Serrapinus notomelas* (Eigenmann, 1915) for Characiformes; *Crenicichla britskii* Kullander, 1982 for Perciformes;

*Hypostomus ancistroides* (Ihering, 1911) for Siluriformes and *Gymnotus carapo* Linnaeus, 1758 for Gymnotiformes.

A total of 899 individuals (21 species) were captured in the period that preceded the introduction of *C. kelberi* (before), while 3,994 individuals (43 species) were caught in all subsequent periods. Thirty-seven individuals of *C. kelberi* were captured along the study.

There were no differences between the fish richness if compared the periods before and after the introduction ( $p=0.86$ ; Fig. 2). The fish richness during the year of 2008 showed a remarkable decreasing ( $p=0.03$ ). However, this fact is probably not related to the *Cichla* introduction, because the number of caught individuals of this species during the mentioned period was low.

There were no difference between the fish abundance before and after the introduction ( $p=0.55$ ; Fig. 3). It was verified a decrease in the fish abundance when there was an increase in the *Cichla* abundance. Posterior to the reduction of *Cichla*, the assemblage abundance was reestablished. The species of *H. marginatus*, *H. eques* and *C. britskii* were the species that exhibited higher decrease in abundance when the number of *Cichla* specimens was elevated. Other observed particularity is that most *Cichla* individuals were sampled in the lateral lagoon with higher fish abundance (FPA).

The same pattern was observed in terms of fish biomass. During the increase in the *Cichla*, population the fish biomass decreased; but the weight just reestablished when *Cichla* abundance reduced. There was no significantly difference between the fish biomass before and after the introduction ( $p=0.677$ ; Fig. 4).

The introduction of *Cichla* did not interfere in the mean length of fish ( $p=0.83$ ; Table 2). The sampled species showed similar size before and after the introduction, even during the period when *Cichla* abundance was high.

The fish assemblage composition did not change after *Cichla* introduction. There was the predominance of Characiformes, followed by Perciformes and Siluriformes in all periods. Characiformes is more abundant in the lagoons, while Perciformes, Siluriformes and Gymnotiformes are more important in the river channel. The unique difference was seen when the

*Cichla* abundance raised, the predominance of Characiformes was lower, due to the decrease of *H. marginatus*. The Siluriformes was the order that increased most after the introduction, but this is probably associated with the higher number samplings, as no species of this order was predominant after the introduction. The relative abundance among the taxonomic orders is presented in Figure 5, for the whole sampling period.

The fish diversity was higher than before the introduction of *Cichla* ( $p=0.04$ ). The number of the predominant species (*H. marginatus*, *H. eques* and *C. britskii*) decreased, what allowed other species of minor importance to increase in abundance, such as *Cyphocharax modestus* (Fernández-Yépez, 1948), *Roeboides descavaldensis* Fowler, 1932 and *Aphyocharax anisitisi* Eigenmann and Kennedy, 1903.

Finally, aquatic insects were the main feeding item of *C. kelberi*, followed by fish of the sub-family tetragonopterinae. Cannibalism was recorded during the whole study period. Detailed analyses of the assemblages fish diet is provided by Ferrareze and Nogueira (*in preparation*).

#### **4. Discussion**

The probability of a given species to become a well succeeded invader is generally low, even rare. When the event is rare, the prediction of the facts becomes hard, because it depends not only on the prediction accuracy, but also on the frequency that the event occurs (Colautti and MacIsaac, 2004; Brasher *et al.*, 2006).

When a species is introduced in a region, only a certain number of individuals will survive and most of them will fail to succeed. Thus, the damage of non native species can just be evaluated after the real introduction, because no one can be completely sure if the establishment of it will occur (Colautti and MacIsaac, 2004; Jeschke and Strayer, 2006).

In the Rosana Reservoir case, the results showed that *C. kelberi* seems not to have had a significant effect on the ichthyofauna, as predicted by Pelicice and Agostinho (2008).

Our results did not show statistically differences in the ichthyofauna structure after the introduction of *C. kelberi* in the reservoir. The diversity values even improved, after the introduction. This fact happened due to the decrease of the number of the most abundant species, diminishing the competition and allowing the increase of the abundance of some species with minor importance as *C. modestus*, *R. descavaldensis* and *A. anisitisi*.

However, despite not have been detected in the assemblages ecological attributes after the *C. kelberi* introduction, some tendencies (“signals”) could be observed, indicating that this species can interfere in the local ichthyofauna. When a high number of predators found an opportunity (“window”) to spread, they can produce pronounced changes on the local fish community, and this possibility cannot be neglected (McKinney, 2006).

Firstly, it is interesting to note that a high number of *Cichla* was found in the lagoon with the higher abundance of small size fish. Second, when the *Cichla* abundance was high, the abundance of the main species and the fish biomass decreased, corroborating with the initial study of the species impact in the Rosana Reservoir (Pelicice and Agostinho, 2009).

These facts could indicate that the species is trying to establish into the new environment and together with the local ichthyofauna. Probably *Cichla* is still not well established in the reservoir, and the initial introduction effects were buffered by the plasticity of the fish along the time (Ruesink, 2005).

The results allowed to conclude that the introduction of *Cichla kelberi* in the reservoir is in the phase 3 (*sensu* Colautti and MacIsaac, 2004). In this phase, the specie can survive and reproduce in the new environment; however it is not established, disseminated and dominant.

It is difficult to point out the reasons to explain why *Cichla* is not properly established, but it could be related with the feeding competition, high rate of cannibalism and the extensive presence of aquatic macrophytes in the reservoir.

Juveniles of *Cichla kelberi*, as several other neotropical fish species, uses the aquatic insects as the main feeding item and some of this species are highly specialized to capture their prey, such as

*Gymnotus* and *Crenicichla* (Ferrareze and Nogueira, *in preparation*). Another fact is that the tetragonipterinae, used by *Cichla*, are also an important feeding item of *Serrasalmus maculatus* Kner, 1858 and *Hoplias malabaricus* (Bloch, 1794).

The feeding competition can reduce the prey availability and raise the cannibalism (Novaes *et al.*, 2004). The cannibalism also can reduce the chances of surviving of a non native fish in a new environment. The drastic reduction of the introduced population, reduce the genetic and morphologic variability, as well as the reproduction success (Wootton, 1990; Santos *et al.*, 2001).

Other important fact preventing *Cichla* to become dominant in the reservoir is the presence of macrophytes, as previously mentioned. The plant structures offer an ideal environment for refuge and shelter for prey, mainly for small sized fish, what makes harder their capture by predators (Rozas and Odum, 1988; Schriver *et al.*, 1995; Ferrareze and Nogueira, 2011).

Therefore, the results showed that *Cichla* cannot destroy the whole ichthyofauna assemblages of a Neotropical reservoir and change the fish assemblage structure immediately after its introduction. But, the real problems about the introduction only will be determined, when the process reaches the next steps (4 and 5). When the species will reach these steps cannot be determined (Colautti and MacIsaac, 2004).

The decrease in the ichthyofauna attributes verified during the year of 2008, such as low richness, abundance, biomass and diversity is probably resulted of the climatic changes verified in that year. There were strong rains in the wet period (from January to March) and a long dry season in the winter/spring of 2008 (Duke Energy data). These changes reflected on the ichthyofauna, promoting the decrease of the ecological attributes, as verified in other studies (Gafny *et al.*, 2000; Barrella and Petrere, 2003).

Despite of the inconclusive results to support the hypothesis that *Cichla kelberi* has caused a negative impact on the ichthyofauna of Rosana Reservoir, the role of non native species in the local fish fauna should be a major concern of aquatic ecology scientists and environmental managers. The continuous monitoring of non-native species is imperative, because in several cases, the introduction

reach the final phase, promoting drastic changes in the local ichthyofauna (Zaret and Paine, 1973; Kaufman, 1992; Macchi *et al.*, 1999). Additionally, it must be considered that the impacts caused by colonization of this undesirable species can be magnified by complex processes, usually correlated with other environmental disturb (Byers, 2002; Shea and Chesson, 2002), especially the negative effects of damming (Agostinho *et al.*, 2007). Nevertheless, the assumptions cannot be totally pessimist, as the system has a natural resiliency that can minimize disturbances (Odum, 2004).

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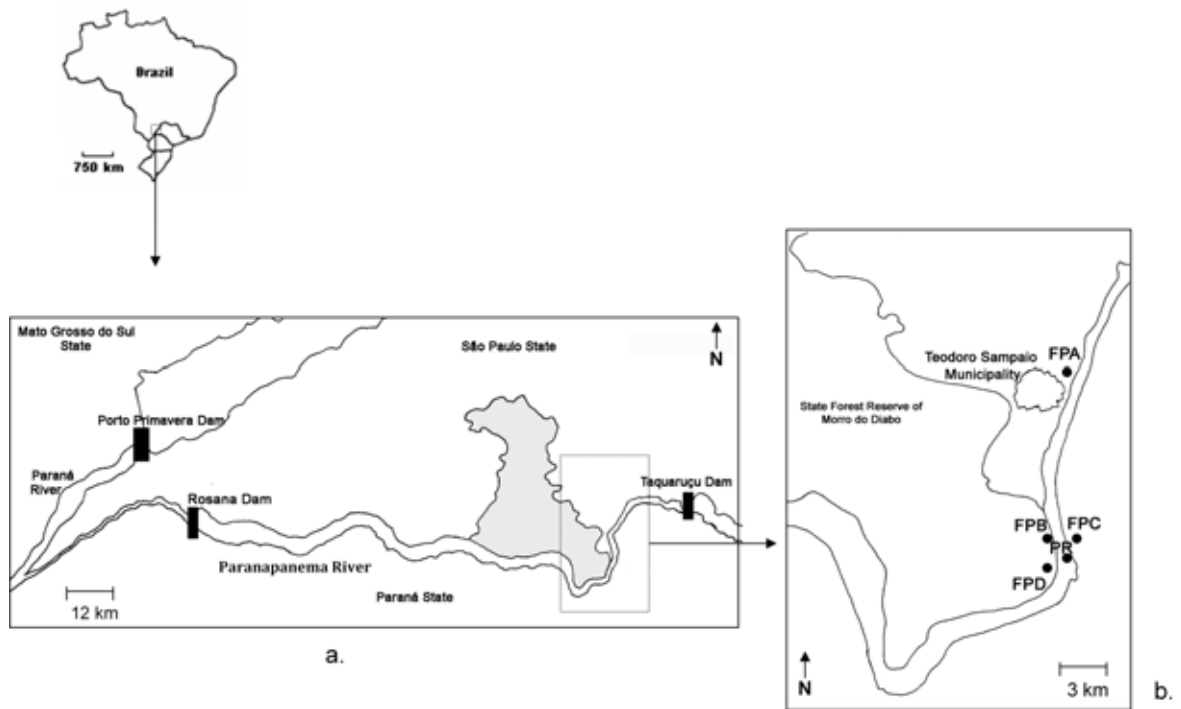
**Table 1.** Denomination of the sampling stations, geographical positioning, lagoons surface area, main aquatic macrophytes and estimated area of connectivity of lagoons with the river/reservoir main channel.

Sampling station	Geographical coordinates	Area (km <sup>2</sup> )	Dominant macrophytes	Connectivity (m <sup>2</sup> )
Lateral lagoon A (FPA)	22° 34' 03.3''S / 52° 09' 11.4''W	0.110	<i>Typha</i> , <i>Eichhornia</i> , <i>Brachiaria</i> , <i>Pontederia</i> and <i>Salvinia</i>	50
Lateral lagoon B (FPB)	22° 36' 56.5''S / 52° 09' 47.3''W	0.024	<i>Eichhornia</i> , <i>Brachiaria</i> , <i>Pontederia</i> , <i>Salvinia</i> , <i>Pistia</i> , <i>Egeria</i> and <i>Nymphaea</i>	6.5
Lateral lagoon C (FPC)	22° 37' 28.9''S / 52° 09' 21.1''W	0.721	<i>Eichhornia</i> , <i>Brachiaria</i> , <i>Pontederia</i> , <i>Salvinia</i> and <i>Egeria</i>	525
Parapananema River Bank (PR)	22° 37' 51.6''S / 52° 09' 30.5''W	-	<i>Typha</i> , <i>Eichhornia</i> , <i>Brachiaria</i> , <i>Pontederia</i> , <i>Salvinia</i> and <i>Pistia</i>	-
Lateral lagoon D (FPD)	22° 38' 22.0''S / 52° 09' 29.0''W	0.063	<i>Eichhornia</i> , <i>Brachiaria</i> , <i>Pontederia</i> , <i>Salvinia</i> , <i>Pistia</i> and <i>Nymphaea</i>	60.2

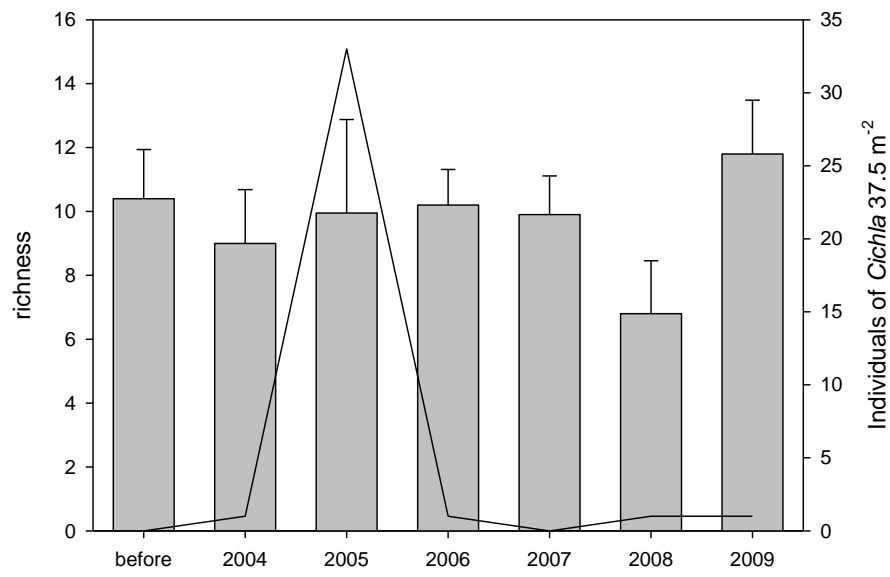
**Table 2.** List of taxa identified in Rosana Reservoir during the study and the mean length (L) of the specimens, before and after the introduction of *Cichla kelberi*.

Taxon		L before	L after
<b>Order Characiformes</b>			
	<b>Family</b>		
<i>Astyanax altiparanae</i> Garutti and Britski, 2000	Characidae	25	25.6
<i>Acestrorhynchus lacustris</i> (Lütken, 1875)	Acestrorhynchidae	-	16
<i>Apareiodon piracicabae</i> (Eigenmann, 1907)	Parodontidae	21	16.7
<i>Aphyocharax anisitsi</i> Eigenmann and Kennedy, 1903	Characidae	18	18.2
<i>Bryconamericus stramineus</i> Eigenmann, 1908	Characidae	23	22.1
<i>Cyphocharax modestus</i> (Fernández-Yépez, 1948)	Curimatidae	20	15.4
<i>Galeocharax knerii</i> (Steindachner, 1875)	Characidae	-	31
<i>Hemigrammus marginatus</i> Ellis, 1911	Characidae	18	17.8
<i>Hoplias malabaricus</i> (Bloch, 1794)	Erythrinidae	74	73
<i>Hyphessobrycon eques</i> (Steindachner, 1882)	Characidae	17	16.5
<i>Leporinus friderici</i> (Bloch, 1794)	Anostomidae	32	32.8
<i>Leporinus octofasciatus</i> Steindachner, 1915	Anostomidae	-	20
<i>Leporinus striatus</i> Kner, 1858	Anostomidae	30	29.5
<i>Metynnis lippincottianus</i> (Cope, 1870)	Characidae	14	14.3
<i>Moenkhausia intermedia</i> Eigenmann, 1908	Characidae	16	16.3
<i>Myleus tiete</i> (Eigenmann and Norris, 1900)	Characidae	-	16
<i>Oligosarcus pintoii</i> Amaral Campos, 1945	Characidae	-	22
<i>Roeboides descavadensis</i> Fowler, 1932	Characidae	28	28.5
<i>Schizodon nasutus</i> Kner, 1858	Anostomidae	28	28.7
<i>Serrapinnus notomelas</i> (Eigenmann, 1915)	Characidae	19	19
<i>Serrasalmus maculatus</i> Kner, 1858	Characidae	16	15.9
<i>Serrasalmus marginatus</i> Valenciennes, 1836	Characidae	-	22
<i>Steindachnerina brevipinna</i> (Eigenmann and Eigenmann, 1889)	Curimatidae	-	30
<b>Order Gymnotiformes</b>			
<i>Eigenmannia trilineata</i> López and Castello, 1966	Sternopygidae	-	47
<i>Eigenmannia virescens</i> (Valenciennes, 1842)	Sternopygidae	-	100
<i>Gymnotus carapo</i> Linnaeus, 1758	Gymnotidae	47	48.6
<i>Rhamphichthys hahni</i> (Meinken, 1937)	Rhamphichthyidae	-	28
<b>Order Siluriformes</b>			
<i>Hypostomus ancistroides</i> (Ihering, 1911)	Loricariidae	19	20.3
<i>Hypostomus</i> sp1	Loricariidae	-	15
<i>Hypostomus</i> sp2	Loricariidae	-	28
<i>Loricariichthys platymetopon</i> Isbrücker and Nijssen, 1979	Loricariidae	-	24
<i>Trachelyopterus galeatus</i> (Linnaeus, 1766)	Auchenipteridae	-	61
<i>Pimelodus maculatus</i> Lacepède, 1803	Pimelodidae	-	28
<i>Rhamdia quelen</i> (Quoy and Gaimard, 1824)	Heptapteridae	-	38
<b>Order Perciformes</b>			
<i>Cichla kelberi</i> Spix and Agassiz, 1831	Cichlidae	-	32
<i>Cichlasoma paranaense</i> Kullander, 1983	Cichlidae	29	27.3
<i>Crenicichla britskii</i> Kullander, 1982	Cichlidae	25	24.6
<i>Crenicichla haroldoi</i> Luengo and Britski, 1974	Cichlidae	-	19
<i>Crenicichla niederleini</i> (Holmberg, 1891)	Cichlidae	-	28
<i>Satanoperca pappaterra</i> (Heckel, 1840)	Cichlidae	17	18.5
<b>Order Synbranchiformes</b>			
<i>Synbranchus marmoratus</i> Bloch, 1795	Synbranchidae	-	130
<b>Order Cyprinodontiformes</b>			
<i>Phalloceros caudimaculatus</i> (Hensel, 1868)	Poeciliidae	-	35
<b>Order Rajiformes</b>			
<i>Potamotrygon motoro</i> (Müller and Henle, 1841)	Potamotrygonidae	*	*

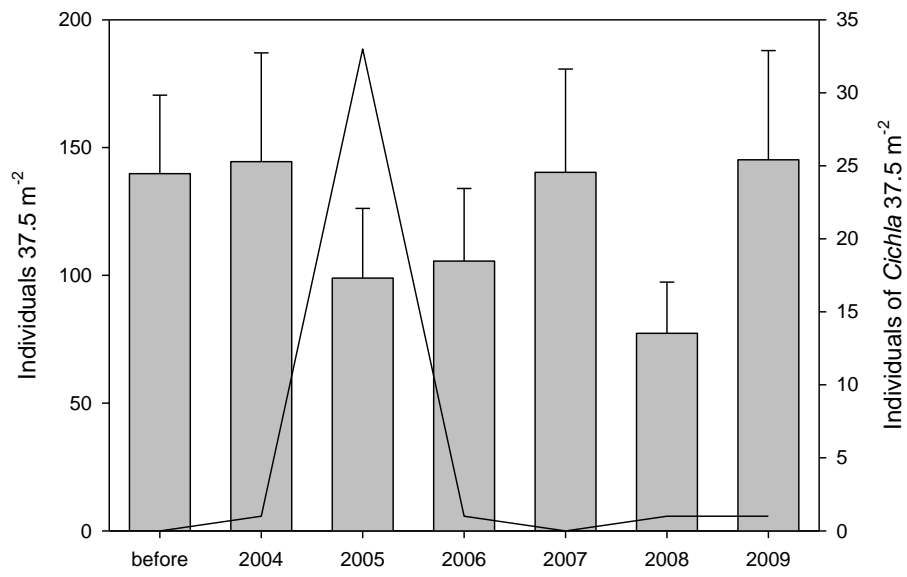
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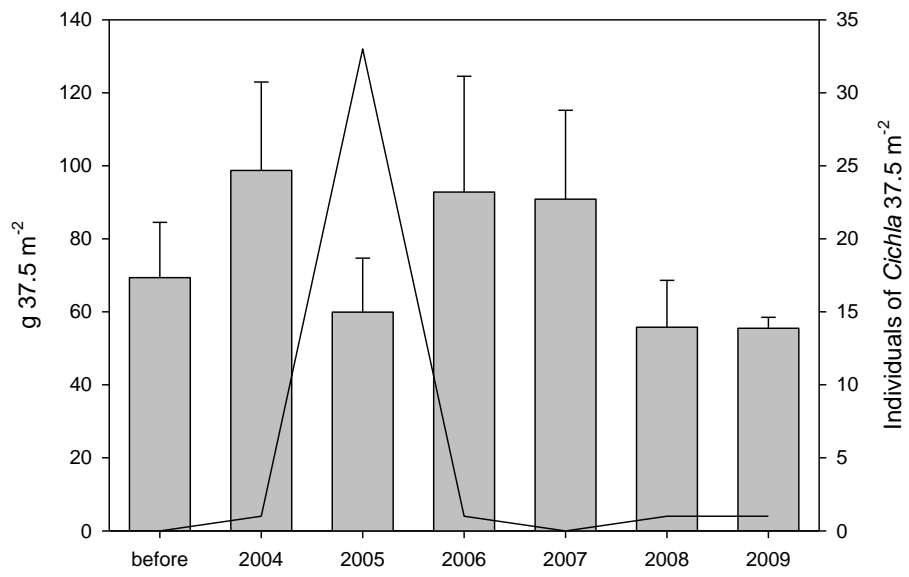
**Figure 1** – Study area in the region of the confluence of Paraná and Paranapanema Rivers (States of São Paulo – SP, Paraná – PR and Mato Grosso do Sul – MS) showing the positioning of Rosana, Taquaruçu and Porto Primavera dams and the State Park of “Morro do Diabo” (gray area) (a.). On the right (detail) the location of the sampling stations and the municipality of Teodoro Sampaio (b.).



**Figure 2** – Mean value (and standard deviation) of species richness at the different sampling stations (gray bars) and density of *Cichla* (continuous line) (37.5 m<sup>2</sup> of net = sampling effort).

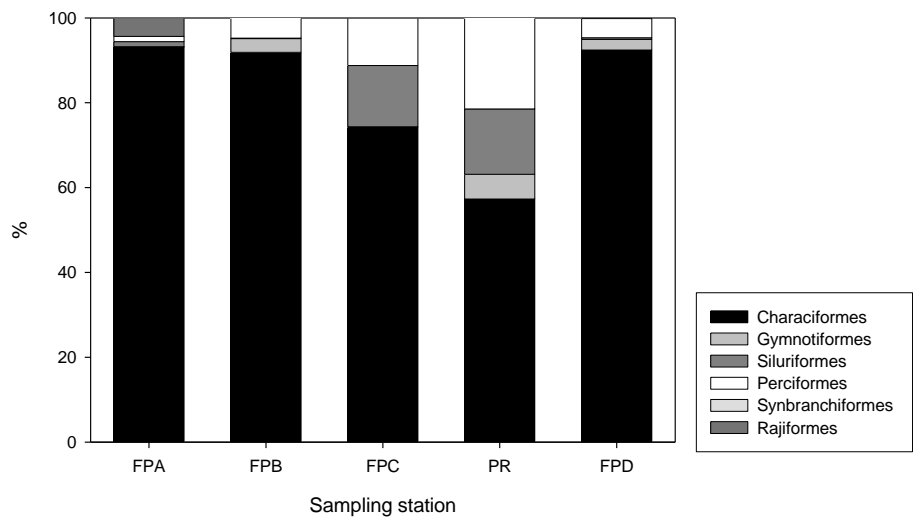


**Figure 3** – Mean value (and standard deviation) of absolute abundance of the ichthyofauna at the different sampling stations (gray bars) and density of *Cichla* (continuous line) (37.5 m<sup>2</sup> of net = sampling effort).

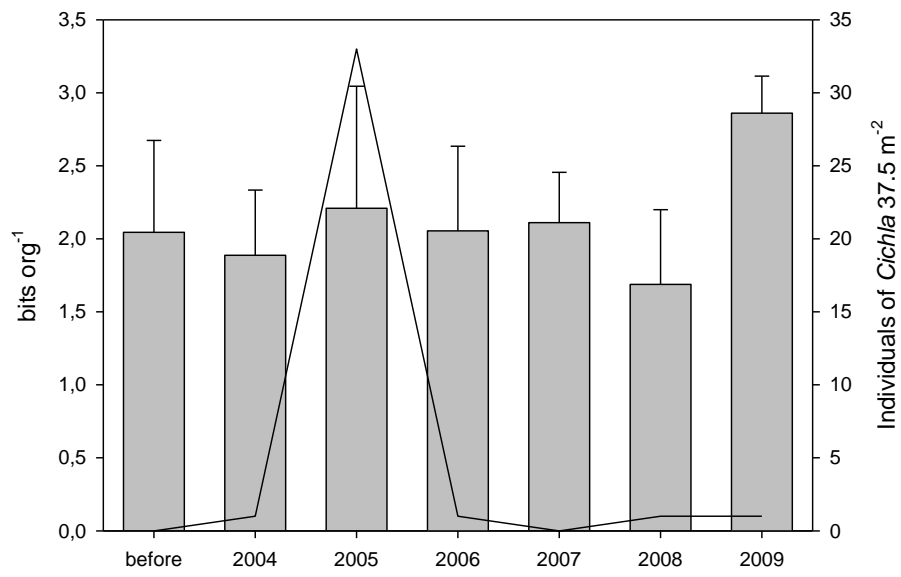


**Figure 4** – Mean value (and standard deviation) of biomass of the ichthyofauna at the different sampling stations (gray bars) and density of *Cichla* (continuous line) (37.5 m<sup>2</sup> of net = sampling effort).





**Figure 5** – Relative abundance of the ichthyofauna at the different sampling stations considering the whole sampling period.



**Figure 6** – Shannon-Winner diversity index (H') of the ichthyofauna at the different sampling stations (gray bars) and density of *Cichla* (continuous line) (37.5 m<sup>2</sup> of net = sampling effort).

## *Capítulo 4*

## **Importance of lateral lagoons for fish feeding in a large tropical reservoir**

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Running title: Fish feeding in lateral lagoons.

## **Abstract**

This study aimed to characterize the feeding ecology of the small fish fauna in a lateral lagoon system of a Neotropical reservoir. Particular emphasis is given on the evaluation of the importance of plankton organisms for the trophic structure of the fish assemblages. The study was carried out in 4 lagoons and at one sampling station in the Paranapanema River. Samplings were performed in September and November of 2004 and January, March, May and August of 2005. Fish were sampled with a net of 7.5m<sup>2</sup>. Five manual throws were performed towards to the aquatic macrophyte stands. The stomach contents of 42 species were analyzed. A total of 183 different items were consumed, which were grouped in 11 food categories. Fish were organized in eight trophic guilds. Insectivorous habits were predominant. DCA analysis showed the feeding pattern of the river fish assemblages was different when compared to the lagoons. In the river the main consumed items were aquatic insects, cladocerans and phytoplankton while in the lagoons the main items were aquatic insects, copepods and cladocerans. Comparing each trophic guild, the species number of insectivorous, algivorous and zooplanktivorous were higher in the lagoons than in the river and only omnivorous exhibited more species in the river compared to the lagoons. In all sites, fish assemblages showed low values of niche amplitude, indicating that species have high trophic specialization. Low values of the niche overlap between pairs of species were observed, indicating that competition for food resources is not too intense. The results showed there was a proportionally higher consume of zooplankton by the smaller fish. Twenty-six percent of the species, 11, used the plankton (algae/microscutaceans) as the main food resource. The data also indicated that fish have a positive selection for Cladocera, but also ingested Copepod as complement in their diet. The results indicate that the lateral lagoons have an important role in the food resources offer for Rosana Reservoir fish. It was also demonstrated that consume of plankton organisms is significant for the smaller species.

*Keywords:* Paranapanema River, niche amplitude, overlap, trophic guilds and selectivity.

## **Importância das lagoas laterais para alimentação dos peixes em um reservatório tropical de grande porte**

### **Resumo**

O objetivo deste estudo foi caracterizar a ecologia da alimentação da ictiofauna de pequeno porte em lagoas laterais de um reservatório neotropical, bem como avaliar a importância dos organismos planctônicos para a estrutura trófica das assembleias de peixes. O estudo foi realizado em quatro lagoas e no canal principal do rio Paranapanema. As amostras foram coletadas em Setembro e Novembro de 2004 e janeiro, Março, Maio e agosto de 2005. Os peixes foram amostrados com uma rede de 7,5m<sup>2</sup>. Cinco arrastos manuais foram realizados junto aos bancos de macrófitas aquáticas. Os conteúdos estomacais de 42 espécies foram analisados. As espécies consumiram 183 diferentes itens, os quais foram agrupados em 11 categorias de alimentação. Oito guildas tróficas foram estabelecidas, de acordo com o recurso alimentar preferencial. Os peixes insetívoros foram predominantes. A DCA mostrou que a alimentação das assembleias de peixes do rio foi diferente das lagoas. No rio, os principais itens foram insetos aquáticos, cladóceros e fitoplâncton, enquanto que nas lagoas os principais itens foram insetos aquáticos, copépodes e cladóceros. Comparando-se cada guilda trófica, o número de espécies de insetívoros, algívoros e zooplânctívoros foi maior nas lagoas do que no rio e somente onívoros apresentaram mais espécies no rio do que nas lagoas. Em todos os pontos foram evidenciados baixos valores de amplitude de nicho, indicando que as espécies apresentam alta especialização trófica. Baixa sobreposição de nicho trófico entre os pares de espécies também foi evidenciada, indicando que a competição pelos recursos não é tão intensa. Os resultados mostraram que há um consumo relativamente maior de zooplâncton pelos peixes de menor porte. Vinte e seis por cento das espécies, 11, utilizaram o plâncton (algas/microcrustáceos) como o principal recurso alimentar. Os dados também indicaram que os peixes se alimentam seletivamente de Cladocera, embora também consumam Copepoda como complemento da sua dieta. Os resultados indicam que as lagoas laterais têm um importante papel na oferta de alimento para os peixes do reservatório e também que os organismos planctônicos são fundamentais na dieta da ictiofauna de pequeno porte.

*Palavras-chave:* Rio Paranapanema, amplitude de nicho, sobreposição, guildas tróficas e seletividade.

## 1. Introduction

The construction of reservoirs for energetic supply in river system is a major human interference that increased for decades in several countries. The river interruption by dams is responsible for several alterations in the river physicochemical and water flow (Júlio *et al.*, 1997; Nogueira *et al.*, 2006; Soares, *et al.*, 2008) as well as in the river and adjacent habitats and in the food resource availability (Hahn and Fugi, 2007). Thus, the reservoirs can endanger the local ichthyofauna, once they transform a lotic and diversified system in a simplified lentic environment (Agostinho and Zalewski, 1995).

Studies on feeding of reservoir ichthyofauna are extremely important for the understanding of the possible changes in the different trophic levels and in the behavior of each species. The feeding spectrum reflects the role of each fish species in the ecosystem (Hahn *et al.*, 2000). Therefore, the available food resources can be a relevant factor for the organism to be succeeded during the process of formation of the new environment (Rodríguez-Ruiz, 1998).

The lateral lagoons and other floodplain habitats are of major importance for the ichthyofauna life cycle, mainly for the smaller species (Agostinho and Zalewski, 1995; Ferrareze and Nogueira, 2011). For this reason, studies about fish feeding ecology in these sites are relevant.

The knowledge about the trophic interactions can provide a better understanding of the interactions among the ichthyofauna component, as well as with other aquatic communities or even with semi-terrestrial and terrestrial organisms (Hahn *et al.*, 1997a; Uieda and Motta, 2007). The fish feeding data can also provide information about habitat integrity, food availability, behavior features and ecological role of each species (Windell and Bowen, 1978; Hahn *et al.*, 1997a).

Most feeding fish studies in the Neotropical region include stomach content analyses and focus mainly on large size fish species. Although, these analyses have produced valuable information, other approaches, such as feeding of small fish, are necessary for a comprehensive understanding of the ichthyofauna ecology (Zavala-Camin, 1996).



Studies on resource partitioning among fish are also important to elucidate the mechanisms that permit a high number of organisms to coexist in the same assemblage (Schoener, 1974; Gerking, 1994). Resource partitioning can be defined as any difference in the use of resources by coexistent species. Some factors, such as competition, can influence the spatial and temporal segregation among species (Ross, 1986). A common approach employed to study resource partitioning in ichthyofauna assemblages is the diet overlap or the niche overlap analysis (Winemiller and Pianka, 1990; Uieda *et al.*, 1997; Merona and Rankinde- Merona, 2004; Esteves *et al.*, 2008). Most studies on freshwater ichthyofauna have showed the predominance of insectivore and a tendency of a reduction on feeding overlap associated to spatial and seasonal variability and trophic level differences (Uieda and Motta, 2007), but few investigations consider changes in the food habit in relation to the food availability (Deus and Petrere-Jr, 2003).

The importance of plankton as a food resource for fish in the neotropics is other interesting question. Studies on food ecology of freshwater neotropical ichthyofauna, differently from temperate regions (Carpenter and Kitchell, 1993), point to the possibility that plankton organisms may not to contribute significantly in the transference of energy and matter along the fish assemblages food webs (Piana *et al.*, 2005). However, the potential role of the plankton community for the small fish is still controversial (Zavala-Camin, 1996) and new information can change previous considerations (Russo and Hahn, 2006).

For the development of the present study two hypotheses were formulated. The first is that the lateral lagoons have a prominent ecological role for the fish feeding. The second is that the plankton is an important food resource for small size fish assemblages. Thus, this research aimed to test the proposed hypotheses through the analysis of the diet of the ichthyofauna sampled in the lateral lagoons system of Rosana Reservoir (Parapanema River, SE, Brazil).

## **2. Material and Methods**

### 2.1. Study area

The study area corresponds to the upstream (tail) zone of Rosana Reservoir, approximately 80 km above dam (Figure 1), which is located at 22° 36'S and 52° 52'W. The reservoir is the last one, from a series of eleven along the Paranapanema River (SP/PR, Brazil), with a surface area of 276 km<sup>2</sup> (watershed of 11,000 km<sup>2</sup>), water retention time of 21 days (annual mean values), shallow (maximum of 26 m close to the dam) and oligo-mesotrophic (Nogueira *et al.*, 2006).

The climate is subtropical humid (average temperature of 21°C). During the study period the rainy season ranged from September/2004 to January/2005 (average of 157 mm), while the dry period ranged from February to August of 2005 (average of 70.7 mm). The annual accumulated precipitation in the study period was 1,207 mm. The rain precipitation data was provided by the meteorological station of the State Park of “Morro do Diabo”, municipality of Teodoro Sampaio (State of São Paulo).

### 2.2. Samplings and laboratory analyses

The study was carried out in 4 lagoons and one sampling station in Paranapanema River (PR), close to the river bank (Figure 1; Table 1). Samplings were carried out in September and November of 2004 and January, March, May and August of 2005.

Two kinds of lagoons were assessed: 3 natural lagoons and one originated by the flood of mining digging (FPA). The natural lagoons (FPB and FPD) are located inside the State Park of Morro do Diabo while the last one (FPC) is located in an area influenced by human activities (agriculture and cattle breeding). The dominant macrophytes of each lagoon, in terms of stand area, were registered (Table 1). Identification of these plants was performed at the genus level, with help of taxonomists of Botany Department from Biosciences Institute of UNESP/Botucatu.

The sampling stations positioning, the area of each lagoon (integration of geometric distances), as well as their connectivity (transversal section of the lagoon mouth) with the river-reservoir main channel, were determined using a Garmin E-Trex GPS.

Fish were sampled with a net of 7.5m<sup>2</sup> (1.5x5m; 0.3 cm of mesh size). In each point/period five manual throws were performed towards to the aquatic macrophyte stands. This sampling system was chosen for its effectiveness to capture small fishes. The organisms were immediately fixed in 10% formalin.

In the laboratory the organisms were transferred to ethanol 70% for permanent storage. Voucher specimens are deposited in the Freshwater Fish Collection of the Department of Zoology (FFCZ 2005-21), State University of São Paulo, Campus of Botucatu.

The biometry of all collected organisms was obtained through measurements of weigh (biomass in g; Mettler Toledo PB 3002 scale, 0.01g accuracy) and length (paquimeter, 0.1 mm) – standard (except for Gymnotiformes and Synbranchiformes) and total.

For taxonomical identification of the fish species it was used specialized literature (Britsk, 1972; Britsk *et al.*, 1986; Britsk *et al.*, 1999; Reis *et al.*, 2003; Nelson, 2006; Graça and Pavanelli, 2007) and consults to the scientific collections of the State University of São Paulo (Campus S. J. R. Preto) and University of São Paulo Museum (MZUSP).

### 3.3. Diet analysis

The fish diet was determined through stomach content analysis. Food items identification was performed under a stereoscopic microscope and microscope, trying to reach the most detailed taxonomic level. The frequency of occurrence (F) and biovolume (B) methods were used. The frequency of occurrence (Hyslop, 1980) was calculated considering the number of fish having a given item in relation to the total number of occurrence of the item. The biovolume (adapted from Esteves and Galetti Jr., 1995) was calculated considering the occupied area of a specific item in relation to the total area occupied by all items. The occupied area was determined using a milimetric dish where was disposed the stomach contents. The feeding habit was determined by the Alimentary Index (AI), using the formula  $AI = (F \times B) / \sum (F \times B)$  (Kawakami and Vazzoler, 1980).

The trophic group of each species was determined by the identification of the most representative feeding categories in each seasonal period, in terms of frequency and dominance (Bennemann *et al.*, 2006) and by Cluster (Statistica software; Statisoft, 2001).

The food items were grouped in 11 categories: Aquatic Insects = insect debris, Coleoptera, Plecoptera, Diptera (Chironomidae, Tanyptodinae, Ceratopogonidae, Tipulidae, Culixidae and Chaoboridae), Ephemeroptera (Caenidae and Polymitarciidae), Trichoptera (Polycentropodidae and Leptoceridae), Heteroptera (Belostomatidae), Odonata (Libellulidae, Gomphidae and Coenagrionidae), Baetidae and Hemiptera (Notonectidae); Terrestrial Insects = remains, Diptera, Hymenoptera, Coleoptera, Hemiptera, Trichoptera, Lepidoptera, Orthoptera, Thysanoptera, Homoptera and Blattodea; Crustaceans = *Macrobrachium amazonicus*, *M. acanthurus* and Branchiura (Argulidae); Fish = entire, scales, muscles and bones; Macroinvertebrates = Mollusca, Araneae, Pseudoscorpian, Acarina, Hirudinea, Phlatyolmintus, Nematoda and invertebrate eggs; Microcrustaceans = Cladocera, Copepoda, Rotifera, Ostracoda and Conchostraca; Algae = different Classes of phytoplankton; Vegetal Matter = stalks, leaves, roots, seeds in different digestion stages; Detritus/sediment = all kinds of bottom material, organic film, mud and sand, Scales = without fish remains and Birds = feather.

In order to identify spatial tendencies interfering in feeding consumption, a Detrended Correspondence Analysis (DCA, Hill and Gauch 1980) was performed with the data of feeding items biovolume (%), considering the species in each station (PCORD software; MacCune and Mefford 1997). The scores were submitted to parametric test (ANOVA), after check of normality presupposes (Statistic software; Statisoft, 2001).

The relative level of diet specialization of the species (niche amplitude) was calculated by the Levin's index (Hurlbert, 1978):  $B_i = [(\sum P_{ij}^2)^{-1} - 1] \cdot (n - 1)^{-1}$ ; where:  $B_i$  is the niche amplitude standardized index,  $P_{ij}$  is the proportion of the food item  $j$  in the diet of  $i$  species and  $n$  is the number of food items. The  $B_i$  value ranges from 0 (species consumed mainly one food resource) to 1

(species consumed all food resources in similar proportions). The values of niche amplitude were arbitrarily considered high ( $> 0.6$ ), intermediate ( $0.4 - 0.6$ ) or low ( $< 0.4$ ) (Novakowski *et al.*, 2008). The diet overlap between species was calculated with the relative weight of food items, using the Pianka Index (1973):  $\theta_{jk} = \sum P_{ij} \cdot P_{ik} / [\sum (P_{ij}^2) \cdot \sum (P_{ik}^2)]^{-2}$ ; where:  $\theta_{jk}$  = Pianka's measure of diet overlap index between j and k species;  $P_{ij}$  = proportion resource  $i$  of the total resources used by species  $j$ ;  $P_{ik}$  = proportion resource  $i$  of the total resources used by species  $k$ ;  $n$  = total number of resource states. This index varies from 0 (no overlap) to 1 (total overlap). The overlap values were arbitrarily considered as high ( $> 0.6$ ), intermediate ( $0.4 - 0.6$ ) or low ( $< 0.4$ ) (Novakowski *et al.*, 2008).

A null model was used to evaluate the significance of the food overlap between species (Gotelli and Entsminger, 2007). The matrix was randomized 10,000 times, using the following options: niche amplitude retained and zeroes reshuffled (RA3, Winemiller and Pianka, 1990). The mean overlap observed is compared to the mean overlap calculated in the null distribution ( $p < 0.05$ ). The feeding overlap and null model analysis were computed using EcoSim 7.0 (Gotelli and Entsminger, 2007).

Zooplankton consumption was analyzed also through the numeric method (N), in which the percentage of each consumed group was calculated in relation to the total number of individuals of all zooplankton groups in the stomach content of the fish species (Hyslop, 1980). This value was associated with the frequency and biovolume values to estimate the Relative Index of Importance (RII), which defines the predominant consumed group ( $RII > 15\%$ ), using the formula (Pinkas *et al.*, 1971):  $RII = (N + B) \cdot F$ .

For comparisons between species, areas and seasons, the AI and RII values were transformed in relative values (%). For determination of feeding preference (Zavala-Camin, 1996), for each zooplankton group, it was used the electivity index formula (Ivlev, 1961):  $E = (r_i - P_i) / (r_i + P_i)$ , where  $E$  = electivity index;  $r_i$  = percentage of each item in the stomach content (RII%);  $P_i$  = percentage of each item in the environment (relative abundance). The electivity index ranges from -1 to +1, being considered positive selectivity when  $> 0$ , absence of selectivity when equal to zero,

negative selectivity when  $< 0$  (Zavala-Camin, 1996). In this study, high selectivity was considered for values equal or higher than 0.6.

To determine the percentage of zooplankton consumption in relation to the fish size it was used an exponential regression by the Statistic software (Statisoft, 2002). Two matrices were confectioned for this analysis: the first with the individual percentage of zooplankton consumption by species and the second with the individual length of each species.

Finally, a one-way ANOVA test was performed to detect differences among sampling sites, after check of normality presupposes (Statistic software; Statisoft, 2001). When differences were detected, the Tukey test was applied to determine the level of significance (Underwood, 1997). Differences between the periods were tested by the test t-student, using the mean of the variables for each season (dry and rainy). Significant different values were considered when  $p < 0.05$  (Underwood, 1997), which were mentioned in the results. The analyses were performed using Statistica™ 6.0 software (Statsoft, 2001).

Additional information on the small size fish assemblage distribution and ecological attributes and limnological characteristic of the study environment is provided by Ferrareze and Nogueira (2011) and Ferrareze and Nogueira (*in press*), respectively.

### **3. Results**

A total of 3,156 stomach contents from 42 species were analyzed (Table 2). A total of 183 items were consumed. The most consumed food resources were the aquatic insects (mainly Chironomidae, Trichoptera and Ephemeroptera; 32 fish species; 74% of the total species); followed by phytoplankton (30 species) and microcrustaceans (28 species), macroinvertebrates (24 species) and, vegetal matter (21 species).

The diet composition of the community (all species grouped) indicated that the most frequent and dominant food category in the diet was the aquatic insects, with AI = 38.4%, followed by

microcrustaceans (AI = 25.8%), phytoplankton (11.6%) and detritus/sediment (8.8%). The other food resources represented less than 15.4% of the diet.

The feeding from the river fish assemblage was different from the lagoon. In the river the main items were aquatic insects, cladocerans and phytoplankton while in the lagoons the main consumed items was aquatic insects, copepods and cladocerans. In the river, there was a higher proportion of aquatic insects and fish in the stomachs. In the lagoons there were higher consumption of microcrustaceans and macroinvertebrates and the exclusive consume of crustacean and feather of bird. Seasonally, there were no differences among the proportion of consumed items by fish ( $p=0.981$ ).

Eight trophic guilds were identified in the cluster (Figure 2) and the DCA analyses (Figure 3). Insectivorous was the predominant category. This group feed preferentially on aquatic insects, using different items to complement their diet, such as fish, macroinvertebrates, microcrustaceans, algae and detritus. Zooplanktivorous was the second most important category. This group feed mainly on microcrustaceans and some species complemented their diet with aquatic insects, algae and vegetal matter. Detritivorous was the third. This group feed exclusively on detritus and some species complemented their diet with algae and vegetal matter. The other categories were the algivorous, which feed preferentially on algae and some species complemented their diet with detritus and vegetal matter; omnivorous, which feed mainly on vegetal fragments, aquatic insects, microcrustaceans and detritus, in similar proportions; piscivorous, which feed preferentially on fish; carcinophagous, which feed on shrimps; and invertivorous, which feed preferentially on macroinvertebrate.

The trophic guilds, insectivorous, zooplanktivorous, omnivorous, algivorous and detritivorous occurred in all sampling stations. Six trophic guilds were observed in the river and eight (all categories) were observed in the lagoons. Seasonally, there was no carcinophagous during the dry period, due to the fact that the *Galeocharax knerii* (Steindachner, 1875) did not occurred in this season. In general, there were difference in the number of species belonging to each trophic guild

when compared the sampling stations ( $p=0.039$ ). Comparing each trophic guilds, the number of species of insectivorous, algivorous and zooplanktivorous were higher in the lagoons than in the river ( $p=0.0489$ ) and only omnivorous had more species in the river than in the lagoons ( $p=0.044$ ).

The ordination of species on the basis of the feeding resource through the detrended correspondence analysis (DCA) (Figure 3), showed a segregation among carcinofagous ( $r=-0.69$ ), detritivorous ( $r=-0.77$ ), algivorous ( $r=-0.59$ ), insectivorous ( $r=0.66$ ) and piscivorous ( $r=0.81$ ) in the axis 1 ( $r=0.6$ ). In the axis 2 ( $r=0.33$ ), a segregation is shown among zooplanktivorous ( $r=-0.7$ ) and algivorous ( $r=0.5$ ). This analysis also evidenced a segregation among the sampling stations, with the river associated to the positive side of Axis 1 ( $r=0.49$ ). The lagoons FPA ( $r=-0.43$ ), FPB ( $r=-0.41$ ), FPC ( $r=-0.42$ ) and FPD ( $r=-0.41$ ) were associated to the negative side of the same axis.

Only six species showed high values of niche amplitude ( $>0,6$ ): *Rhamphichthys hahni* (Meinken, 1937), *Crenicichla haroldoi* Luengo & Britski, 1974, *Pimelodus maculatus* Lacepède. 1803, *Phalloceros caudimaculatus* (Hensel, 1868), *C. niederleinii* (Holmberg, 1891) and *Metynniss lippincottianus* (Cope, 1870); eleven species showed moderate values of niche amplitude and 25 showed low values of niche amplitude (Table 1). The high number of species that showed low values of niche amplitude indicated that species has a specialized diet, consuming preferentially a restrict number of food items.

The trophic niche amplitude values were higher in the lagoons, mainly at the one located inside the preservation area, compared to the Paranapanema River ( $p=0.002$ ). Exception occurred in FPC, where the lower values of niche amplitude were observed ( $p=0.01$ ). Seasonally, the niche amplitude was lower in the dry season ( $p=0.03$ ), indicating that the species were more generalist in the rainy period.

The feeding overlap were higher than the expected through the model calculation ( $p < 0.00001$ ), indicating that the values are not random (Table 3). The values of diet overlap were low (mean = 0.22) for 68% of species pairs (Figure 4). Species that presented intermediate or high diet overlap were mainly the ones grouped in the same trophic guild. Among insectivorous fish, the



intermediate/high values of diet overlap occurred in 42% of species pairs. Among the zooplanktivorous fish, the intermediate values were observed in 55% of species pairs. For all species pairs of algivorous, detritivorous, piscivorous intermediate or high values of overlap were verified. Other eleven values of intermediate or high overlap occurred among fish from different guilds, but that share some resources, such as detritus, vegetal matter and macroinvertebrates.

Among the sampling stations, there were no significant differences among the values of feeding overlap. However, it is important to notice that in FPC there was a high frequency of low feeding overlap ( $p=0.04$ ) and in FPD there was a elevated proportion of high feeding overlap ( $p=0.042$ ). Seasonally, there were no difference among the feeding overlap ( $p=0.637$ ).

Finally, there was higher consume of zooplankton by fish when these organisms were smaller ( $r=0.64$ ,  $F=4.04$ ,  $p=0.0456$ ). Five of 28 fish species that consumed zooplankton showed high positive electivity ( $>0.6$ ). These species were *Hemigrammus marginatus* Ellis, 1911, *Satanoperca pappaterra* (Heckel, 1840), *Bryconamericus stramineus* Eigenmann, 1908, *Hyphessobrycon eques* (Steindachner, 1882) and *Moenkhausia intermedia* Eigenmann, 1908. Cladocera was the only group that showed high and positive values of electivity. *Daphnia gessneri* Herbst, 1967 and *Ceriodaphnia silvestrii* Daday, 1902 were the unique species which were highly selected by fish. Conversely, there was a high proportion of negative electivity for copepods in the zooplankton food consumption, although the ingestion of this group by fish was important, mainly in the lagoons. The dominant Copepoda species in the environment, *Notodiaptomus iheringi* Wright, 1935 and *Thermocyclops decipiens* (Kiefer, 1929), were not ingested by fish. These results indicated that the fish select positively to feed on Cladocera species at the same time as they consume Copepoda as complement in their diet.

Among the sampling stations, the selectivity for cladocerans was higher in the Paranapanema River ( $p=0.048$ ), while there were higher frequency of negative selectivity in the lagoons. Among the copepods, there were higher frequency of negative selectivity in the rivers than in the lagoons

( $p=0.02$ ). Seasonally, there were higher values of selectivity of zooplankton during the rainy period than the dry season ( $p=0.01$ ) (Figure 5).

#### **4. Discussion**

River lateral lagoons and other kinds of floodplain habitats are supposed to have an important role for fish ecology, including feeding processes (Hahn *et al.*, 1997b; Meschiatti and Arcifa, 2002). In the present study the detrended correspondence analysis (DCA) showed a clear segregation among the river/reservoir sampling station and the lagoons. In the lagoons a higher number of trophic guilds were represented, as well as higher values of niche amplitude, lower values of niche overlap, despite a higher number of fish living in these environments (Ferrareze and Nogueira, 2011). Differences in the main food resources that were consumed were also evident, when compared the river/reservoir and lagoons. The main food items in the river were aquatic insect, copepods and phytoplankton, while the main food items in the lagoons were aquatic insect, copepods and cladocerans. There was also more consume of fish by the river ichthyofauna and more consume of microcrustaceans and macroinvertebrates in the lagoons. The other distinctiveness was the high number of omnivorous species in the river while the insectivorous and planktivorous were more frequent in the lagoons.

The DCA and cluster analysis also showed that the plankton have a significant role in the feeding of the small fish. Eleven species (26% of the total) used the plankton as the main food resource (four algivorous and seven zooplanktivorous). Considering all the sampling stations, the phytoplankton and the zooplankton were widely consumed by the fish assemblages. Only the aquatic insects were more consumed than the plankton by fish. Zooplankton was the second group in terms of dominance and frequency in the fish diet and phytoplankton was the third. Different from other study (mostly based on large size fish) on diet of the freshwater neotropical ichthyofauna (Piana *et al.*, 2005), our results indicate that the plankton organisms contributed significantly in the transference of energy

and matter responsible for the formation and maintenance of the biomass of small size fish, which corroborates patterns observed in temperate regions (Carpenter and Kitchell, 1993).

The high consumption of plankton in this study reflects the sampling environment. The lateral lagoons are important habitats for the development of plankton (Straškraba and Tundisi, 2000; Panarelli *et al.*, 2008) and these environments has also propitious limnological conditions for the plankton capture by fish, such as high water transparency, low turbidity and low water flux (Ferrareze *et al.*, *in press*). Nevertheless, the river also exhibits good conditions for ingestion of plankton, due to the influence of the Taquaruçu Reservoir, just upstream located, which export high amount of plankton organisms to the lotic stretch of Rosana Reservoir (Nogueira *et al.*, 2008; Naliato *et al.*, 2009; Nogueira *et al.*, 2010)

In Rosana Reservoir, 13 species used aquatic (mainly larvae of Chironomidae, Trichoptera and Ephemeroptera) and terrestrial insects as their main food resource, and almost all the other species also complemented their diet with these food resources, demonstrating that aquatic insects are the main food resource in this reservoir. Despite the fact that aquatic insects are an important food resource for fishes in floodplains (Hahn *et al.*, 1997b) and in recently impounded rivers (Luz-Agostinho *et al.*, 2006), insectivorous fish are not the dominant trophic guild in most Brazilian reservoirs (Agostinho *et al.*, 2007).

In the present study, the fish captures occurred in the littoral zones, which can explain the high consumption of aquatic insects by many species. The littoral zones exhibit high spatial heterogeneity due to the presence of macrophytes and woody debris that allow the colonization of a diversified fauna (generally associated to the periphyton), such as crustaceans and aquatic insects (Oliveira *et al.*, 2005). They are abundant food resources for species of diverse trophic guilds (Hahn *et al.*, 1997b), sustaining a high fish diversity (Gido *et al.*, 2002).

The number of omnivorous fish was relatively low, comparing to the fact that this group is considered to be dominant in several Brazilian reservoirs (Agostinho *et al.*, 2007). The proportion of the omnivorous species may be related to the environmental degree of perturbation (Merona *et al.*,

2003). This group is better succeeded in environments with great influence of seasonality (Resende, 2000), due to their capacity to reduce the time for feeding and in their optimization to obtain energy and matter from the food (Schoener, 1971).

The high abundance of individuals that feed on detritus observed in this study seems to be a recurrent pattern for the reservoirs fluvial stretches, as the fish feed on the detritus and mud deposited in non consolidate bottoms (Hahn *et al.*, 1998). The consumption of detritus by tropical fish is considered a fundamental feeding strategy, because this, enhance the energetic efficiency and the assemblage productivity (Araujo-Lima *et al.*, 1995; Lowe-McConnell, 1999; Alvim and Peret, 2004).

The low number of piscivorous in the assemblages reflects the focus of this study on the small size fish fauna. Most captured organisms were small and do not have the habit of feeding on fish (Casatti *et al.*, 2003; Pelicice *et al.*, 2005). Even for the large size species, predominated in the sample young individuals which have morphological limitations for consumption of other fish (Zuniga and Escobar, 1994; Mehner and Thiel, 1999; Rettig, 2003), such as *C. kelberi* and the *S. maculatus*.

In spite of the high number of food items explored by the species, most of them showed preferential consumption, evidenced by the low values of the niche amplitude in all sampling stations. This fact indicates that the fish assemblages are composed by specialist species, in terms of feeding processes. The high dominance by a relatively few kinds of resources suggest a correlation with their abundance in the environment (Novakowski *et al.*, 2008), and is not related to morphological limitations for the consumption of particular resources (Gerking, 1994; Resende, 2000). Fish tended to be more generalists in the rainy period, in agreement with other studies in the neotropics that reported a more generalist diet in the rainy season, when most resources are more abundant (Prejs and Prejs, 1987; Deus and Petrere Jr., 2003). In the lagoons fish showed higher values of niche amplitude and higher representativeness of trophic guilds, reflecting the alimentary plasticity of this fauna that can use different food resources, according to their availability (Esteves and Aranha, 1999; Hahn *et al.*, 2004). An important result that reinforces this explanation is that several species

were classified in more than one trophic category, reflecting the trophic plasticity of the reservoir ichthyofauna.

In one side, higher diversity and abundance of resources may favor the opportunistic use, resulting in a more generalist food spectrum; but, on the other side, specialization can be selected due to the high nutritional value of certain items (Hahn *et al.*, 1997a).

Low diet overlap values were observed for almost all pairs of species, indicating differences in the diet composition. These results, combined with observe the low niche amplitude for most species, suggest a high degree of food partitioning among, in agreement with other studies on Neotropical fish communities (Ross, 1986; Uieda *et al.*, 1997; Esteves *et al.*, 2008; Novakowski *et al.*, 2008; Mérona and Rankin-de-Mérona, 2004).

However, when overlap was analyzed independently within each trophic guild, some different patterns were observed. In some guilds, the species showed high trophic niche overlap, such as for insectivorous, algivorous and zooplanktivorous. In this case, others factors can favor their coexistence, such as habitat spatial heterogeneity and complexity, combined with temporal, population and behavioral variability (May, 1986; Schoener, 1974). The species can be segregated by differential feeding or exhibit differences in the strategies of foraging, as observed in a stream by Uieda *et al.* (1997) and in macrophytes stands by Casatti *et al.* (2003) and Pelicice *et al.* (2006). This hypothesis can explain the fact that in Rosana fish assemblages, the species from different trophic guilds can explore varied microhabitats, such as macrophytes stands (insectivorous and algivorous), bottom sediments (invertivorous and detritivorous) and the water column (piscivoros, zooplanktivorous and algivorous), resulting in low values of niche overlap (Winemiller, 1989; Gerking, 1994; Mathews, 1998).

Similar pattern of low values of niche overlap is also observed in other ichthyofauna assemblages, with low seasonal variation of feeding (Gomes and Verani, 2003; Novakowski *et al.*, 2008) and under influence of environmental gradients (Esteves *et al.*, 2008).

For all sampled environment, the null models indicated that the observed niche overlap was higher than the simulated, indicating that the observed patterns were not created randomly and they reflected biological processes. The variance data also was higher than the simulated, showing that the species were structured in trophic guilds. It occurred because the pairs of species that belong to the same guild showed overlap values higher than the species pairs that belong to different guilds, generating high variances (Winemiller and Pianka, 1990). The trophic niche overlap is high between related guilds, moderate between guilds which share some resources, and is zero when the species that belong to different guilds, do not share any resource (Inger and Colwell, 1977).

The results also showed that smaller is the fish, more they feed on zooplankton, corroborating other studies (Mehner and Thiel, 1999; Rettig, 2003). When the fish grow, they change their feeding behavior, and feed on their specific food items (Lima-Junior and Goitein, 2003). This can be explaining due to changes caused by morphologic limitations (“gape-limitation”), efficiency for prey capture and strategies of foraging (Zagarese, 1991; Mehner and Thiel, 1999; Rettig, 2003). These results are important because they reinforce the significant role of zooplankton in the feeding of small fish.

In relation to the ingestion of zooplankton by fish, the results showed there is selectivity, mainly on cladocerans. In this reservoir, Cladocera were less dominant and frequent in the zooplankton assemblages (Ferrareze and Nogueira, *in preparation*), but they were positively selected by fish. This occur probably because the main cladoceran species, *D. gessneri* and *C. silvestrii*, have large size body, reduced velocity of swimming, as well as high nutritional value (Zagarese, 1991). Other factors that may explain the high selectivity for Cladocera is their size, visibility, facility to catch, movement, nutritional quality and digestibility (O'brien, 1987).

The results also showed that fish had low selectivity for Copepoda and they consume this group as dietary complement. A behavior characteristic of copepods that influences the low selectivity by fish is the ability of avoid predation through by effective swimming, diurnal migration and perception of

predator (Nassal *et al.*, 1998). Despite the low selectivity by fish, copepods may construct a high proportion in their diet, even when the selectivity is absent or negative (Lair *et al.*, 1996).

The fact that many fish species have consumed a high quantity of zooplankton, though with restrict selectivity, reinforces the idea of the species are more opportunistic, consuming this resource because it is abundant. When resource availability is high the species may use it opportunistically, characterizing as generalist consumers (Wener and Hall, 1974; Khadka and RamakrishnaRao, 1986; Deus and Petrere Jr., 2003). Our results showed that there was higher selectivity when the abundance of zooplankton was higher in the environment (Ferrareze and Nogueira *in preparation*).

To summarize, the fish assemblage showed low values of niche amplitude, demonstrating that the species have a relatively high trophic specialization, and the low niche overlap between the species pair suggested that the species do not compete by the same resources. However, the differences among the sampling stations were evidenced by the consumption of distinct main food resources and also in the differential trophic organization between river/reservoir and lagoons, confirming that the lateral compartments are an important factor for the fish assemblage maintenance of Rosana Reservoir.

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**Table 1.** Denomination of the sampling stations, geographical positioning, lagoons surface area, main aquatic macrophytes and estimated area of connectivity of lagoons with the river/reservoir main channel.

Sampling station	Geographical coordinates	Area (km <sup>2</sup> )	Dominant macrophytes	Connectivity (m <sup>2</sup> )
Lateral lagoon A (FPA)	22° 34' 03.3''S / 52° 09' 11.4''W	0.110	<i>Typha</i> , <i>Eichhornia</i> , <i>Brachiaria</i> , <i>Pontederia</i> and <i>Salvinia</i>	50
Lateral lagoon B (FPB)	22° 36' 56.5''S / 52° 09' 47.3''W	0.024	<i>Eichhornia</i> , <i>Brachiaria</i> , <i>Pontederia</i> , <i>Salvinia</i> , <i>Pistia</i> , <i>Egeria</i> and <i>Nymphaea</i>	6.5
Lateral lagoon C (FPC)	22° 37' 28.9''S / 52° 09' 21.1''W	0.721	<i>Eichhornia</i> , <i>Brachiaria</i> , <i>Pontederia</i> , <i>Salvinia</i> and <i>Egeria</i>	525
Parapanema River Bank (PR)	22° 37' 51.6''S / 52° 09' 30.5''W	-	<i>Typha</i> , <i>Eichhornia</i> , <i>Brachiaria</i> , <i>Pontederia</i> , <i>Salvinia</i> and <i>Pistia</i>	-
Lateral lagoon D (FPD)	22° 38' 22.0''S / 52° 09' 29.0''W	0.063	<i>Eichhornia</i> , <i>Brachiaria</i> , <i>Pontederia</i> , <i>Salvinia</i> , <i>Pistia</i> and <i>Nymphaea</i>	60.2

**Table 2.** List of species and the respective acronyms (Acr), Trophic guild (TG), number of analyzed stomachs (n), standard length (L) (mm), niche amplitude (A) and diet composition (relative alimentary index). Food categories: AI = Aquatic insect; TI = Terrestrial insects; CR = Crustaceans; FI = Fish; MA = Macroinvertebrates; MI = Microcrustaceans; AL = Algae; VM = Vegetal matter; DS = Detritus/Sediment; SC = Scales; BI = Bird remains. Trophic guilds: Ins = Insectivorous; Zoo = Zooplanktivorous; Alg = Algivorous; Omn = Omnivorous; Inv = Invertivorous; Det = Detritivorous; Pis = Piscivorous and Car = Carcinophagous

	Acr	SS	TG	n	L	A	Food Categories									
							DS	VM	AL	MI	CR	AI	TI	MA	SC	FI
<b>Order Characiformes</b>																
<i>Astyanax altiparanae</i> Garutti & Britski, 2000	Aalt	FPA	Ins	3	30	0.53		5.0	20.0	2.5	65.0	5.0			2.5	
<i>Astyanax altiparanae</i> Garutti & Britski, 2000	Aalt	FPB	Zoo	6	28	0.31	0.1	16.2	8.8	55.1	14.3	2.3	1.5	1.8		
<i>Astyanax altiparanae</i> Garutti & Britski, 2000	Aalt	FPC	Omn	7	31	0.29		17.2	38.9	18.2	20.2	4.6	0.3	0.6		
<i>Astyanax altiparanae</i> Garutti & Britski, 2000	Aalt	PR	Ins	7	33	0.27		1.4	8.2	9.0	71.9	8.1	0.7	0.5	0.2	
<i>Astyanax altiparanae</i> Garutti & Britski, 2000	Aalt	FPD	Omn	27	29	0.21		0.2	44.8	1.7	46.8	4.4	1.6	0.4	0.1	
<i>Acestrorhynchus lacustris</i> (Lütken, 1875)	Alac	PR	Pis	3	16	0.55					2.5				97.5	
<i>Apareiodon piracicabae</i> (Eigenmann, 1907)	Apir	PR	Zoo	4	27	0.30	9.3	4.7	10.5	74.4			1.2			
<i>Apareiodon piracicabae</i> (Eigenmann, 1907)	Apir	FPD	Det	6	27	0.05	80.0	9.0	11.0							
<i>Aphyocharax anisitsi</i> Eigenmann & Kennedy, 1903	Aani	FPA	Zoo	25	22	0.26		0.0	0.4	72.3	21.2	0.1	0.4	5.6		
<i>Aphyocharax anisitsi</i> Eigenmann & Kennedy, 1903	Aani	FPB	Ins	7	21	0.20		0.8	0.2	15.8	83.2					
<i>Aphyocharax anisitsi</i> Eigenmann & Kennedy, 1903	Aani	FPC	Zoo	96	23	0.18				95.1	4.5	0.4				
<i>Aphyocharax anisitsi</i> Eigenmann & Kennedy, 1903	Aani	PR	Ins	29	23	0.22			0.7	39.9	55.4		0.5	3.5	0.1	
<i>Aphyocharax anisitsi</i> Eigenmann & Kennedy, 1903	Aani	FPD	Ins	12	20	0.30			0.6	18.3	79.1		0.7	1.3		
<i>Bryconamericus stramineus</i> Eigenmann, 1908	Bstr	FPA	Zoo	30	30	0.32		0.4	0.8	90.6	6.0			2.1		
<i>Bryconamericus stramineus</i> Eigenmann, 1908	Bstr	FPB	Zoo	57	28	0.23	0.7	19.1	0.6	75.1	2.7		0.1	1.7		
<i>Bryconamericus stramineus</i> Eigenmann, 1908	Bstr	FPC	Zoo	98	31	0.32		2.5	0.2	92.9	1.1			3.2		
<i>Bryconamericus stramineus</i> Eigenmann, 1908	Bstr	PR	Omn	95	31	0.42		0.2	1.3	36.3	47.4	3.2	0.7	10.9		
<i>Bryconamericus stramineus</i> Eigenmann, 1908	Bstr	FPD	Zoo	50	27	0.46		7.2	1.6	77.5	3.6	7.6	0.4	2.0		
<i>Cyphocharax modestus</i> (Fernández-Yépez, 1948)	Cmod	FPA	Ins	3	26	0.45	10.9			3.6	10.9		54.5	9.1	10.9	
<i>Cyphocharax modestus</i> (Fernández-Yépez, 1948)	Cmod	FPB	Omn	4	25	0.50				34.6	21.9	32.9	7.1	2.4	1.2	
<i>Cyphocharax modestus</i> (Fernández-Yépez, 1948)	Cmod	FPC	Zoo	9	28	0.23				91.9	7.3	0.8				
<i>Cyphocharax modestus</i> (Fernández-Yépez, 1948)	Cmod	PR	Omn	11	28	0.35		5.8	0.2	37.5	45.6	5.8	0.8	3.9	0.4	
<i>Cyphocharax modestus</i> (Fernández-Yépez, 1948)	Cmod	FPD	Ins	8	25	0.37	0.3	0.5	1.1	0.8	75.6		16.2		5.6	
<i>Galeocharax knerii</i> (Steindachner, 1875)	Gkne	FPB	Car	1	41	0.00					100.0					
<i>Hemigrammus marginatus</i> Ellis, 1911	Hmar	FPA	Zoo	200	22	0.14		1.2	0.1	86.2	11.5	0.2	0.4	0.2	0.1	
<i>Hemigrammus marginatus</i> Ellis, 1911	Hmar	FPB	Zoo	198	22	0.23		2.0	0.8	58.1	32.0	3.8	1.4	1.0	0.9	
<i>Hemigrammus marginatus</i> Ellis, 1911	Hmar	FPC	Zoo	100	23	0.27		0.3	0.1	94.9	3.6	0.1	0.6	0.3	0.2	
<i>Hemigrammus marginatus</i> Ellis, 1911	Hmar	PR	Zoo	140	23	0.37		1.4	0.1	61.8	32.3	0.2	3.7		0.4	
<i>Hemigrammus marginatus</i> Ellis, 1911	Hmar	FPD	Omn	300	20	0.35		0.5	6.5	42.9	43.4	5.1	1.0	0.3	0.2	
<i>Hoplias malabaricus</i> (Bloch, 1794)	Hmal	FPB	Pis	2	89	0.22					100.0					
<i>Hoplias malabaricus</i> (Bloch, 1794)	Hmal	FPC	Inv	3	90	0.11							90.0	1.0	9.0	
<i>Hoplias malabaricus</i> (Bloch, 1794)	Hmal	FPD	Pis	1	91	0.00									100.0	
<i>Hyphessobrycon eques</i> (Steindachner, 1882)	Hequ	FPA	Zoo	80	21	0.29		1.7	0.2	82.5	12.9		0.9	1.8	0.0	
<i>Hyphessobrycon eques</i> (Steindachner, 1882)	Hequ	FPB	Zoo	108	20	0.26		4.1	0.7	54.6	33.9	0.0	4.3	2.3	0.2	
<i>Hyphessobrycon eques</i> (Steindachner, 1882)	Hequ	FPC	Zoo	54	22	0.28		0.8	0.3	92.6	2.1		3.9		0.3	
<i>Hyphessobrycon eques</i> (Steindachner, 1882)	Hequ	PR	Zoo	50	24	0.50		8.5	0.2	61.8	16.6		5.7	3.1	4.2	
<i>Hyphessobrycon eques</i> (Steindachner, 1882)	Hequ	FPD	Zoo	104	20	0.27		0.5	0.6	67.1	26.6	0.0	4.9	0.1	0.2	

**Table 2. Continued.**

<i>Leporinus friderici</i> (Bloch. 1794)	Lfire	FPB	Ins	7	38	0.49		7.5	7.5	40.0	37.5	7.5			
<i>Leporinus friderici</i> (Bloch. 1794)	Lfire	FPC	Ins	13	38	0.36		15.0	25.0		50.0		10.0		
<i>Leporinus octofasciatus</i> Steindachner. 1915	Loct	FPB	Ins	6	24	0.33			5.0	10.0	85.0				
<i>Leporinus octofasciatus</i> Steindachner. 1915	Loct	FPC	Ins	4	24	0.24			10.0	15.0	75.0				
<i>Leporinus striatus</i> Kner. 1858	Lstr	FPC	Alg	11	40	0.31		60.0	5.0		35.0				
<i>Metynnis lippincottianus</i> (Cope. 1870)	Mlip	FPA	Zoo	11	14	0.51				70.0	30.0				
<i>Metynnis lippincottianus</i> (Cope. 1870)	Mlip	FPD	Zoo	10	14	0.72				60.0	30.0	10.0			
<i>Moenkhausia intermedia</i> Eigenmann. 1908	Mint	FPA	Zoo	29	20	0.23	0.2	0.2	92.2		5.0		0.2	2.2	
<i>Moenkhausia intermedia</i> Eigenmann. 1908	Mint	FPB	Zoo	23	20	0.34	1.1	3.3	68.4		25.5		0.5	1.3	
<i>Moenkhausia intermedia</i> Eigenmann. 1908	Mint	PR	Zoo	22	23	0.42	1.1	0.4	58.5		29.9		0.7	4.1	5.4
<i>Moenkhausia intermedia</i> Eigenmann. 1908	Mint	FPD	Zoo	40	21	0.41	3.3	12.5	52.0		28.3		1.6	0.7	1.6
<i>Myleus tiete</i> (Eigenmann & Norris. 1900)	Mtie	FPB	Ins	3	20	0.69					100.0				
<i>Myleus tiete</i> (Eigenmann & Norris. 1900)	Mtie	PR	Ins	2	20	0.22					100.0				
<i>Oligosarcus pintoii</i> Amaral Campos. 1945	Opin	FPB	Omn	16	28	0.61	3.4	1.7	25.6		49.6	3.4	15.4		0.9
<i>Oligosarcus pintoii</i> Amaral Campos. 1945	Opin	FPC	Zoo	12	28	0.23	0.3		95.9		2.3		0.8	0.8	
<i>Oligosarcus pintoii</i> Amaral Campos. 1945	Opin	PR	Ins	4	29	0.41					100.0				
<i>Oligosarcus pintoii</i> Amaral Campos. 1945	Opin	FPD	Omn	9	28	0.79			20.5		46.6		27.4		5.5
<i>Roeboides descalvadensis</i> Fowler. 1932	Rdes	FPA	Omn	13	36	0.65		3.4	37.2		46.0			8.7	4.7
<i>Roeboides descalvadensis</i> Fowler. 1932	Rdes	FPB	Omn	22	34	0.38	24.5	1.9	11.7		21.6		0.4	39.4	0.6
<i>Roeboides descalvadensis</i> Fowler. 1932	Rdes	FPC	Zoo	16	36	0.43	1.5	0.0	85.6		9.4		0.2	3.3	
<i>Roeboides descalvadensis</i> Fowler. 1932	Rdes	PR	Zoo	16	38	0.36	1.2	0.1	67.3		23.6		0.0	7.9	
<i>Roeboides descalvadensis</i> Fowler. 1932	Rdes	FPD	Ins	22	34	0.46	3.7	1.4	21.7		56.6	1.1	0.2	15.3	
<i>Schizodon nasutus</i> Kner. 1858	Snas	FPA	Alg	12	36	0.22	3.3	68.1	21.9		6.6				
<i>Schizodon nasutus</i> Kner. 1858	Snas	FPB	Ins	3	36	0.97					100.0				
<i>Schizodon nasutus</i> Kner. 1858	Snas	FPD	Omn	21	36	0.45			44.8		50.8	4.4			
<i>Serrapinnus notomelas</i> (Eigenmann. 1915)	Snot	FPA	Alg	68	25	0.08	1.0	0.2	85.6	10.7	1.7		0.2	0.6	
<i>Serrapinnus notomelas</i> (Eigenmann. 1915)	Snot	FPB	Alg	55	22	0.11	0.0	1.0	84.8	9.1	4.6		0.4	0.0	
<i>Serrapinnus notomelas</i> (Eigenmann. 1915)	Snot	FPC	Alg	22	26	0.11	0.1	0.3	51.8	47.6	0.2		0.0	0.0	
<i>Serrapinnus notomelas</i> (Eigenmann. 1915)	Snot	PR	Alg	31	27	0.12	4.5	0.1	74.7	19.8	0.7		0.0	0.2	0.1
<i>Serrapinnus notomelas</i> (Eigenmann. 1915)	Snot	FPD	Alg	58	21	0.07	0.3	0.1	93.5	2.2	3.4		0.3	0.2	0.0
<i>Serrasalmus maculatus</i> Kner. 1858	Smac	FPA	Ins	23	22	0.24			0.3	5.7	87.7		0.0	4.8	1.4
<i>Serrasalmus maculatus</i> Kner. 1858	Smac	FPB	Ins	20	22	0.06	0.6	0.7	1.6		97.1		0.1		
<i>Serrasalmus maculatus</i> Kner. 1858	Smac	FPC	Ins	15	23	0.22			1.0	6.4	82.8		0.2	7.7	2.0
<i>Serrasalmus maculatus</i> Kner. 1858	Smac	PR	Ins	11	24	0.15	2.4	2.7	0.4		87.6		0.1	2.0	4.9
<i>Serrasalmus maculatus</i> Kner. 1858	Smac	FPD	Ins	35	20	0.19	1.5	8.2	5.8		82.7		0.1	1.1	0.5
<i>Serrasalmus marginatus</i> Valenciennes. 1836	Smar	FPA	Ins	4	40	0.69			5.0		60.0			35.0	
<i>Serrasalmus marginatus</i> Valenciennes. 1836	Smar	FPB	Pis	1	40	0.00									100.0
<i>Serrasalmus marginatus</i> Valenciennes. 1836	Smar	FPD	Ins	7	40	0.54	5.0	10.0		10.0	55.0		20.0		
<i>Steindachnerina brevipinna</i> (Eigenmann & Eigenmann. 1889)	Sbre	FPA	Det	12	42	0.08	83.9	6.1	10.0						
<i>Steindachnerina brevipinna</i> (Eigenmann & Eigenmann. 1889)	Sbre	FPB	Det	26	40	0.11	57.0		42.8	0.1			0.1	0.0	
<i>Steindachnerina brevipinna</i> (Eigenmann & Eigenmann. 1889)	Sbre	FPC	Det	16	44	0.02	91.2		8.5				0.3		
<i>Steindachnerina brevipinna</i> (Eigenmann & Eigenmann. 1889)	Sbre	FPD	Det	35	39	0.02	85.7		14.1	0.0			0.1	0.1	
<b>Order Gymnotiformes</b>															
<i>Eigenmannia trilineata</i> López & Castello. 1966	Etri	FPA	Ins	1	53	0.00					100.0				
<i>Eigenmannia trilineata</i> López & Castello. 1966	Etri	FPB	Ins	9	52	0.18			1.6		93.8		4.7		

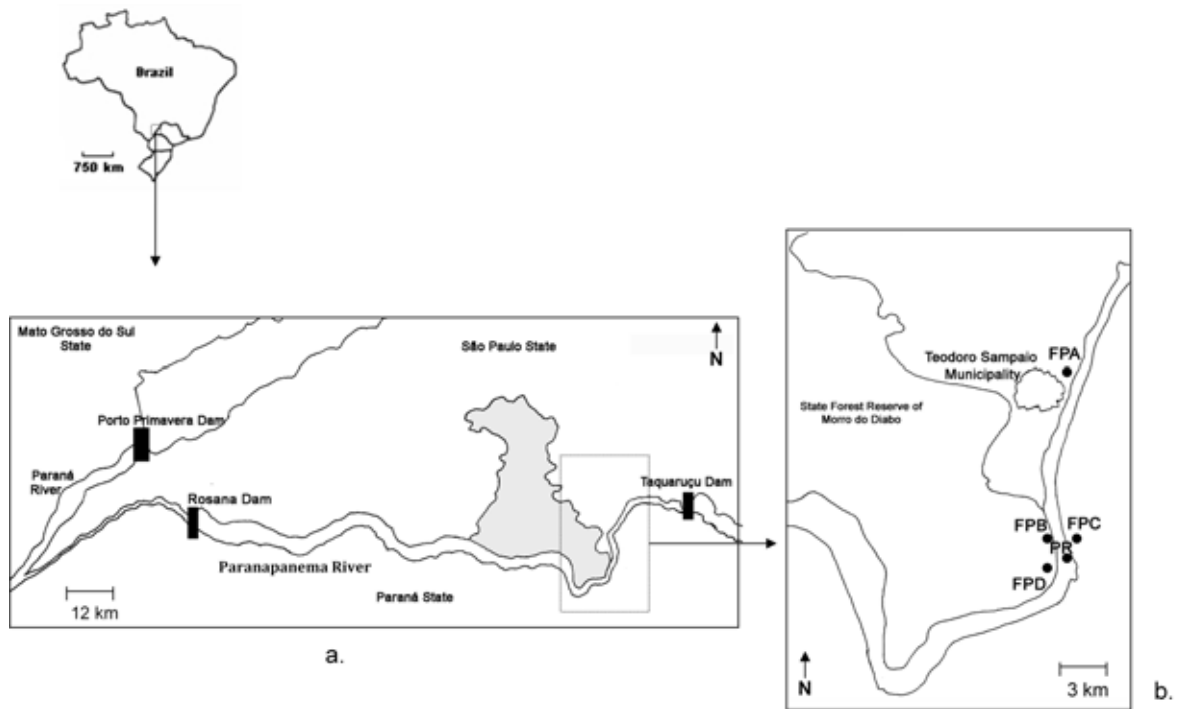
**Table 2. Continued.**

<i>Eigenmannia trilineata</i> López & Castello. 1966	Etri	FPC	Ins	8	54	0.43			22.0	75.0	3.0		
<i>Eigenmannia trilineata</i> López & Castello. 1966	Etri	FPD	Ins	16	53	0.23		0.7	19.0	78.0	2.3		
<i>Eigenmannia virescens</i> (Valenciennes. 1842)	Evir	FPB	Ins	5	108	0.41	32.9	2.7		61.6	2.7		
<i>Gymnotus carapo</i> Linnaeus. 1758	Gcar	FPB	Ins	16	55	0.32	0.2	0.0	4.6		94.1	0.5	0.5
<i>Gymnotus carapo</i> Linnaeus. 1758	Gcar	PR	Ins	5	56	0.45					72.4	1.7	25.9
<i>Gymnotus carapo</i> Linnaeus. 1758	Gcar	FPD	Ins	14	54	0.32		0.1	5.0		90.8	3.0	1.1
<i>Rhamphichthys hahni</i> (Meinken. 1937)	Rhah	FPA	Alg	4	36	0.95		60.0		40.0			
<b>Order Siluriformes</b>													
<i>Hypostomus ancistroides</i> (Ihering. 1911)	Hanc	FPA	Det	16	23	0.11	72.6		27.4				
<i>Hypostomus ancistroides</i> (Ihering. 1911)	Hanc	FPC	Alg	15	23	0.44	21.5		78.3		0.2		
<i>Hypostomus ancistroides</i> (Ihering. 1911)	Hanc	PR	Det	20	24	0.11	65.8		34.2				
<i>Hypostomus</i> sp1	Hsp1	FPA	Det	14	15	0.23	55.4		44.6				
<i>Hypostomus</i> sp1	Hsp1	FPB	Alg	7	15	0.53	40.0		60.0				
<i>Hypostomus</i> sp1	Hsp1	FPC	Alg	21	15	0.32	33.0		67.0				
<i>Hypostomus</i> sp1	Hsp1	PR	Det	14	16	0.07	73.1		26.9				
<i>Hypostomus</i> sp2	Hsp2	FPC	Alg	14	35	0.59	25.0		75.0				
<i>Loricariichthys platymetopon</i> Isbrücker & Nijssen. 1979	Lor	FPC	Det	6	28	0.29	60.0	0.0	35.0		5.0		
<i>Loricariichthys platymetopon</i> Isbrücker & Nijssen. 1979	Lor	FPD	Det	6	27	0.07	85.0	5.0	10.0		0.0		
<i>Trachelyopterus galeatus</i> (Linnaeus. 1766)	Tgal	FPC	Ins	1	70	0.00					100.0		
<i>Pimelodus maculatus</i> Lacepède. 1803	Pmac	FPD	Zoo	8	32	0.67			55.0	45.0			
<i>Rhamdia quelen</i> (Quoy & Gaimard. 1824)	Rque	PR	Ins	4	45	0.08			10.0	90.0			
<b>Order Perciformes</b>													
<i>Cichla kelberi</i> Spix & Agassiz. 1831	Ckel	FPA	Ins	8	41	0.22		1.4	18.7	74.3	0.7	3.5	1.4
<i>Cichla kelberi</i> Spix & Agassiz. 1831	Ckel	FPB	Ins	3	40	0.80				80.0			20.0
<i>Cichla kelberi</i> Spix & Agassiz. 1831	Ckel	FPC	Ins	2	42	0.00				100.0			
<i>Cichla kelberi</i> Spix & Agassiz. 1831	Ckel	FPD	Ins	6	40	0.74				68.7			31.3
<i>Cichlasoma paranaense</i> Kullander. 1983	Cpar	FPA	Det	13	35	0.18	54.3	1.7	3.4	40.0		0.6	
<i>Cichlasoma paranaense</i> Kullander. 1983	Cpar	FPB	Det	13	34	0.24	50.9	3.4	3.3	40.1	2.0		0.3
<i>Cichlasoma paranaense</i> Kullander. 1983	Cpar	FPD	Ins	14	34	0.37		0.4	3.1	59.4	34.6		2.5
<i>Crenicichla britskii</i> Kullander. 1982	Cbri	FPA	Ins	12	33	0.19		0.1	0.8	96.2		3.0	
<i>Crenicichla britskii</i> Kullander. 1982	Cbri	FPB	Ins	16	30	0.13			0.7	94.4	2.7	1.7	0.5
<i>Crenicichla britskii</i> Kullander. 1982	Cbri	FPC	Ins	16	33	0.11	1.0	0.1	1.0	95.1	2.4		0.5
<i>Crenicichla britskii</i> Kullander. 1982	Cbri	PR	Ins	14	34	0.16		0.1	0.2	98.2	1.0		0.6
<i>Crenicichla britskii</i> Kullander. 1982	Cbri	FPD	Ins	11	33	0.56			38.2	61.8			
<i>Crenicichla haroldoi</i> Luengo & Britski. 1974	Char	FPC	Zoo	8	22	0.72			80.0	20.0			
<i>Crenicichla niederleini</i> (Holmberg. 1891)	Cnie	FPC	Ins	6	32	0.27				98.5			1.5
<i>Crenicichla niederleini</i> (Holmberg. 1891)	Cnie	FPD	Ins	3	31	0.97				100.0			
<i>Satanoperca pappaterra</i> (Heckel. 1840)	Spap	FPC	Zoo	28	17	0.13			90.0		10.0		
<i>Satanoperca pappaterra</i> (Heckel. 1840)	Spap	PR	Omn	15	18	0.65	16.7	25.3	13.3	42.7		2.0	
<i>Satanoperca pappaterra</i> (Heckel. 1840)	Spap	FPD	Zoo	15	17	0.39		4.6	87.1	6.4	2.0		
<b>Order Synbranchiformes</b>													
<i>Synbranchus marmoratus</i> Bloch. 1795	Symar	FPD	Ins	2	130	0.47	20.0			80.0			
<b>Order Cyprinodontiformes</b>													
<i>Phalloceros caudimaculatus</i> (Hensel. 1868)	Pcau	FPB	Ins	3	22	0.67				100.0			

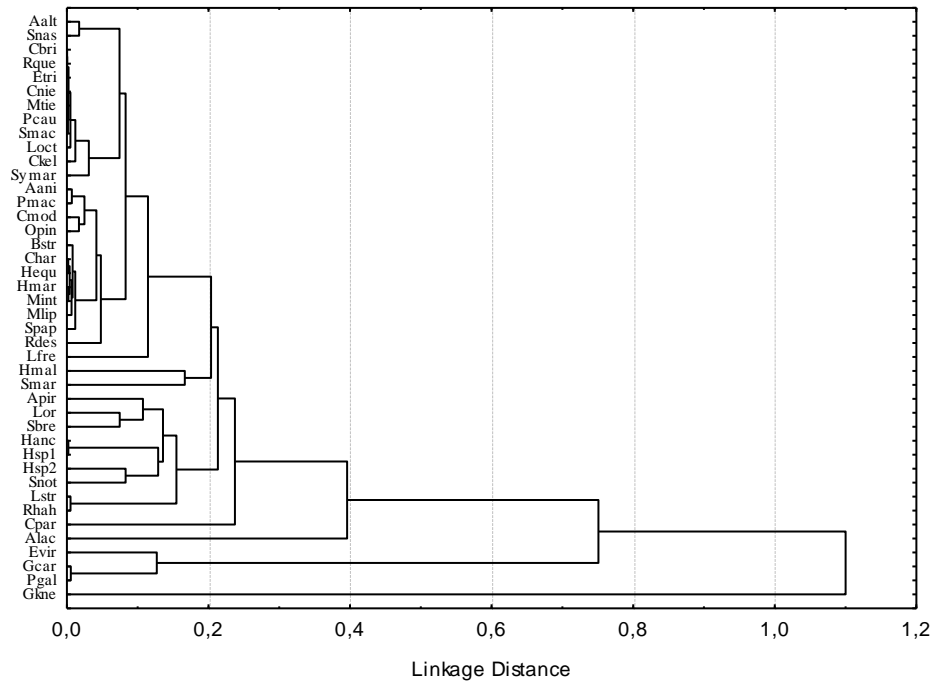


**Table 3.** Null models results, indicating the observed and simulated mean and variance of the feeding overlap (Pianka's Index) between fish species of the assemblages from different sampling stations.

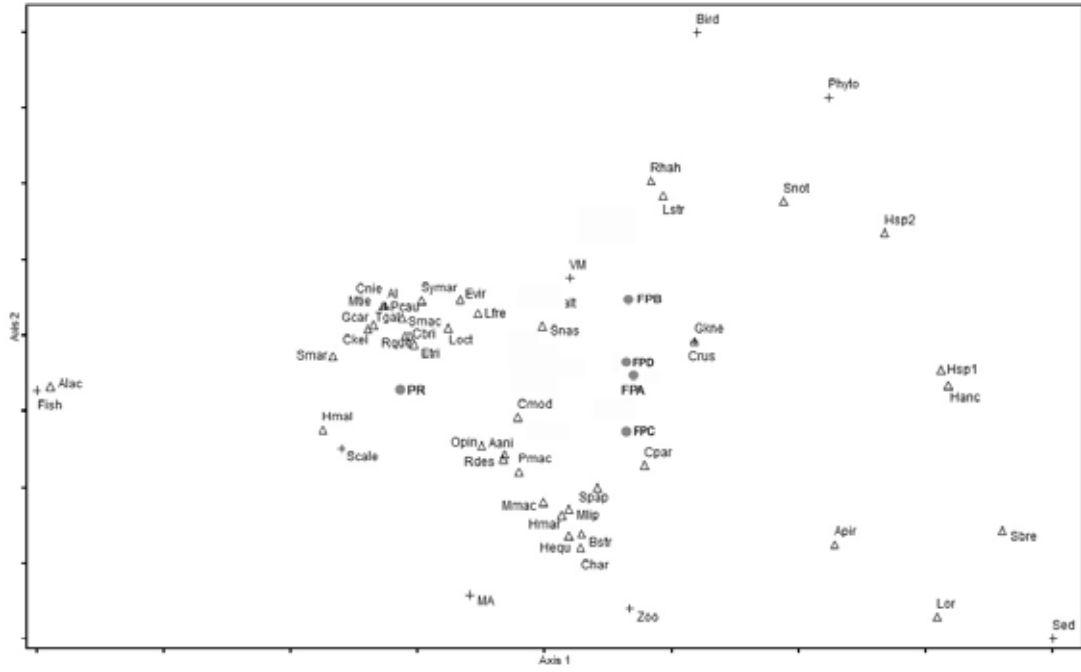
	<b>Observed mean</b>	<b>Simulated mean</b>	<b>p</b>	<b>Observed variance</b>	<b>Simulated variance</b>	<b>p</b>
<b>FPA</b>	0.043	0.010	0.000	0.004	0.001	0.000
<b>FPB</b>	0.092	0.030	0.000	0.009	0.003	0.000
<b>FPC</b>	0.113	0.039	0.000	0.017	0.006	0.000
<b>PR</b>	0.158	0.050	0.000	0.016	0.005	0.000
<b>FPD</b>	0.021	0.007	0.000	0.014	0.004	0.000



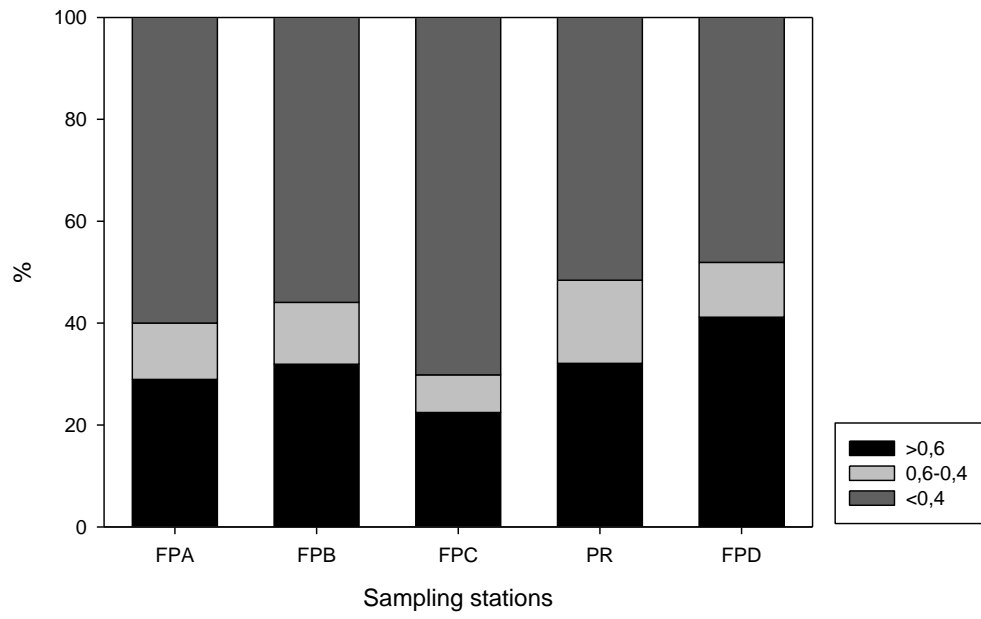
**Figure 1** – Study area in the region of the confluence of Paraná and Paranapanema Rivers (States of São Paulo – SP, Paraná – PR and Mato Grosso do Sul – MS) showing the positioning of Rosana, Taquaruçu and Porto Primavera dams and the State Park of “Morro do Diabo” (gray area) (a.). On the right (detail) the location of the sampling stations and the municipality of Teodoro Sampaio (b.).



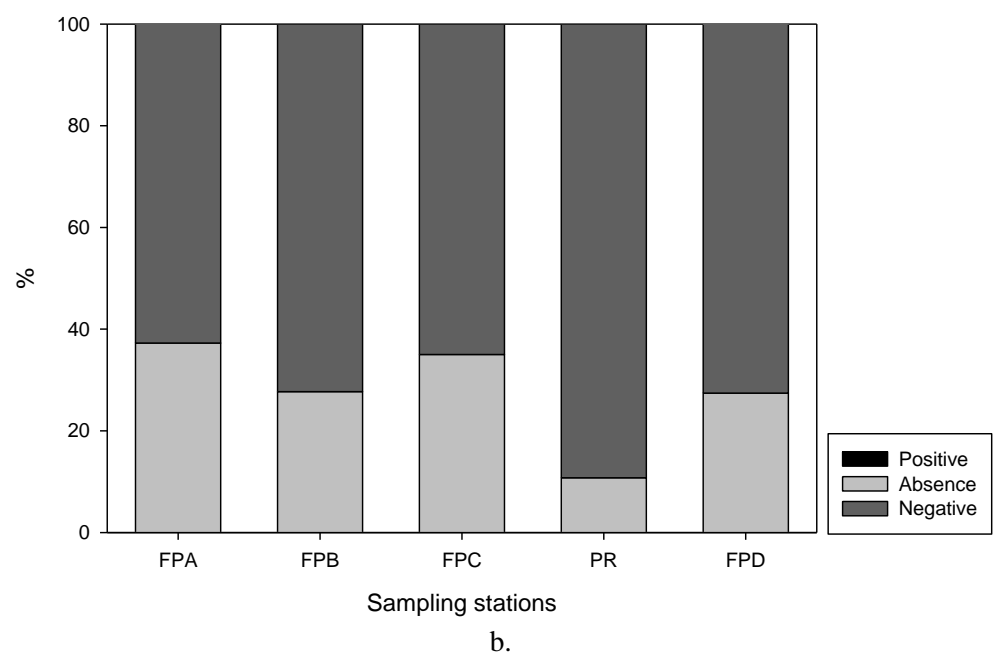
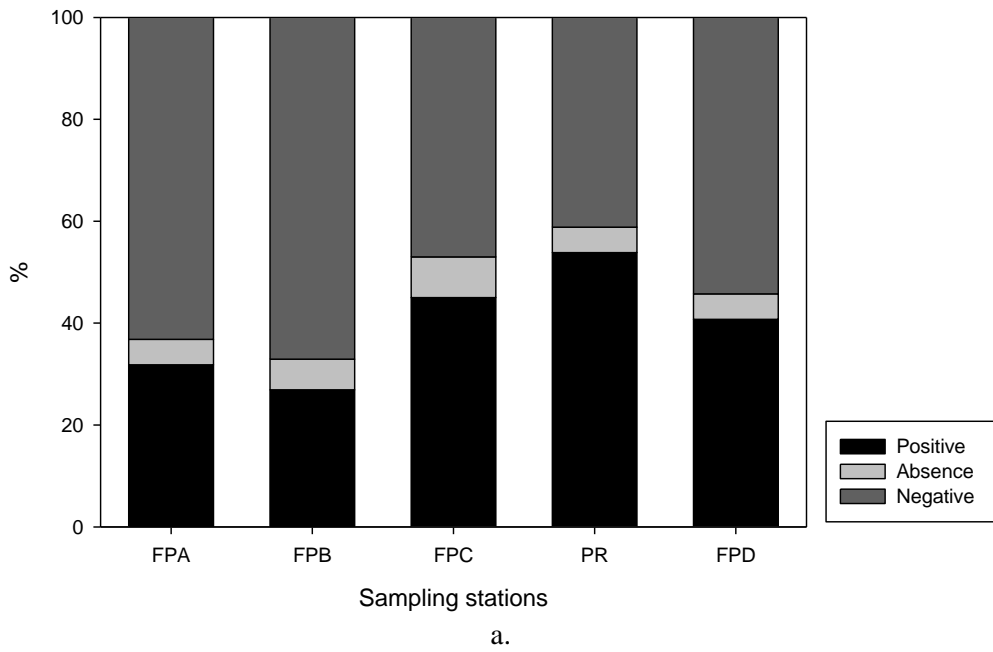
**Figure 2** – Cluster analysis based on diet similarity among species from the different sampling stations.



**Figure 3** – Detrended correspondence analysis (DCA) showing the distribution of the fish species in relation to the feeding consume.



**Figure 4** – Relative frequency (%) of diet overlap between all the species pairs from the different sampling stations.



**Figure 5** – Relative frequency (%) of the electivity index scores, for Cladocera (a.) and Copepod (b.), of the ichthyofauna from the different sampling stations.

*Anexo1*

Lista de ocorrência dos táxons fitoplancctônicos nos diferentes pontos e períodos de coleta.

Táxons	Setembro			Novembro			Janeiro			Março			Maio			Agosto			
	FPA	FPB	FPD	FPA	FPB	FPD	FPA	FPB	FPD	FPA	FPB	FPD	FPA	FPB	FPD	FPA	FPB	FPD	
<i>Bacillariophyceae</i>																			
<i>Achnanthes deflexa</i>			X																
<i>Achnanthes exigua</i> var. <i>exigua</i>						X			X							X			X
<i>Achnanthes inflata</i> var. <i>inflata</i>			X		X	X			X			X			X			X	X
<i>Achnanthes salvadoriana</i>			X												X			X	X
<i>Actinella brasiliensis</i>			X																
<i>Amphipleura lindheimeri</i>		X	X		X	X		X	X		X	X		X	X		X	X	X
<i>Amphipleura pellicida</i>			X			X						X							
<i>Amphora linearis</i>								X				X							X
<i>Amphora ovalis</i> var. <i>libyca</i>									X			X							
<i>Asterionella formosa</i>		X	X		X	X													
<i>Aulacoseira alpigena</i>		X	X		X	X		X	X		X	X		X	X		X	X	X
<i>Aulacoseira ambigua</i> var. <i>ambigua</i> f. <i>ambigua</i>		X	X		X	X					X	X		X	X		X	X	
<i>Aulacoseira ambigua</i> var. <i>ambigua</i> f. <i>spiralis</i>		X	X		X	X		X	X		X	X		X	X		X	X	X
<i>A. granulata</i> var. <i>angustissima</i> f. <i>angustissima</i>		X	X		X	X		X	X		X	X		X	X		X	X	X
<i>Aulacoseira granulata</i> var. <i>curvata</i>			X											X	X		X	X	X
<i>Aulacoseira granulata</i> var. <i>ambigua</i> f. <i>spiralis</i>		X	X		X	X		X	X		X	X		X	X		X	X	X
<i>Aulacoseira granulata</i> var. <i>granulata</i> f. <i>granulata</i>		X	X		X	X		X	X		X	X		X	X		X	X	X
<i>Cocconeis placentula</i> var. <i>lineata</i>			X									X						X	
<i>Cocconeis gematulus</i>		X	X		X	X		X	X		X	X		X	X		X	X	X
<i>Cyclotella stelligera</i>					X						X	X					X	X	X
<i>Cymbella affinis</i> var. <i>affinis</i>			X						X								X	X	X



























*Anexo2*







Táxons	Setembro					Novembro					Janeiro					Março					Maio					Agosto									
	FPA	FPB	FPC	PR	FPD	FPA	FPB	FPC	PR	FPD	FPA	FPB	FPC	PR	FPD	FPA	FPB	FPC	PR	FPD	FPA	FPB	FPC	PR	FPD	FPA	FPB	FPC	PR	FPD					
<i>Argyrodaptomus fuscatus</i> (Sars, 1901)			X		X																														X
<i>Notodaptomus henseni</i> Dahl, 1894	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
<i>Notodaptomus conifer</i> (Sars, 1901)	X		X			X	X	X	X	X						X	X	X	X	X						X	X	X	X	X	X	X	X	X	X
<i>Notodaptomus iheringi</i> Wright, 1935			X						X		X	X																							
<i>Notodaptomus deitersi</i> (Poppe, 1891)										X																									
Cyclopidae																																			
<i>Encyclops ensifer</i> Kiefer, 1936																																			X
<i>Mesocyclops longisetus</i> (Thiébaud, 1914)			X							X	X	X			X	X	X			X	X	X			X	X	X			X					
<i>Mesocyclops meridianus</i> Kiefer, 1926	X		X							X	X	X			X	X	X			X	X	X			X	X	X			X					
<i>Mesocyclops ogunnus</i> Onabamiro, 1957			X	X	X					X	X	X			X	X	X			X	X	X			X	X	X			X					
<i>Metaecyclops mendocinus</i> (Wierzejski, 1892)			X	X						X	X	X			X	X	X			X	X	X			X	X	X			X					
<i>Microcyclops anceps</i> (Richard, 1897)																																			X
<i>Microcyclops celbaensis</i> (Marsh, 1919)				X						X					X					X					X					X					
<i>Paracyclops chiltoni</i> (Thomson, 1882)										X					X					X					X					X					
<i>Thermocyclops decipiens</i> (Kiefer, 1929)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X					
<i>Thermocyclops minutus</i> (Lowndes, 1934)	X				X	X	X			X	X	X			X	X	X			X	X	X			X	X	X			X					
<i>Thermocyclops inversus</i> (Kiefer, 1936)	X				X																														