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PROGRAMA DE PÓS-GRADUAÇÃO EM CIÊNCIAS BIOLÓGICAS (BIOLOGIA VEGETAL)

INFLUÊNCIA DO ESTADO TRÓFICO E DO HÁBITAT NA DISTRIBUIÇÃO DAS DIATOMÁCEAS EM REPRESAS DO MÉDIO RIO TIETÊ/ALTO SOROCABA (SP, BRASIL)

ELAINE CRISTINA RODRIGUES BARTOZEK

Tese apresentada ao Instituto de Biociências do Campus de Rio Claro, Universidade Estadual Paulista, como parte dos requisitos para obtenção do título de Doutor em Ciências Biológicas (Biologia Vegetal).

Novembro - 2017

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ORIENTADORA: DRA. DENISE DE CAMPOS BICUDO

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CERTIFICADO DE APROVAÇÃO

TÍTULO DA TESE: INFLUÊNCIA DO ESTADO TRÓFICO E DO HÁBITAT NA DISTRIBUIÇÃO DAS DIATOMÁCEAS EM REPRESAS DO MÉDIO RIO TIETÊ/ALTO SOROCABA (SP, BRASIL)

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Rio Claro, 15 de setembro de 2017

"Few objects are more beautiful than the minute siliceous cases of the diatomaceae: were these created that they might be examined and admired under the higher powers of the microscope?"

Darwin, 1866

Instrução

Já se disse que duas asas conduzirão o espírito humano à presença de Deus.

Uma chama-se Amor, a outra, Sabedoria.

Pelo amor, que, acima de tudo, é serviço aos semelhantes, a criatura se ilumina e aformoseia por dentro, emitindo, em favor dos outros, o reflexo de suas próprias virtudes; e, pela sabedoria, que começa na aquisição do conhecimento, recolhe a influência dos vanguardeiros do progresso, que lhe comunicam os reflexos da própria grandeza, impelindo-a para o Alto.

Através do amor valorizamo-nos para a vida.

Através da sabedoria somos pela vida valorizados.

Daí o imperativo de marcharem juntas a inteligência e a bondade.

(...)

Conhecer é patrocinar a libertação de nós mesmos, colocando-nos a caminho de novos horizontes na vida.

Corre-nos, pois, o dever de estudar sempre, escolhendo o melhor para que as nossas ideias e exemplos reflitam as ideias e os exemplos dos paladinos da luz.

Francisco Cândido Xavier (Emmanuel). Pensamento e Vida.

Ao meu esposo Geraldino,

aos meus pais Luis e Cleozete

e aos meus irmãos Evandro, Erica, Renato e Renan...

meus amores, minha família, meus companheiros de jornada...

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RESUMO GERAL

O objetivo desta tese foi avaliar os principais fatores que controlam a biodiversidade e distribuição das diatomáceas acumuladas no sedimento superficial e planctônicas em represas tropicais. Cinco represas (19 estações de amostragem) localizadas na bacia do Médio Tietê/Alto Sorocaba variando de oligo- a hipereutróficas foram amostradas no verão e no inverno de 2014. As diatomáceas planctônicas foram amostradas no verão e no inverno e as do sedimento superficial (2 cm) foram coletadas no inverno. Além disso, foi utilizado o banco de dados do projeto temático *AcquaSed* (abióticos e de diatomáceas) para a análise dos principais fatores estruturadores das diatomáceas do sedimento superficial e planctônicas. Ainda, foi realizado o estudo florístico das diatomáceas de um subconjunto de represas do projeto temático, destacando as novas citações para o Brasil e Estado de São Paulo, bem como as informações sobre ocorrência das espécies em relação ao gradiente trófico. Os resultados demonstraram que o gradiente trófico foi o principal fator organizador da comunidade de diatomáceas tanto do sedimento superficial quanto planctônicas e que a biodiversidade (inferida pela diversidade beta) foi negativamente relacionada ao gradiente de enriquecimento. Entretanto, fatores espaciais também foram importantes preditores na estruturação das diatomáceas quando a maior escala espacial foi abordada (cinco bacias hidrográficas). A Contribuição dos Locais para a Diversidade Beta do componente substituição de espécies (Repl$_{LCBD}$) também apresentou relação negativa com a eutrofização, sendo que os maiores valores de Repl$_{LCBD}$ foram observados em ambientes oligo- e mesotróficos, indicando que estes ambientes foram os que apresentaram maior contribuição para a diversidade beta. As diatomáceas tanto do sedimento superficial como planctônicas foram representadas principalmente por espécies cêntricas como *Aulacoseira ambigua*, *A. granulata* var. *angustissima*, *A. granulata* var. *granulata*, *Cyclotella meneghiniana* e *Discostella stelligera*, as quais apresentaram os maiores valores de Contribuição das Espécies para a Diversidade Beta (SCBD) e possivelmente são espécies com potencial bioindicador. Tanto as diatomáceas do sedimento superficial quanto as planctônicas apresentaram padrões similares de distribuição e foram influenciadas principalmente por variáveis ambientais associadas à produtividade (fósforo e nitrogênio total, clorofila-*a* e transparência da água). Entretanto, as diatomáceas do sedimento superficial exibiram respostas mais evidentes ao gradiente de enriquecimento, possivelmente devido ao caráter integrador dos sedimentos, acumulando informações dos

diferentes habitats e ao longo do tempo, demonstrando seu grande potencial em estudos sobre biodiversidade e sobre os padrões que determinam a distribuição de espécies em represas. O levantamento florístico incluiu sete novos registros para o Brasil e cinco para o Estado de São Paulo, demonstrando a importância de tais estudos, principalmente nas regiões tropicais onde a flora de diatomáceas é ainda relativamente menos conhecida do que em regiões temperadas. Esta tese apresenta informações que podem contribuir para orientar futuros estudos sobre a dinâmica e biodiversidade de comunidades aquáticas, principalmente em represas tropicais. Também amplia a aplicação da abordagem com a contribuição dos locais (LCBD) e das espécies (SCBD) para a diversidade beta que podem ser aplicados para identificar ambientes prioritários para conservação e recuperação.

Palavras-chave: biodiversidade, diversidade beta, LCBD, metacomunidades, SCBD, sedimento superficial.

GENERAL ABSTRACT

The objective of this thesis was to evaluate the main factors controling the biodiversity and distribution of surface sediments and planktonic diatoms in tropical reservoirs. Five reservoirs (19 sampling sites) located in the Médio Tietê/Alto Sorocaba basin ranging from oligo- to hypereutrophic conditions were sampled in summer and winter of 2014. Planktonic diatoms were sampled in summer and winter and surface sediment diatoms (2 cm) were sampled in winter. Furthermore, the data set of the *AcquaSed* project (abiotic and diatoms) was used to analyze the main drivers of surface sediment and phytoplankton diatoms. A floristic survey was carried out by using a subset of the this project, highlighting the new records for Brazil and São Paulo state, as well as information about the species occurrence along the trophic gradient. The results showed that the trophic state was the the main driver of the diatom assemblage in both surface sediment and phytoplankton, and biodiversity (infered by beta diversity) was negatively related to the enrichment gradient. However, spatial factors were also important predictors for diatom structure when the larger spatial scale was included (five drainage basins). The Local Contribution to Beta Diversity of the species replacement component ($Repl_{LCBD}$) also showed negative correlation with eutrophication, and highest $Repl_{LCBD}$ values were observed in oligo- and mesotrophic environments, suggesting that these environments showed higher contribution to beta diversity. Surface sediment and planktonic diatoms were mainly represented by centric species such as *Aulacoseira ambigua*, *A. granulata* var. *angustissima*, *A. granulata* var. *granulata*, *Cyclotella meneghiniana* and *Discostella stelligera*. These species presented the higher values of Species Contribution to Beta Diversity (SCBD) and possibly can be used as bioindicators. Surface sediment and planktonic diatoms showed similar patterns of distribution and they were mainly influenced by productivity-related variables (total phosphorus and nitrogen, chlorophyll-*a* and water transparency). Moreover, surface sediment diatoms presented a more evident response to the enrichment gradient, possibly due to the integrative characteristics of sediments, accumulating information from different habitats and over time, demonstrating its high potential for studies on biodiversity and patterns that determinate species distribution in reservoirs. The floristic study added seven new diatom records for Brazil and five for São Paulo state, demonstrating the importance of such studies, mainly in tropical regions where the diatom flora is comparatively less known when compared to temperate regions. This thesis presents information to assiste future studies about the dinamics and biodiversity of aquatic

assemblages, mainly in tropical reservoirs. It also amplifies the LCBD and SCBD approaches, which can be applied to identify priority sites for conservation and restoration initiatives.

Key-words: biodiversity, beta diversity, LCBD, metacommunity, SCBD, surface sediments.

INTRODUÇÃO GERAL

Compreender os mecanismos que determinam os padrões de distribuição das espécies, suas abundâncias e interações representa um dos principais temas em ecologia de comunidades (Field et al. 2009, Logue et al. 2011). Tais padrões podem variar conforme a escala espacial observada, sugerindo que diferentes princípios podem ser aplicados a diferentes escalas (Leibold et al. 2004). A ideia de diferentes processos ocorrendo em diferentes escalas espaciais e que influenciam a composição e diversidade de diferentes comunidades representa o cerne da teoria de metacomunidades (Logue et al. 2011). Uma metacomunidade é definida como um conjunto de comunidades locais que são interligadas através de dispersão e com múltiplas espécies com potencial de interação (Leibold et al. 2004). Normalmente, as comunidades são organizadas por uma combinação de fatores abióticos e bióticos e por processos de dispersão (Heino et al. 2015). Nos últimos anos numerosos esforços vêm sendo direcionados com o intuito de determinar a contribuição relativa destes fatores para a estruturação das comunidades de diferentes grupos de organismos como bactérias, fitoplâncton, macrófitas aquáticas, diatomáceas, invertebrados e peixes (Beisner et al. 2006, Donohue et al. 2009, Astorga et al. 2012, Alahuhta et al. 2014, Dong et al. 2016).

Conforme sintetizado por Leibold et al. (2004), a teoria de metacomunidades compreende quatro perspectivas: *neutra* (neutral), *dinâmica de manchas* (patch dynamics), *seleção de espécies* (species sorting) e *efeito de massa* (mass effect). Cada um deles pode ser distinguido pela ênfase que dá na combinação de processos locais, processos regionais, distúrbios e grau de equivalência entre os traços das espécies (Brown et al. 2017). Na perspectiva *neutra*, todas as espécies são consideradas ecologicamente equivalentes e o ambiente não possui efeito sobre as comunidades, uma vez que a limitação da dispersão é o principal mecanismo que afeta a estrutura da metacomunidade (Heino et al. 2010). Assim, espera-se que a similaridade entre as comunidades diminuirá à medida que houver aumento da distância espacial entre elas (Heino et al. 2015). Para a perspectiva *dinâmica de manchas*, os ambientes são idênticos entre si e capazes de abrigar as populações com a melhor capacidade de colonização (Leibold et al. 2004, Heino et al. 2010). Os melhores colonizadores serão capazes de ocupar, por exemplo, locais mais isolados ou que sofreram distúrbio recente (Heino et al. 2015). Na perspectiva *seleção de espécies*, as condições ambientais (heterogeneidade ambiental) e as interações bióticas é que determinam as espécies que ocorrerão em determinada localidade, uma vez que todas as espécies têm

suficiente capacidade de dispersão (Leibold et al. 2004, Heino et al. 2015). Finalmente, *efeito de massa* considera as taxas de imigração e emigração importantes para a dinâmica das populações e afirma que elevadas taxas de dispersão permitem que as espécies ocorram mesmo em locais onde as condições ambientais não sejam ideais (Leibold et al. 2004). Entretanto, os quatro paradigmas não podem ser utilizados para descrever todas as possíveis dinâmicas de metacomunidades, uma vez que eles não são mutuamente exclusivos com relação aos mecanismos que estruturam as metacomunidades e também não representam completamente o espaço inferencial da teoria de metacomunidades (Logue et al. 2011, Winegardner et al. 2012, Brown et al. 2017). Além disso, Winegardner et al. (2012) consideram que *efeito de massa* e *dinâmica de manchas* são, na verdade, casos especiais de *seleção de espécies* e sugerem que os ecólogos devem pensar principalmente no que estes paradigmas significam em termos de condições ambientais e dispersão para as metacomunidades.

Aplicar o conceito da teoria de metacomunidades para compreender a dinâmica de microrganismos como bactérias e microalgas vem sendo um interessante desafio aos ecólogos, uma vez que a visão tradicional é a de que estes organismos são ubiquamente distribuídos devido a sua elevada capacidade dispersão, sugerindo que "tudo está em todo lugar, mas, o ambiente é que seleciona" (Baas-Becking 1934, Finlay et al. 2002). Apesar da biodiversidade de microrganismos ainda ser relativamente pouco conhecida, principalmente em regiões tropicais que abrigam maior biodiversidade e menor número de estudos comparativamente às regiões temperadas (Dudgeon et al. 2006), atualmente esta visão de distribuição ubíqua vem sendo cada vez mais contestada. Evidências recentes sugerem que existem variações regionais na estrutura de comunidades de microrganismos que não podem ser explicadas apenas baseando-se em alterações das condições ambientais, ou seja, que assim como macrorganismos, os microrganismos também podem exibir pronunciada estrutura espacial (Telford et al. 2006, Heino et al. 2010).

Assim, a estrutura de uma comunidade é determinada por fatores ambientais em nível local e por processos espaciais em nível regional, sendo que a contribuição relativa de cada um destes fatores preditores é dependente da capacidade de dispersão do grupo biológico, da escala espacial considerada e da presença de gradientes ambientais (Heino et al. 2015). Quanto maior a capacidade de dispersão de um grupo de organismos, espera-se, em princípio, maior contribuição do ambiente na variação da estrutura da comunidade uma vez que a limitação da dispersão é baixa (Heino 2013). Embora elevadas taxas de dispersão possam anular o efeito ambiental na estrutura das comunidades. Além disso, quanto maior

a escala espacial, maior será o papel de fatores espaciais, pois a limitação da dispersão das espécies aumentará proporcionalmente com o aumento da escala espacial e, por último, quanto maior for o gradiente ambiental, maior será a contribuição de fatores ambientais na estruturação das comunidades (Heino et al. 2015).

Nos ecossistemas aquáticos continentais, as comunidades aquáticas funcionam como metacomunidades e compreender o seu funcionamento e os fatores que controlam a sua estrutura representa um tema de grande interesse, visto que estes ambientes apresentam elevada riqueza de espécies em relação à área ocupada por ambientes aquáticos, chegando a ser considerados hotspots de biodiversidade (Dudgeon et al. 2006, Strayer & Dudgeon 2010, Dallas et al. 2016). As diatomáceas (Bacillariophyta) estão entre os microrganismos aquáticos mais representativos em termos de biodiversidade e vem sendo amplamente utilizadas para detectar respostas das comunidades em função das alterações ambientais e espaciais. Dentre as características que destacam este grupo de algas estão a sua elevada riqueza tanto local como regionalmente, curto ciclo de vida, as preferências ecológicas das espécies são relativamente bem conhecidas, principalmente em regiões temperadas e suas frústulas formadas por sílica polimerizada ($S_iO_2.nH_2O$) que permitem boa preservação, sendo resistentes à decomposição (Bennion 1995, Sayer et al. 1999, Lobo et al. 2002, Smol 2008, Bennion et al. 2011). Em geral, espera-se que as comunidades de diatomáceas sejam estruturadas principalmente por fatores ambientais, devido a sua elevada capacidade de dispersão e pela presença de gradientes ambientais, conforme demonstrado em vários estudos (e.g. Astorga et al. 2012, Heino et al. 2012, Zorzal-Almeida et al. 2017a). Entretanto, as comunidades também podem estar espacialmente estruturadas quando grandes escalas espaciais (Telford et al. 2006) e ambientes pristinos são considerados (Heino et al. 2010), devido a baixa influência das condições ambientais (no segundo caso).

Paralelamente aos estudos sobre metacomunidades, outro tema importante em ecologia de comunidades e que também vem recebendo a atenção dos ecólogos é compreender a diversidade de espécies e sua organização no espaço. Este fenômeno foi inicialmente apresentado por Whittaker (1960, 1972) que descreveu os níveis alfa, beta e gama de diversidade em comunidades naturais. Alfa refere-se à diversidade local (riqueza de espécies num local ou amostra, por exemplo) e gama é a diversidade regional (diversidade de diferentes locais numa região). Diversidade beta é definida como "a extensão da substituição de espécies ou alterações bióticas ao longo de gradientes ambientais" (Whittaker 1972). Atualmente, existe um grande interesse dos ecólogos em relação à diversidade beta, pois avaliar as variações espaciais (ou temporais ou ao longo de

gradientes ambientais) na composição de espécies permite testar hipóteses sobre os processos que geram e mantém a biodiversidade nos ecossistemas (Legendre & De Cáceres 2013).

Estudos sobre diversidade beta podem focar em dois aspectos de estrutura de comunidades. O primeiro é a *substituição de espécies* (species replacement ou turnover) que se refere às mudanças direcionais na composição da comunidade de um local para outro ao longo do espaço, do tempo ou de um gradiente ambiental (Legendre & De Cáceres 2013). O segundo aspecto, *diferença de riqueza* (richness difference), refere-se ao fato de que uma comunidade pode incluir um número maior de espécies do que outra (Legendre 2014). *Aninhamento* pode ser considerado um tipo de *diferença de riqueza*, onde as espécies que ocorrem num local representam um subconjunto de outro com maior riqueza (Baselga 2012, Legendre 2014). Frequentemente, ambos os processos (*substituição de espécies* e *diferença de riqueza*) atuam conjuntamente sobre as comunidades, diferindo apenas suas proporções devido, por exemplo, a taxas de extinção, colonização e dispersão das espécies, resultando em padrões complexos de diversidade beta (Carvalho et al. 2012). Assim, principalmente nos últimos anos vários métodos foram propostos para estimar a diversidade beta e seus componentes *(substituição de espécies* e *diferença de riqueza),* principalmente aqueles baseados na dissimilaridade entre as comunidades (Podani & Schmera 2011, Baselga 2010, 2012, Podani et al. 2013).

Recentemente, Legendre & De Cáceres (2013) propuseram utilizar a variância total da comunidade como estimativa da diversidade beta. De acordo com os autores, uma das vantagens desta abordagem é que, além de estimar a contribuição relativa da *substituição de espécies* e *diferença de riqueza*, este método permite determinar a contribuição dos locais e das espécies para a diversidade beta. A Contribuição do Local para a Diversidade Beta (*Local Contribution to Beta diversity* - LCBD) representa o quão singular é uma unidade amostral em termos de composição da comunidade em relação às demais, enquanto que a Contribuição das Espécies para a Diversidade Beta (*Species Contribution to Beta Diversity* - SCBD) apresenta a contribuição de cada espécie para a diversidade beta (Legendre & De Cáceres 2013). Assim, conhecer a importância de determinados locais e das espécies para a diversidade beta pode ser interessante para iniciativas de conservação e recuperação da biodiversidade. Altos valores de LCBD podem indicar locais com elevada riqueza e com uma combinação de espécies pouco usual e com interesse para conservação, enquanto que baixos valores de LCBD podem indicar locais mais degradados e com baixa riqueza e que precisam ser recuperados (Legendre & De Cáceres 2013, Legendre 2014).

Posteriormente, Legendre (2014) estendeu o cálculo do índice LCBD para os dois componentes de diversidade beta, *substituição de espécies* (Repl$_{LCBD}$) e *diferença de riqueza* (RichDiff$_{LCBD}$), para medir o quão excepcional é cada local em termos de cada componente.

Diversos fatores vêm sendo apontados como importantes para alterar a diversidade nos ambientes aquáticos como o uso e a ocupação do solo (Heino et al. 2017), heterogeneidade ambiental (Thomaz et al. 2003, Zorzal et al. 2017b) e produtividade (Chase & Leibold 2002, Chase 2010). A produtividade, em particular, vem sendo indicada como um dos principais fatores que podem influenciar a biodiversidade aquática. Embora existam evidências de que o aumento da produtividade possa promover aumento da diversidade (Chase 2010), outros estudos vêm demonstrando que o rápido enriquecimento dos ambientes aquáticos (eutrofização antropogênica) resulta em diminuição da diversidade devido à homogeneização destes ambientes (Donohue et al. 2009, Vilar et al. 2014, Zorzal et al. 2017b). Para as comunidades de diatomáceas, além da relação negativa entre a diversidade beta e a produtividade (Zorzal et al. 2017b), altos níveis de eutrofização podem atuar como um filtro ecológico selecionando aquelas espécies capazes de tolerar tais condições ambientais, como diatomáceas planctônicas que são capazes de se manter na coluna d'água devido as suas adaptações morfológicas (Vilar et al. 2014). Portanto, no contexto da teoria de metacomunidades e diversidade beta, as diatomáceas representam um ótimo grupo para detectar respostas das comunidades às alterações ambientais e espaciais, conforme mencionado anteriormente.

Em nível mundial, as diatomáceas vêm sendo amplamente utilizadas para compreender os principais fatores que influenciam a estruturação de comunidades principalmente em rios e riachos (Soininen et al. 2004, Heino et al. 2010) e em lagos naturais de regiões temperadas (Blanco et al. 2004, Bennion et al. 2014), de modo que que há necessidade de avançar o conhecimento ecológico deste grupo de algas em regiões tropicais. No Brasil, a maioria dos estudos de cunho ecológico com diatomáceas também é desenvolvida em ecossistemas lóticos (e.g. Bere & Tundisi 2011a, 2011b, 2012, Wetzel et al. 2012) e focam no seu potencial como bioindicadoras (Lobo et al. 2004, Hermany et al. 2006). Entretanto, represas artificiais vêm sendo comparativamente negligenciadas, embora elas representem importantes ecossistemas no cenário nacional, uma vez que as principais bacias hidrográficas do país foram reguladas pela construção de barramentos (Júlio Júnior et al. 2005). Tais ecossistemas possuem grande potencial para analisar alterações ambientais tanto temporais quanto espaciais, uma vez que representam

importantes pontos de convergência das diferentes atividades desenvolvidas na bacia hidrográfica, refletindo, portanto, as múltiplas atividades humanas e os impactos decorrentes dessas atividades (Thornton et al. 1990, Rebouças 1999, Tundisi 2012).

Apesar dos estudos sobre a dinâmica de diatomáceas serem desenvolvidos no Brasil principalmente com comunidades epilíticas e planctônicas (e.g. Salomoni et al. 2005, Raupp et al. 2009), as diatomáceas que se acumulam nos sedimentos superficiais apresentam um grande potencial para estudos sobre biodiversidade (Gregory-Eaves & Beisner 2011). Os sedimentos integram organismos ao longo do tempo e do espaço e, assim, capturam informações do ecossistema como um todo mais eficientemente do que a coluna d'água e podem, portanto, apresentar respostas mais refinadas do que outros habitats (Gregory-Eaves & Beisner 2011). Estudos sobre as diatomáceas acumuladas em sedimentos de represas brasileiras são recentes, mas ainda bastante escassos. Presentemente, destacam-se quatro levantamentos florísticos (Fontana & Bicudo 2009, 2012, Almeida & Bicudo 2014, Faustino et al. 2016) e dois estudos ecológicos, quais sejam, Zorzal-Almeida et al. (2017b) que avaliaram a diversidade beta em 23 reservatórios do Estado de São Paulo e Zorzal-Almeida et al. (2017a) que avaliaram a resposta das diatomáceas planctônicas e de sedimento superficial em relação à heterogeneidade ambiental, uso do solo e conectividade em um sistema de seis reservatórios conectados também no Estado de São Paulo. Destacam-se ainda, dois trabalhos sobre a reconstrução paleoambiental da eutrofização de duas represas urbanas (Costa-Böddeker et al. 2012, Fontana et al. 2014).

Assim, o objetivo central deste trabalho foi analisar comparativamente a dinâmica de comunidades de diatomáceas de diferentes hábitats (plâncton e sedimentos superficiais) em cinco represas com distintos estados tróficos, situadas na Bacia do Médio Tietê/Alto Sorocaba. Esperava-se que (a) o estado trófico será o principal eixo direcionador da organização estrutural da comunidade de diatomáceas independentemente do tipo de hábitat, (b) que haverá relação negativa entre biodiversidade de diatomáceas e a eutrofização, (c) que os ambientes mais eutrofizados apresentarão menores valores de Contribuição dos Locais para a Diversidade Beta (LCBD), (d) que as espécies de diatomáceas particularmente associadas a condições oligotróficas apresentarão maiores valores de Contribuição das Espécies para a Diversidade Beta (SCBD) e (e) que as diatomáceas dos sedimentos superficiais fornecerão respostas mais sensíveis à eutrofização do que as planctônicas, uma vez que as primeiras fornecem respostas integradas no espaço e tempo (Smol 2008).

Por fim, a presente contribuição está vinculada a um projeo multidisciplinar mais amplo (Projeto *AcquaSed*) e contribuirá com informações limnológicas e autoecológicas de diatomáceas para a elaboração de um banco de dados regionais (rede de calibração), cujo propósito é avançar na compreensão dos padrões de distribuição das diatomáceas, sua utilização em bioindicação e sua aplicação na elaboração de um modelo de função de transferência diatomáceas-fósforo.

APRESENTAÇÃO DA TESE

A presente tese está organizada em três capítulos que serão submetidos a revistas especializadas em estudos ecológicos e florísticos. O **Capítulo 1** aborda as variações da diversidade beta na comunidade de diatomáceas de sedimento superficial e planctônicas em cinco represas com distintos estados tróficos (oligo- a hipereutrófica), com foco na eutrofização antropogênica. O **Capítulo 2** trata dos principais fatores estruturadores (preditores ambientais e espaciais) de diatomáceas do sedimento superficial e planctônicas em 31 represas do Estado de São Paulo. Este capítulo englobou todas as represas do projeto temático *AcquaSed*. Por fim, o **Capítulo 3** compreende o levantamento florístico das diatomáceas do sedimento superficial e planctônicas de 10 represas de três bacias hidrográficas, destacando as espécies com primeira citação para o Brasil e para o Estado de São Paulo e as informações ecológicas, focando principalmente a distribuição das espécies no gradiente de estado trófico.

MATERIAL E MÉTODOS GERAIS

Área de estudo

A área de estudo foi diferente entre os capítulos. O primeiro capítulo foi desenvolvido a partir dos dados coletados em 19 estações de amostragem de cinco represas da bacia do Médio Tietê/Alto Sorocaba. O segundo capítulo compreendeu as 31 represas do projeto temático AcquaSed e um total de 113 estações de amostragem, distribuídas em cinco bacias hidrográficas (Piracicaba, Capiravi e Jundiaí; Alto Tietê; Médio Tietê/Alto Sorocaba; Ribeira de Iguape/Litoral Sul e Alto Paranapanema), e o último capítulo considerou 10 represas de três bacias hidrográficas, com um total de 50 estações de amostragem (Piracicaba, Capiravi e Jundiaí; Alto Tietê e Médio Tietê/Alto Sorocaba). A descrição detalhada da área de estudo do Capítulo 1 é apresentada a seguir, uma vez que esta foi a área central deste estudo e foi incluída em todos os capítulos. Detalhes das áreas de estudo dos Capítulos 2 e 3 são apresentados nos próprios capítulos.

A Bacia Hidrográfica do Médio Tietê/Alto Sorocaba (Unidade de Gerenciamento de Recursos Hídricos – UGRHI 10) está localizada na região centro-sudeste do Estado de São Paulo e é constituída pela bacia do rio Sorocaba e de outros tributários do rio Tietê (Figura 1), com exceção dos rios Piracicaba, Capivari e Jundiaí que são afluentes do rio Tietê pela sua margem direita e compõem a bacia dos rios Piracicaba, Capivari e Jundiaí (UGRHI 5). Compreende o trecho que vai desde a barragem do Rasgão, à montante, até a barragem de Barra Bonita, à jusante (SigRH 2013). A área total da bacia do Médio Tietê/Sorocaba é de 12.108 km^2 e abrange 34 municípios com uma população de aproximadamente 12 milhões de pessoas (IPT 2008).

Ao longo do rio Tietê vários reservatórios foram construídos principalmente para atender à crescente demanda por energia elétrica. Devido ao carreamento de material alóctone em toda a bacia hidrográfica, o rio Tietê é constantemente impactado por efluentes domésticos e industriais recebidos em todo seu curso, desde a região mais industrializada do estado até o interior, onde estão localizadas monoculturas intensivas, indústrias, usinas de álcool e açúcar que contribuem para a deterioração da água (IPT 2008). A bacia do Médio Tietê/Alto Sorocaba, em particular, recebe forte influência das populações que residem à montante, principalmente da Bacia do Alto Tietê (UGRHI 06), que transfere águas com elevada carga de nutrientes, conforme demonstrado pelo monitoramento efetuado pela CETESB (2016).
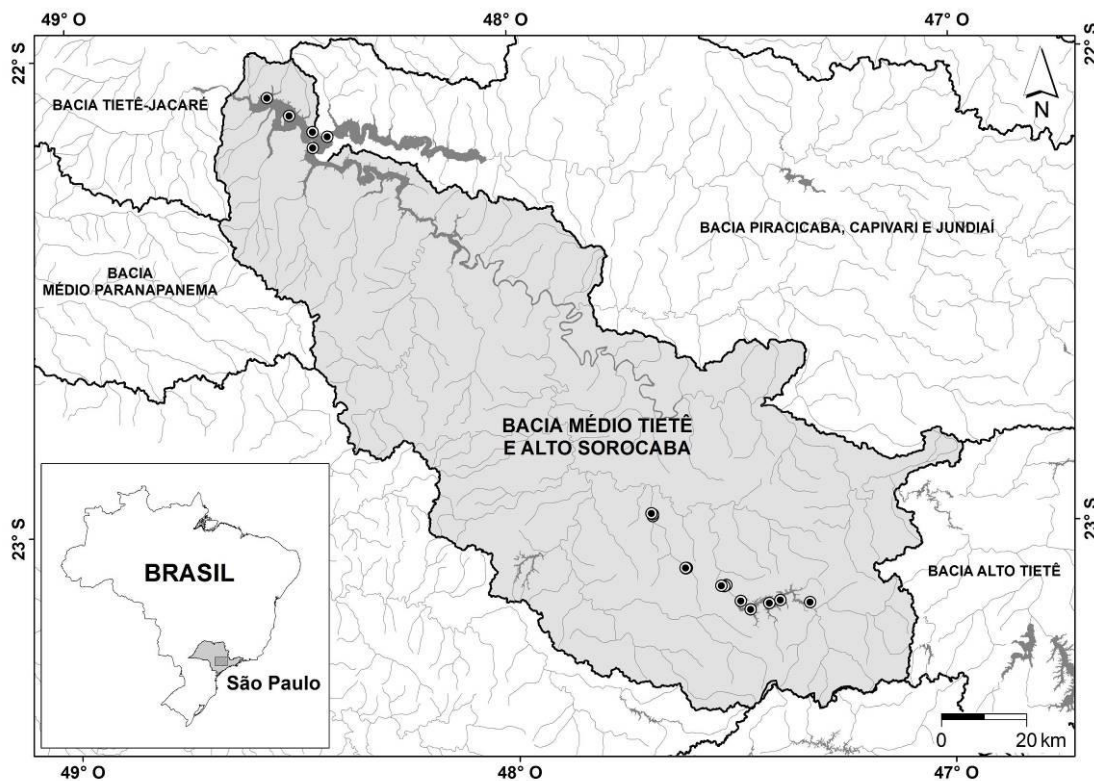
Figura 1. Mapa da Bacia Hidrográfica do Médio Rio Tietê-Alto Sorocaba indicando das 19 estações de amostragem distribuídas nas cinco represas principais incluídas neste estudo.

Este estudo compreendeu cinco represas (com 19 estações de amostragem) que foram abordadas em todos os capítulos (Figura 1) e que apresentam distintos estados tróficos[1]: Santa Helena (oligotrófica), Itupararanga (mesotrófica), Ipaneminha (mesotrófica), Hedberg (eutrófica) e Barra Bonita (hipereutrófica). Em seguida é apresentado um breve resumo sobre a construção e os principais usos de cada represa.

Represa de Santa Helena (Figura 2). Construída em 1938 e localizada no Município de Votorantim, é formada pelo represamento do rio Sorocaba. A barragem da Pequena Central Hidrelétrica (PCH) de Santa Helena é responsável pela produção de energia para consumo industrial, principalmente produção de cimento, uma das principais atividades industriais do município (Grupo Votorantim Energia 2015).

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[1] O estado trófico das represas foi inferido com os dados do presente estudo.
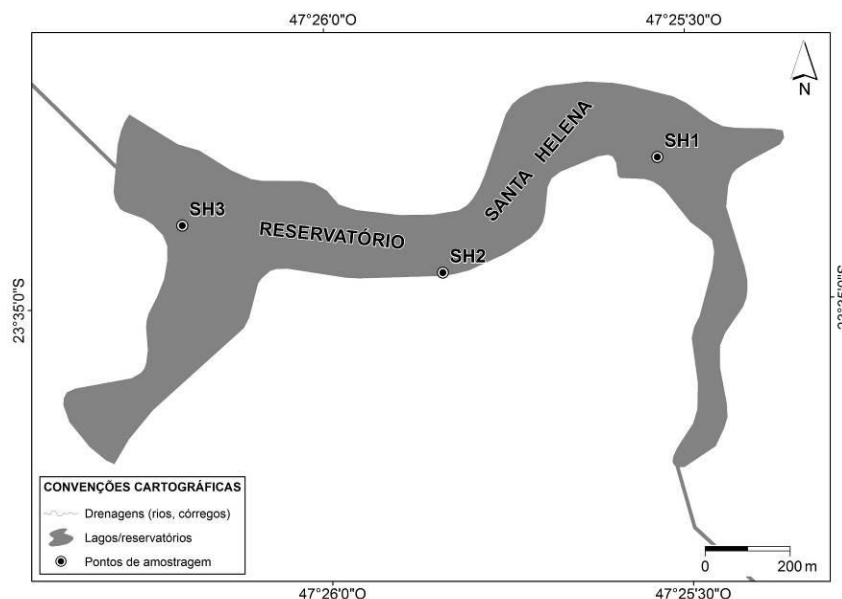
Figura 2. Represa de Santa Helena e localização das três estações de amostragem.

Represa de Itupararanga (Figura 3). Localizada no curso do Alto Rio Sorocaba, teve sua barragem construída em 1912 pela Light para gerar energia elétrica a partir do represamento dos rios Sorocamirim, Sorocaboçu e Una, tributários do rio Sorocaba. Em 1974, a usina passou a ser administrada pela Companhia Brasileira de Alumínio (CBA), do grupo Votorantim, e desde então a energia gerada atende exclusivamente esta empresa (Grupo Votorantim Energia 2015). Atualmente, a represa atende parte do abastecimento nos municípios de Sorocaba, Votorantim, Mairinque, Alumínio, Ibiúna e São Roque, totalizando aproximadamente 800 mil habitantes (IPT 2008). Além da geração de energia e abastecimento público, suas águas são aproveitadas para irrigação, navegação e lazer. Entre as atividades econômicas desenvolvidas na bacia destaca-se a atividade industrial nos municípios de Sorocaba, Votorantim e Alumínio. As atividades agrícolas e a vegetação nativa ocupam 42% e 25%, respectivamente, da área da bacia de drenagem (Cunha & Calijuri 2011). Em 1998, foi criada a Área de Preservação Ambiental (APA) de Itupararanga, com área de aproximadamente 936,5 km², declarando todo o entorno da represa como área de proteção ambiental (Secretaria do Meio Ambiente de São Paulo 2017).
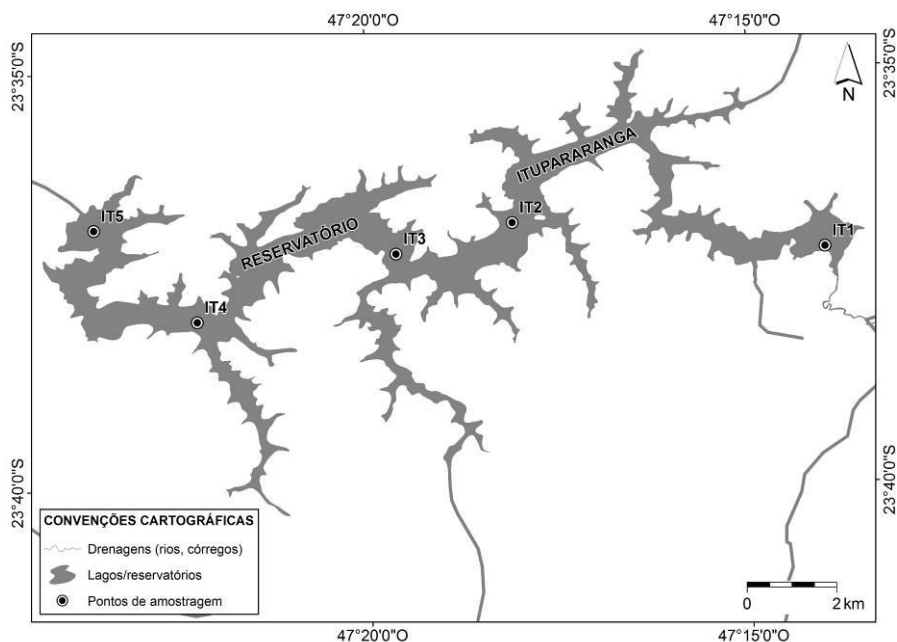
Figura 3. Represa Itupararanga e localização das cinco estações de amostragem.

Represa Ipaneminha (Figura 4). Localizada no município de Sorocaba e construída em 1976. Desde 1987 este município realiza a captação de suas águas para abastecimento público municipal. A represa Ipaneminha foi formada ao longo do rio Ipanema, um dos principais afluentes do rio Sorocaba e é utilizada como auxiliar da represa de Itupararanga, principalmente em períodos de estiagem. O monitoramento da qualidade da água do manancial é realizado mensalmente pelo SAAE Sorocaba – Serviço Autônomo de Água e Esgoto de Sorocaba (SAAE Sorocaba 2017).
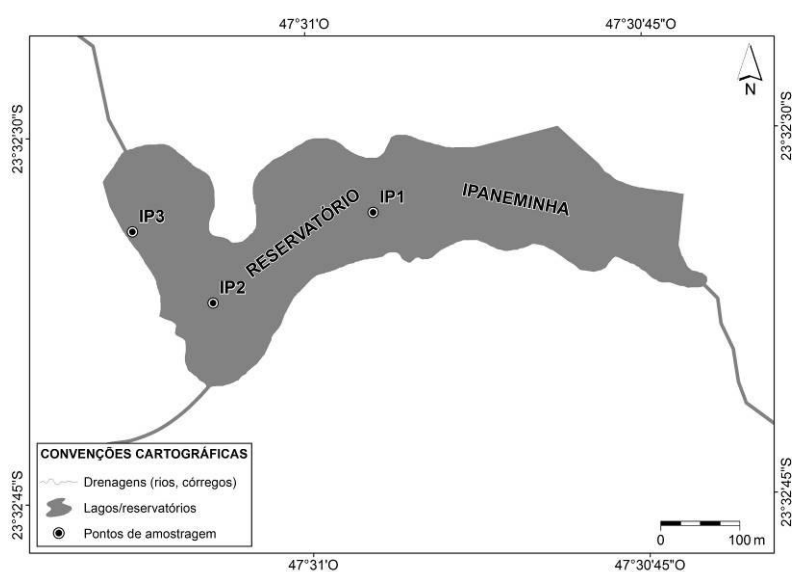
Figura 4. Represa Ipaneminha e localização das três estações de amostragem.

Represa Hedberg (Figura 5). Localizada na Floresta Nacional de Ipanema (FLONA Ipanema), a represa foi construída em 1811 e é formada pelo represamento dos rios Ipanema e Verde, que por sua vez integram a bacia do rio Sorocaba (Ibama 2003), sendo, portanto, o reservatório mais antigo do Brasil (Salazar 1983). A unidade de conservação federal foi criada em 1992 e desde 1995 é aberta ao público para visitação, sendo que a represa Hedberg compõe o patrimônio histórico da unidade de conservação. Além disso, próximo à represa existe infraestrutura instalada para recepção de visitantes (restaurante, lanchonete, quiosques e parque infantil).
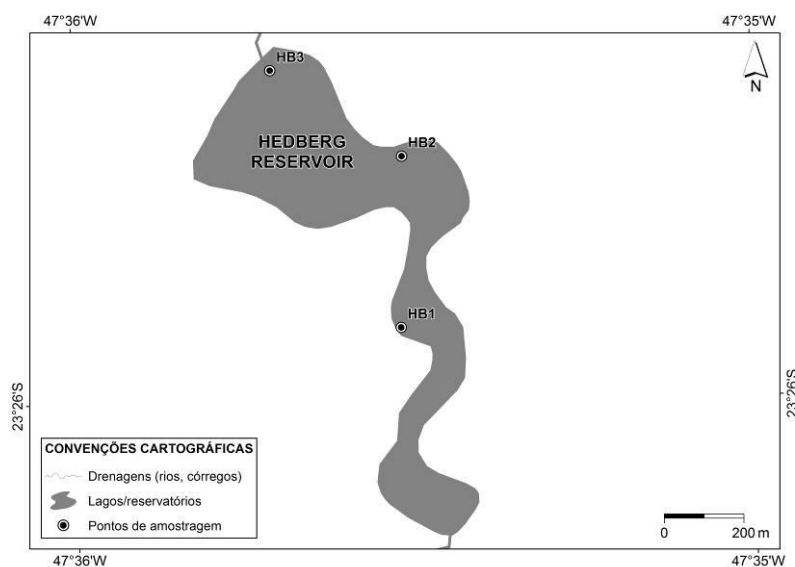
Figura 5. Represa Hedberg e localização das três estações de amostragem.

Represa de Barra Bonita (Figura 6). Localizada na bacia do Médio Tietê Inferior, é o primeiro e mais antigo de uma série de seis grandes represamentos construídos ao longo do rio Tietê, com o principal objetivo de geração de energia elétrica (Tundisi et al. 2008). Sua construção foi concluída em 1964 com o represamento dos rios Piracicaba e Tietê, localizando-se em uma das regiões mais populosas e desenvolvidas do interior do Estado de São Paulo. Além da geração de energia elétrica, as águas da represa são utilizadas para turismo, recreação, irrigação e abastecimento rural, urbano e industrial (Valêncio et al. 2012). Maia (2009) destaca que praticamente todo o esgoto doméstico e industrial das cidades da região é lançado diretamente nos corpos d'água sem qualquer tratamento, o que vem resultando na deterioração de suas águas.
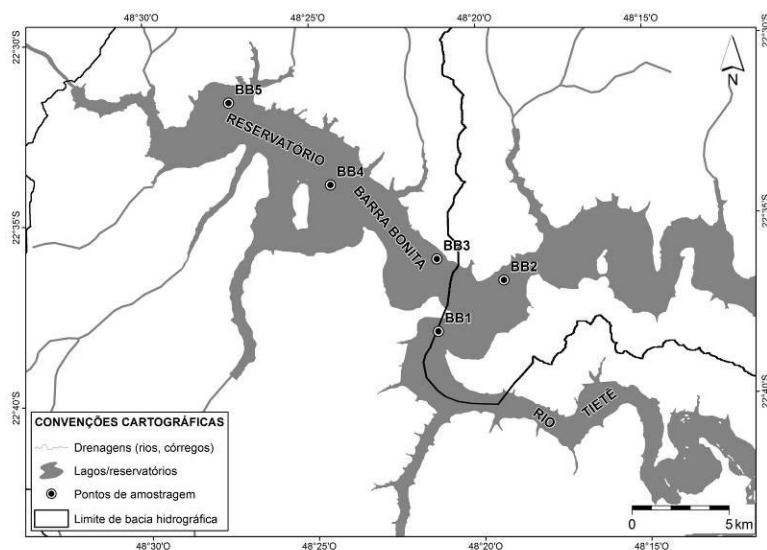
Figura 6. Represa de Barra Bonita e localização das cinco estações de amostragem.

A Tabela 1 resume as principais características das cinco represas e a Tabela 2 apresenta o número de amostras analisadas em cada sistema.

Tabela 1. Principais características dos cinco reservatórios estudados na bacia do Médio Tietê/Alto Sorocaba. Vmax: volume máximo.

	Santa Helena	Itupararanga	Ipaneminha	Hedberg	Barra Bonita
Operação	1938[a]	1912[a]	1976[b]	1811[c]	1963[e]
Área (km²)	0,38[a]	30,0[a]	0,15[b]	0,13[c]	310[e]
Vmax (10⁶ m³)	1,84[a]	302[a]	0,20[b]	0,50[d]	3.160[e]
Profundidade média (m)	10,5[a]	7,8[a]	3,2*	5,2*	10,2[e]
Tempo de retenção (dias)	3[a]	120-280[a]	-	-	30-90[e]
Principal uso	Geração de energia[a]	Abastecimento e geração de energia[a]	Abastecimento	Desativada	Geração de energia[e]
Estado trófico	Oligotrófica[f]	Mesotrófica[f]	Mesotrófica[f]	Eutrófica[f]	Hipereutrófica[f]

a: informação do Grupo Votorantim Energia (2015); b: informação do SAAE Sorocaba (2017); c: Ibama (2008); d: Silva et al. (2016); e: Tundisi et al. (2008); f: informações obtidas neste estudo; (-): informação não disponível; *: profundidade máxima obtida neste estudo.

Tabela 2. Resumo das coletas para as cinco represas selecionadas neste estudo.

Tipo de amostra	Represa	Verão	Inverno
Fitoplâncton	Santa Helena	3	3
	Itupararanga	5	5
	Ipanema	3	3
	Hedberg	3	3
	Barra Bonita	5	5
Sedimento superficial	Santa Helena	-	3
	Itupararanga	-	5
	Ipanema	-	3
	Hedberg	-	3
	Barra Bonita		5
TOTAL			**57**

Amostragens em campo e tratamento das amostras

O total de 19 estações de amostragem foram selecionadas nas cinco represas e a seleção dos locais levou em conta sua utilização para abastecimento (no caso de Itupararanga e Ipaneminha), abrangência da heterogeneidade da qualidade da água dos compartimentos das represas em relação à eutrofização e o local mais profundo de cada represa na região da barragem. Assim, as estações de amostragem foram distribuídas no corpo central dos principais braços (no caso de Barra Bonita), na entrada dos principais tributários ou próximo de estações de captação de água e na região da barragem. As amostragens da coluna d'água foram realizadas no verão e no inverno com auxílio de garrafa de van Dorn na subsuperfície, profundidade média e 1 m acima do sedimento. A temperatura da água, pH, turbidez, condutividade elétrica e oxigênio dissolvido foram obtidos *in situ* com auxílio de sonda multiparâmetro Horiba U50. A transparência da água foi obtida a partir das medidas do disco de Secchi (Cole 1992). As análises das demais variáveis limnológicas (oxigênio dissolvido, alcalinidade, nitrito, nitrato, amônio, ortofosfato, fósforo total dissolvido, nitrogênio e fósforo total e sílica solúvel reativa) seguiram o protocolo do American Public Health Association (APHA 2005). As amostras para a fração dissolvida dos nutrientes foram filtradas em filtro Whatman GF/F, em baixa pressão (< 0,5 atm). A partir do material retido no filtro foi realizada a análise de clorofila-*a* (corrigida da feofitina) seguindo o método do etanol 90% (Sartory & Grobellar 1984), corrigida dos feopigmentos por acidificação. O Índice de Estado Trófico (IET) proposto por Carlson (1977) e modificado por Lamparelli (2004) foi calculado para represas a partir dos valores de fósforo total e clorofila-*a* da subsuperfície da coluna d'água.

As diatomáceas fitoplanctônicas também foram amostradas com garrafa de van Dorn no verão e no inverno em três diferentes profundidades (subsuperfície, profundidade

média e 1 m acima do sedimento) e amostras integradas foram utilizadas para caracterizar a coluna d'água de cada estação amostral. As diatomáceas do sedimento superficial foram amostradas apenas no inverno com testemunhador de gravidade UWITEC aproveitando-se os dois primeiros centímetros superficiais, que geralmente integram de um a dois anos de informação (excepcionalmente até quatro anos em locais com baixa taxa de sedimentação) (Smol 2008).

As amostras de diatomáceas do sedimento superficial e do fitoplâncton foram oxidadas segundo o método de Battarbee (2001), utilizando peróxido de hidrogênio (H_2O_2 35%) e ácido clorídrico (HCl 37%) e as lâminas permanentes foram preparadas utilizando Naphrax® como meio de inclusão (*IR* = 1,73). Para a confecção das lâminas permanentes, foram integrados de 50 a 80 mL de amostras de cada um dos estratos amostrados na coluna da água (subsuperfície, profundidade média e um metro acima do fundo). Para as lâminas do sedimento superficial oxidou-se 0,5 g de sedimento seco e, após sua oxidação, utilizou-se de 0,05 mL a 0,30 mL de amostra oxidada para montagem das lâminas.

O exame taxonômico das diatomáceas foi baseado em análise populacional de modo a representar a variabilidade morfológica dos táxons. A análise foi feita utilizando microscópio óptico binocular Zeiss Axioskop 2 plus equipado com contraste-de-fase e sistema de captura de imagem. A identificação dos táxons foi realizada a partir de obras clássicas e recentes (e.g. Hustedt 1950, Patrick & Reimer 1966, Round et al. 1990, Metzeltin & Witkowski 1996, Lange-Bertalot et al. 2011) bem como floras regionais (e.g. Almeida et al. 2014, Marquardt & Bicudo 2014, Faustino et al. 2016). O sistema de classificação utilizado foi o de Medlin & Kaczmarska (2004) para as categorias supra-ordinais e Round et al. (1990) para as subordinais.

Para análise quantitativa das diatomáceas foi realizada contagem em transeções longitudinais nas lâminas permanentes de acordo com o método de Battarbee et al. (2001), tendo como unidade básica de contagem a valva (frústula completa foi considerada como duas). Fragmentos foram incluídos desde que sua identificação fosse possível e que se visualizasse, pelo menos, 50% da valva (Battarbee et al. 2001). Em cada amostra dois critérios foram adotados para o estabelecimento do limite de contagem: mínimo de 400 valvas no total e eficiência mínima de contagem de 90% (Pappas & Stoermer 1996) para padronizar o esforço de quantificação das amostras. As amostras foram depositadas no "Herbário Científico do Estado Maria Eneyda P. Kauffmann Fidalgo" do Instituto de Botânica de São Paulo sob os números de herbários de SP469229 a SP469247 para as

lâminas de sedimento superficial e SP469453 e SP469454 e SP469488 a SP469523 para as planctônicas.

Para a análise numérica dos dados, a riqueza específica foi considerada como o número de táxons por unidade amostral (Magurram 2013). Cada capítulo da tese possui análises numéricas específicas conforme os respectivos objetivos. Todas as análises foram desenvolvidas utilizando-se o ambiente R v. 3.3.1 (R Core Team 2016).

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CAPÍTULO 1

Surface sediment diatoms respond more effectively than phytoplankton to eutrophication gradients

Surface sediment diatoms respond more effectively than phytoplankton to eutrophication gradients

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Abstract

Beta diversity, the spatial and temporal variation in species composition, is a key concept in community ecology. This study aimed at studying variations in beta diversity of surface sediment and planktonic diatom assemblages in tropical reservoirs ranging from oligo- to hypereutrophic conditions. We expect that beta diversity will be negatively correlated to the eutrophication gradient and that this relation will be more efficiently captured by the surface sediment assemblage. In general, the species replacement contributed most to beta diversity and, then, we modelled the relation between Local Contribution to Beta Diversity from this component (Repl$_{LCBD}$) and proxies of productivity (total phosphorus, total nitrogen and axis one of PCA). We found that beta diversity of surface sediment and summer phytoplankton diatoms was negatively related to the eutrophication gradient. This negative relation was more evident in the surface sediment assemblage, as predicted, probably because surface sediments integrate individuals from different habitats and over time, allowing a more refined response to variations in beta diversity. Winter phytoplankton diatoms did not present a clear response to the predictor variables. In general, oligo- and mesotrophic sites and the species *Punctastriata lancettula* particularly associated to oligotrophic conditions showed higher Repl$_{LCBD}$ and SCBD$_{Total}$ values, mainly in the surface sediment assemblage. However, species with preferences for nutrient-rich environments also presented high SCBD$_{Total}$ values in the surface sediment

and planktonic (summer and winter) assemblages. Species such as *Aulacoseira ambigua*, *A. granulata* var. *angustissima*, *A. granulata* var. *granulata*, *Cyclotella meneghiniana* showed high frequency in samples and high abundance variation. Our study demonstrated the potential of diatom assemblages from tropical reservoirs, particularly from the surface sediment in biodiversity studies, since they presented clear response to the eutrophication gradient, capturing integrated information from the ecosystem.

Key-words: beta diversity, biodiversity, eutrophication, LCBD, SCBD, uniqueness.

Introduction

Freshwater ecosystems harbor high biodiversity despite the area covered by freshwater habitats (Strayer and Dudgeon 2010) and understanding the process that structure and maintain biodiversity in the ecosystems have large interest in community ecology (Legendre and De Cáceres 2013; Sor et al. 2018). Beta diversity, which estimates the differentiation of communities among sites in terms of species richness and composition (Whittaker 1960; 1972), is an interesting approach to study biodiversity because it allows identifying important sites across a landscape, which may represent priority for conservation and restoration initiatives, for example. Beta diversity comprises two different processes that contribute jointly to differentiation of sites: species replacement and richness difference. In brief, species replacement (or turnover) is related to the fact that "species tend to replace each other along ecological gradients" and richness difference implies that "one community may include a larger number of species than another" (Legendre 2014). Richness difference can be called nestedness when a poorest site is a subset of a richest site (Baselga 2012).

Environmental gradients and species occurrence across the landscape are factors that can positively affect beta diversity (López-González et al. 2015; Sor et al. 2018). Computing beta diversity has been used to understand community response to natural (Lamy et al. 2015; Myers et al. 2015) and anthropogenic disturbances, such as eutrophication of aquatic ecosystems (Vilar et al. 2014; Zorzal-Almeida et al. 2017a). Eutrophication, principally caused by phosphorus and nitrogen loads, has been widely reported as a primary threat to aquatic biodiversity and it represents a global challenge to environmental conservation and management (Smith and Schindler 2009; Bennion and Simpson 2011). Despite nutrient enrichment has been positively related to beta diversity

(Chase and Leibold 2002; Chase 2010), severe eutrophication may result in unfavorable environmental conditions to aquatic species, leading to reduction in beta diversity (Donohue et al. 2009; Vilar et al. 2014; Zorzal-Almeida et al. 2017a).

Diatoms (Bacillariophyta) are among the most used biological groups in biodiversity studies of aquatic ecosystems because they are sensitive to changes in environmental conditions (Bennion and Simpson 2011). Aside from planktonic diatoms, the assemblages accumulated in surface sediments have an important contribution to biodiversity studies, given surface sediments accumulate individuals from different habitats and through time, capturing integrated information from the whole ecosystem and its watershed over longer time scales (Smol 2008; Dong et al. 2011). Nonetheless, the potential of these organisms was not fully explored (Gregory-Eaves and Beisner 2011). On the other hand, planktonic diatoms can provide important information about seasonal changes in the assemblage dynamics, since they rapidly respond to changes in mixing patterns, light and nutrients availability (Fonseca and Bicudo 2011). Therefore, it is expected that surface sediment diatoms can provide a more effective response to changes in biodiversity in freshwater ecosystems than phytoplankton.

Both planktonic and benthic diatom assemblages have been widely explored in order to access the ecological status of lakes and rivers (Potapova and Charles 2007; Bennion and Simpson 2011; Tammelin et al. 2017). However, few studies have focused on the biodiversity of both assemblages simultaneously (Zorzal-Almeida et al. 2017a). Particularly in tropical regions, most of ecological studies were carried out in lotic ecosystems (Sor et al 2018; Bere and Tundisi 2011; 2012 Wetzel et al. 2012). For lentic tropical environments, planktonic diatoms were analyzed in response to the flood pulse in an Amazonian lake (Raupp et al. 2009) and to characterize the dynamic of the diatom assemblage in lake and river (Algarte et al. 2017). Regarding studies encompassing surface sediment diatoms, they found that diatoms responded primarily to anthropogenic eutrophication and environmental heterogeneity (Faustino et al. 2016; Zorzal-Almeida et al. 2017a). Thus, there is a need to investigate whether diatom assemblages from different habitats exhibit the same general patterns of biodiversity.

This study aims at studying beta diversity in diatom communities from surface sediment and phytoplankton across a set of tropical reservoirs with different trophic status (ranging from oligo- to hypereutrophic conditions). We decomposed beta diversity into the relative contributions of species replacement (turnover) and richness difference (nestedness) components to better examine the response of diatom communities to

anthropogenic eutrophication. We also partitioned total beta diversity into LCBD and SCBD components to verify which sites and diatom species are the most important contributors to beta diversity in this set of reservoirs. We predicted that (i) beta diversity will be negatively correlated to anthropogenic eutrophication and the negative relation will be more evident in the surface sediment assemblage, and (ii) oligotrophic sites and species particularly related to such conditions will present higher contribution to beta diversity.

Material and methods

Study area and field work

      The study area encompasses five reservoirs located in the Médio Tietê/Alto Sorocaba Basin (Figure 1) used for water supply and power generation. The reservoirs were selected in order to comprise a trophic gradient (from oligo- to hypereutrophic conditions): Santa Helena (oligotrophic), Itupararanga (mesotrophic), Ipaneminha (mesotrophic), Hedberg (eutrophic) and Barra Bonita (hypereutrophic). There were three to five sampling sites per reservoir and sites were distributed according to the reservoir size, the main water inputs (main rivers or streams) and in the deepest region of the reservoirs.
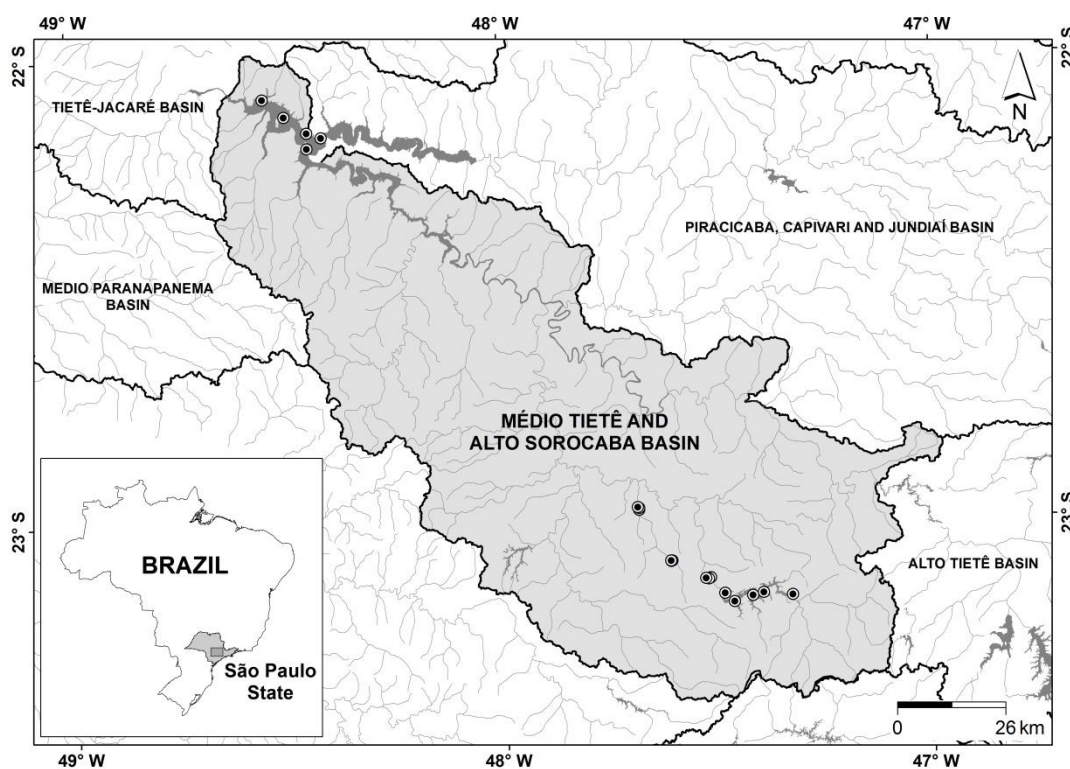
Fig. 1 Location of the five reservoirs and sampling sites in the Médio Tietê/Alto Sorocaba basin. Grey area represents the watershed of the reservoirs.

We sampled nineteen sites in the five reservoirs during two climatic periods (austral winter and summer) in 2014. Water samples were collected with a van Dorn bottle (at subsurface, mean depth, and 1 m above the sediments) and we used the mean values of the variables to describe the environmental conditions of each sampling site. Water temperature (ºC), pH and conductivity ($\mu S\ cm^{-1}$) were measured in field using standard electrodes (Horiba U-50). The analytical procedure for dissolved oxygen (DO, mg L^{-1}), total nitrogen (TN, $\mu g\ L^{-1}$), total phosphorus (TP, $\mu g\ L^{-1}$) and soluble reactive silica (SRS, mg L^{-1}) followed Standard Methods (APHA 2005). We extracted chlorophyll-*a* ($\mu g\ L^{-1}$) using 90% ethanol (Sartory and Grobbelaar 1984) and we estimated the Trophic State Index following an adapted Carlson's TSI to tropical reservoirs (Zorzal-Almeida et al. 2017b), based on the values of chlorophyll-*a* and total phosphorus.

Integrated water column samples were used to describe the phytoplankton diatom assemblage. Surface sediment diatoms were sampled only in winter (19 samples) using a UWITEC gravity corer. Each site was sampled in triplicate, using the first two centimeters of the sediment core. Diatom samples were oxidized according to Battarbee et al. (2001), using concentrated hydrogen peroxide (H_2O_2 35%) and hydrochloric acid (HCl 37%). Permanent slides were prepared using Naphrax® as inclusion medium. Diatoms were quantified at a magnification of 1000× and counting limit was determined by two criteria: a minimum of 400 valves per slide (Battarbee et al. 2001) and at least 90% in counting efficiency (Pappas and Stoermer 1996). Species abundances are expressed as a percentage of the total diatom counts in each sample.

Data analysis

We computed total beta diversity (BD_{Total}) as the total variance of the community composition for the five reservoirs together and for each reservoir individually (surface sediment in winter and phytoplankton datasets in summer and winter) using Hellinger-transformed species-by-site matrices of diatom relative abundances and presence-absence data (Legendre and De Cáceres 2013). Then, BD_{Total} of all reservoirs and reservoirs individually was partitioned into species replacement ($Repl_{Total}$) and richness difference ($RichDiff_{Total}$) components in order to identity their relative contributions to BD_{Total} (Legendre 2014). We also calculated the Local Contribution to Beta Diversity ($LCBD_{Total}$) and Species Contribution to Beta Diversity ($SCBD_{Total}$) coefficients from BD_{Total} of all reservoirs together. In short, $LCBD_{Total}$ values represent "the degree of uniqueness of the

sampling units in terms of community composition" and $SCBD_{Total}$ values represent the relative contribution of each species to the overall beta diversity. The larger the values of $LCBD_{Total}$ and $SCBD_{Total}$ coefficients, the greater the contribution of a site and a species to BD_{Total}, respectively. Further details about BD_{Total}, $LCBD_{Total}$ and $SCBD_{Total}$ calculations can be found in Legendre and De Cáceres (2013). We also calculated LCBD values from the species replacement ($Repl_{LCBD}$) component to identify how exceptional each sampling site is in terms this component (Legendre 2014).

We run a principal component analysis (PCA) with log-transformed environmental variables (except pH) to reduce the dimensionality of the environmental data. We run PCAs using three different sets of environmental variables: values of summer, winter and mean values between summer and winter. Each PCA allowed us to access the most important environmental variables to be used as predictors in our models for summer, winter and surface sediment diatoms, respectively. PCA ordination showed that the reservoirs sampling sites were ordered mainly in relation to the trophic gradient (see Results). Thus, based on the first axis of PCA, we selected total phosphorus (TP), total nitrogen (TN), chlorophyll-*a* (Chl) and Trophic State Index (TSI, Table 2) as predictor variables in our candidate models. Subsequently, the first axis of PCA (PC1) was retained to be used as a predictor as well (Philippi 1993). We also used species richness as a covariable for each candidate model. We modeled these predictor variables (TP, TN, Chl, TSI and PC1) separately because they were highly collinear.

Since $LCBD_{Total}$ and $Repl_{LCBD}$ values range from 0 to 1, we used beta regression (Cribari-Neto and Zeileis 2010) to model their variations in relation to the selected environmental variables (TP, TN, Chl, TSI and PC1, see Results) for surface sediment and phytoplankton diatoms (summer and winter).

We modeled $SCBD_{Total}$ values, which also range from 0 to 1, in relation to community metrics (frequency in samples and total abundance) using beta regression to test which one is the most important to $SCBD_{Total}$. Following Burnham and Anderson (2002) recommendations, we calculated the second-order Akaike information criterion (AIC_c) for each of our fitted models. The model with smaller value of AIC_c is considered the best model. However, models with AIC_c differences (delta AIC_c) between 0-2, 4-7 and > 10 have substantial level of empirical support, less empirical support and no empirical support, respectively (Burnham and Anderson 2002).

All statistical analyses were performed in R v. 3.3.1 (R Core Team 2016) using the packages vegan for PCA analysis (Oksanen et al. 2017), adespatial for BD_{Total}, $Repl_{Total}$,

RichDiff$_{Total}$, LCBD$_{Total}$, SCBD$_{Total}$ and Repl$_{LCBD}$ calculations (Dray et al. 2017) and betareg to model the relationship between LCBD$_{Total}$ and Repl$_{LCBD}$ and the predictor variables (Cribari-Neto and Zeileis 2010).

Results

The reservoirs ranged from oligo- to hypereutrophic conditions. Higher conductivity, nutrients (total nitrogen and total phosphorus) and chlorophyll-*a* values were recorded in the hypereutrophic reservoir (Barra Bonita), while the smallest values were observed in the oligotrophic reservoir (Santa Helena, Table 1). Higher water transparency was also found in oligo- and mesotrophic reservoirs (Santa Helena and Itupararanga).

Table 1 Environmental variables (minimum, maximum and mean values) recorded in the five reservoirs in summer and winter. Depth: depth of the sampling site (m), Secchi: water transparency (m), Temp: water temperature (°C), Cond: conductivity (µS cm^{-1}), DO: dissolved oxygen (mg L^{-1}), TN: total nitrogen (µg L^{-1}), TP: total phosphorous (µg L^{-1}), SRS: soluble reactive silica (mg L^{-1}), Chl: chlorophyll-*a* (µg L^{-1}).

	Santa Helena		Itupararanga		Ipaneminha		Hedberg		Barra Bonita	
	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean
Summer										
Depth	4.0-9.5	7.2	5.9-14.0	9.7	2.1-3.2	2.7	2.0-5.2	3.9	13.6-16.7	16.7
Secchi	1.0-1.2	1.1	0.7-1.3	0.9	0.4-0.5	0.5	0.3-0.4	0.4	0.4-1.0	0.4
Temp	24.3-24.6	24.5	24.1-25.5	24.6	23.2-23.3	23.3	22.3-22.7	22.5	26.4-27.2	26.4
pH	6.9-7.0	7.0	6.7-7.6	7.1	6.6-6.7	6.7	6.5-6.6	6.5	7.3-8.0	7.7
Cond	94.5-100.0	100.0	90.0-109.7	98.4	158.5-161.5	160.0	104.3-117.0	110.4	341.7-383.0	321.7
DO	5.7-6.2	6.0	3.2-6.5	4.7	3.1-4.1	3.5	3.8-4.3	4.1	2.1-4.1	3.7
TN	482.3-506.0	502.5	447.0-2270.0	1196.1	478.4-597.0	543.4	672.4-755.5	767.2	4670.5-10651.0	5393.0
TP	9.0-12.6	11.1	11.1-53.0	24.2	28.8-36.6	33.5	77.1-109.0	88.2	172.5-381.3	289.3
SRS	2.7-2.8	2.8	2.0-3.0	2.6	3.0-3.4	3.1	6.2-6.5	6.3	3.2-4.1	3.6
Chl	3.2-5.0	4.2	10.1-27.6	15.7	4.8-10.2	6.7	5.1-25.4	15.7	28.0-67.0	67.0
Winter										
Depth	4.0-9.1	6.9	4.5-13.9	9.3	1.5-2.2	1.8	2.0-5.0	3.7	12.0-20.0	15.2
Secchi	1.6-1.9	1.8	0.8-1.7	1.1	0.7-0.9	0.8	0.6-1.0	0.8	1.0-1.7	1.4
Temp	16.5-17.3	17.0	16.7-18.6	17.3	19.4-21.8	20.4	18.4-19.5	18.9	18.1-18.5	18.3
pH	7.0-7.3	7.2	6.6-7.4	5.6	7.3-7.5	7.4	8.3-8.7	8.5	7.0-7.6	7.3
Cond	97.5-102.7	100.6	97.0-115.7	103.7	158.5-174.0	168.3	156.0-157.3	157.0	337.3-487.7	390.0
DO	6.2-7.2	6.8	4.2-7.4	6.0	9.0-10.5	9.5	6.2-8.2	7.0	2.4-7.3	5.2
TN	600.0-660.0	633.8	829.1-1070.0	988.0	1281.0-1349.7	1321.2	1519.2-1658.4	1598.0	2752.3-9767.0	5459.7
TP	16.3-20.0	18.2	21.6-46.3	30.2	31.0-36.5	33.7	71.1-85.3	77.6	118.4-503.0	249.2
SRS	1.0	1.0	2.3-4.1	2.8	1.3-1.6	1.4	2.1-2.7	2.5	1.7-2.3	1.9
Chl	2.8-4.2	3.2	3.4-30.0	14.4	9.7-12.7	11.0	4.2-74.5	32.0	29.0-66.6	48.5

Total species richness was 142, 141 and 126 for surface sediment, summer and winter phytoplankton diatom assemblages, respectively. Considering abundance and presence-absence data, total beta diversity (BD_{Total}) for all reservoirs was similar and ranged respectively from 0.38 (surface sediment) to 0.41 (summer phytoplankton) and from 0.38 (surface sediment) to 0.40 (summer phytoplankton, Figure 2). The contribution of the species replacement component ($Repl_{Total}$) was, in general, higher than that of richness difference component ($RichDiff_{Total}$). However, the $RichDiff_{Total}$ component increased for some reservoirs using presence-absence data, mainly when surface sediment diatoms were considered (Figure 2D). All further analysis showed similar results using abundance or presence-absence data, therefore, we will present results of abundance data hereafter.
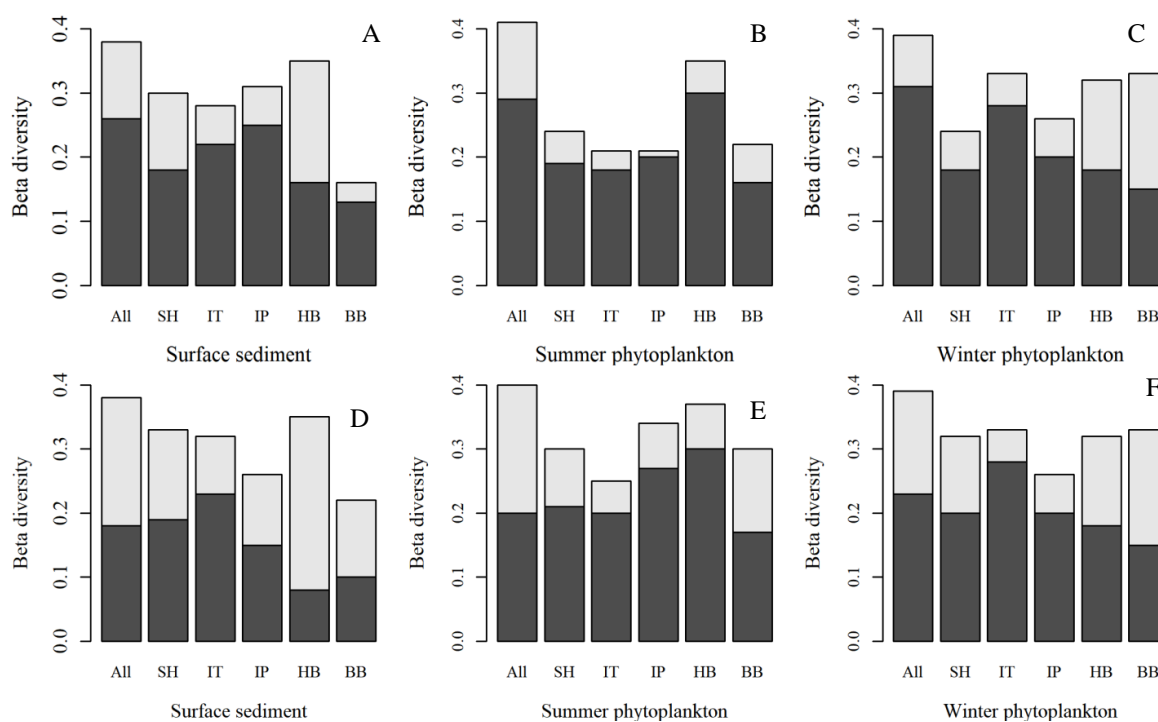
Fig. 2 Variation in beta diversity components - species replacement ($Repl_{Total}$, dark gray) and richness difference ($RichDiff_{Total}$, light gray) - for (A and D) surface sediment, (B and E) summer phytoplankton and (C and F) winter phytoplankton diatoms (line 1 is based on abundance data and line 2 on presence-absence data). SH: Santa Helena (oligotrophic), IT: Itupararanga (mesotrophic), IP: Ipaneminha (mesotrophic), HB: Heberg (eutrophic) and BB: Barra Bonita (hypereutrophic) reservoirs. Total beta diversity ranges from 0 to 1.

PCAs performed with environmental variables from summer, winter and mean values between summer and winter ordered the sampling sites mainly in relation to the trophic gradient along the first axis. The most important variables of axis one of PCA (PC1) were total phosphorus (TP), total nitrogen (TN), chlorophyll-*a* (Chl) and Trophic State Index (TSI, Table 2). Thus, PC1 clearly reflects an eutrophication gradient, where these environmental variables have positive correlation with PC1.

Models fitted with $LCBD_{Total}$ and $Repl_{LCBD}$ values exhibited similar general patterns. Thus, we will present the results of models fitted between $Repl_{LCBD}$ values and our predictor variables, since this was the most representative component of this set of reservoirs. For the surface sediment assemblage, $Repl_{LCBD}$ values were significantly and negatively related to the indicators of eutrophication (TP or PC1, including or not species richness as explanatory variable). These models were similarly supported by the data according to delta AIC_c (Table 3; Figure 3). For summer phytoplankton diatoms, $Repl_{LCBD}$ values were significantly related to total nitrogen concentration or PC1 (including species richness as explanatory variable, Table 3, Figure 4). $Repl_{LCBD}$ was negatively correlated to species richness for phytoplankton in summer. The residuals of the selected models did not show any spatial autocorrelation. In Figures 3 and 4 we plotted the models with the lowest AIC_c values for surface sediment and summer phytoplankton diatoms. For both diatom assemblages, $Repl_{LCBD}$ values were negatively related to the variables expressing a trophic gradient. It is noteworthy that the negative relationship between $Repl_{LCBD}$ and explanatory variables was more evident in the surface sediment dataset (Figures 3 and 4). Furthermore, for winter phytoplankton diatoms there were no superior model according to the AIC_c criteria. All the selected models are available in Electronic Supplementary Material for both abundance-based (Table S1) and presence-absence data (Table S2).

Table 2 PCA results showing that eutrophication indicators are positively and significantly (p<0.05) correlated with the first axis of PCA. Environmental variables codes available in Table 1.

	Mean summer and winter	Summer	Winter
TP	0.94	0.88	0.93
TN	0.92	0.94	0.95
Chl	0.79	0.77	0.69
TSI	0.89	0.73	0.81

Table 3 Selected models for species replacement LCBD (Repl$_{LCBD}$) values for surface sediment and summer phytoplankton diatom using abundance data.

	Estimate	*SE*	*Z*	*P*	*AICc*
Surface sediment					
Intercept	-2.10	0.13	-16.32	0.00000	-126.6
TP(log)	-0.20	0.03	-6.16	0.00000	
Intercept	-1.95	0.16	-12.48	0.00000	-125.7
TP(log)	-0.22	0.03	-6.73	0.00000	
Richness	0.00	0.00	-1.52	0.12900	
Intercept	-2.75	0.07	-38.58	0.00000	-124.6
PC1	-0.28	0.04	-6.43	0.00000	
Richness	-0.01	0.00	-2.48	0.01310	
Summer phytoplankton					
Intercept	-2.64	0.08	-35.11	0.00000	-127.7
PC1	-0.15	0.05	-3.26	0.00113	
Richness	-0.01	0.00	-3.53	0.00042	
Intercept	-1.99	0.33	-6.12	0.00000	-124.9
TN(log)	-0.10	0.04	-2.54	0.01117	
Richness	-0.01	0.00	-2.88	0.00401	

Fig. 3 Relationship between the Local Contribution to Beta Diversity of the replacement component (Repl$_{LCBD}$) of surface sediment diatoms and total phosphorus concentrations based on abundance data. Blue: oligotrophic, golden and green: mesotrophic, red: eutrophic, purple: hypereutrophic.
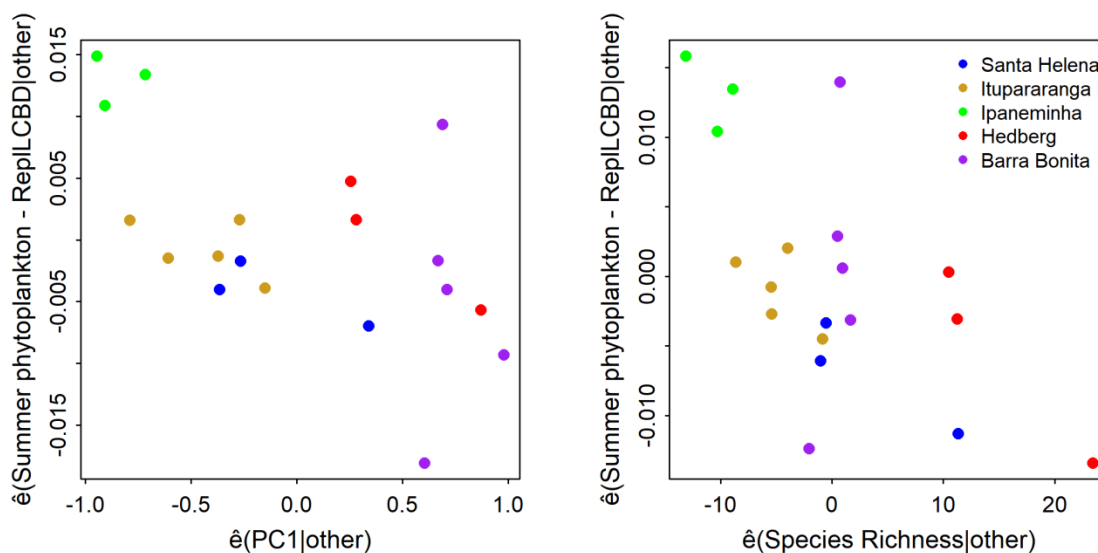
Fig. 4 Relationship between the Local Contribution to Beta Diversity of the replacement component (Repl$_{LCBD}$) of phytoplankton diatoms in summer and axis one of PCA (PC1, Fig. 4A), controlling for species richness (Fig. 4B). Blue: oligotrophic, golden and green: mesotrophic, red: eutrophic, purple: hypereutrophic.

Species Contribution to Beta Diversity (SCBD$_{Total}$) values were significantly correlated to frequency in samples and total abundance (see Tables S4 and S5 in Electronic Supplementary Material). However, the models based on frequency in samples presented lowest AIC$_c$ values and then better represented the variation in SCBD$_{Total}$ values than total abundance for the three diatom assemblages. Regarding species composition, Table 4 presents the ten first diatoms with higher SCBD$_{Total}$ values for surface sediment, summer and winter phytoplankton diatoms, respectively and, in general, these three assemblages shared some diatom species. In the surface sediment assemblage, the benthic species *Punctastriata lancettula* presented the higher SCBD$_{Total}$ value, while for the planktonic assemblages, *Nitzschia palea* was the most important species in summer and *Discostella stelligera* in winter. However, we highlight that for the three diatom assemblages, several planktonic chain forming diatoms also showed high values of SCBD$_{Total}$, such as *Aulacoseira* species (Table 4, Figure 5). Secondarily, other solitary species were also important contributors to these diatom assemblages, such as species of *Fragilaria*.

Table 4 List of the ten first species with higher SCBD$_{Total}$ values for surface sediment, summer and winter phytoplankton diatoms. Taxa in bold represent species common to the three diatom assemblages.

Surface sediment species	SCBD	Summer phytoplankton species	SCBD	Winter phytoplankton species	SCBD
Punctastriata lancettula	0.191	_Nitzschia palea_	0.200	**_Discostella stelligera_**	0.163
Aulacoseira ambigua	0.091	**_Discostella stelligera_**	0.168	**_Aulacoseira granulata_ var. _granulata_**	0.138
Aulacoseira granulata var. _angustissima_	0.077	**_Discostella pseudostelligera_**	0.105	**_Aulacoseira granulata_ var. _angustissima_**	0.107
Cyclotella meneghiniana	0.067	_Fragilaria spectra_	0.103	**_Cyclotella meneghiniana_**	0.086
Discostella stelligera	0.063	**_Cyclotella meneghiniana_**	0.052	_Fragilaria tenera_	0.083
Aulacoseira granulata var. _granulata_	0.060	**_Aulacoseira ambigua_**	0.045	**_Aulacoseira ambigua_**	0.060
Eunotia intricans	0.032	**_Punctastriata lancettula_**	0.036	_Achnanthidium_ sp.2	0.044
Fragilaria aquaplus	0.022	**_Aulacoseira granulata_ var. _angustissima_**	0.034	_Achnanthidium minutissimum_	0.035
Fragilaria longifusiformis	0.021	**_Aulacoseira granulata_ var. _granulata_**	0.024	**_Punctastriata lancettula_**	0.030
Planothidium rostratum	0.018	_Fragilaria longifusiformis_	0.023	_Navicula rostellata_	0.020
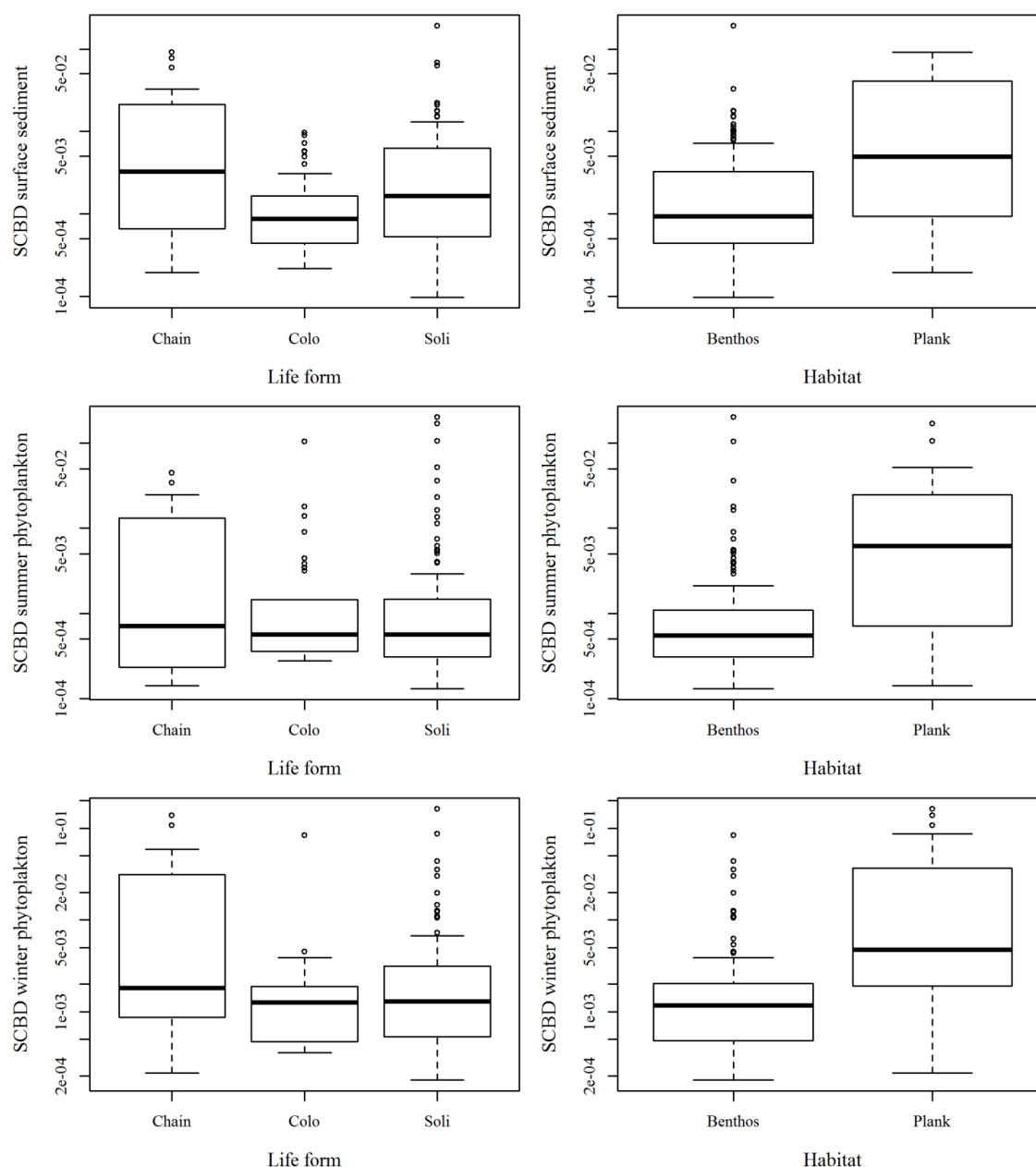
Fig. 5 Boxplot of Species Contribution to Beta Diversity (SCBD$_{Total}$) values according to diatoms life form and habitat (plotted in log scale) for surface sediment (row 1), summer phytoplankton (row 2) and winter phytoplankton assemblages (row 3). Chain: species that form chain; Colo: colonial species; Soli: solitary species; Benthos: benthic species; Plank: planktonic species.

Discussion

We found that both Local and Species Contributions to Beta Diversity (Repl$_{LCBD}$ and SCBD$_{Total}$) coefficients were significantly related to the selected predictor variables.

The significant and negative correlation between $Repl_{LCBD}$ values and productivity-related variables (TN, TP and PC1) suggests that the trophic gradient is the most important factor responsible for variations of beta diversity in these reservoirs and that eutrophic sites have lower contribution to total beta diversity, while oligo- and mesotrophic sites have contributed most to beta diversity. Sites with high $Repl_{LCBD}$ values have assemblages with a more particular species composition, and therefore, they may be of interest for conversation, while sites with low $Repl_{LCBD}$ values may be of interest for restoration initiatives (Legendre and De Cáceres 2013; Heino & Gronröos 2016). Eutrophication has been recognized as one of the principal stressors of freshwater ecosystems and considerable efforts have been employed to understand how communities respond to such environmental changes (Smith and Schindler 2009). In agreement to our findings, the negative effects of severe anthropogenic eutrophication on beta diversity have been reported in previous studies, where high levels of nutrient enrichment resulted in the homogenization of the environment, and as a result, to a simplification of assemblages selecting those species able to persist in such conditions (Donohue et al. 2009; Villar et al. 2014; Zorzal-Almeida et al. 2017a).

Despite the similar general results showed by surface sediment and summer phytoplankton diatoms, the negative relationship between $Repl_{LCBD}$ values and eutrophication indicators was best revealed by the surface sediment diatoms, probably because surface sediment integrates organisms over space and time and, therefore, captures information from the whole environment more efficiently than the water column (Smol 2008; Gregory-Eaves and Beissner 2011). Indeed, benthic diatom assemblages, mainly from lotic environments, have been successfully used to study environmental conditions of aquatic ecosystems (Potapova and Charles 2002; Potapova and Charles 2007; Heino et al. 2012; Pajunen et al. 2017). From the methodological perspective, surface sediment requires less samplings over time because of its integrative characteristics, whereas a single water column sample is usually considered as a snapshot of the living planktonic assemblages (Gregory-Eaves and Beissner 2011). As a result, assemblages sampled in the surface sediment and water column have been found to be really comparable only after seasonal samplings of the planktonic assemblages (Bunting et al. 2007; Manca et al. 2007).

$LCBD_{Total}$ and $Repl_{LCBD}$ calculations are relatively new approaches and they have been used to estimate important sites to beta diversity for stream invertebrates (Heino and Grönroos 2016; Heino et al. 2017; Sor et al. 2018), lake zooplankton (Lopes et al. 2014; Minouni et al. 2015) and river fishes (Kong et al. 2017). None of these studies have

correlated these coefficients to the productivity of the studied environments, except Heino and Grönroos 2016 who found weak variation in $LCBD_{Total}$ of invertebrate assemblages in relation to local environmental variables. Thus, this study adds new information by demonstrating the negative effects of nutrient enrichment on beta diversity and pointing that the most enriched sites have lower contribution to beta diversity.

Regarding species composition, some diatom species were shared between surface sediment and phytoplankton assemblages. $SCBD_{Total}$ values were significantly related to the frequency of occurrence in samples and total abundancy. However, we found that frequency in samples was the most important community metric to account for variations in $SCBD_{Total}$, independently of the assemblage (surface sediment or phytoplankton). Usually, it is expected that species with a more restrict occurrence in samples (with small niche breadth) have higher contribution to beta diversity (Slatyer et al. 2013). That pattern was found for the species *Punctastriata lancettula*, which presented high abundance in the oligotrophic reservoir (Santa Helena) in both surface sediment and phytoplankton in summer and winter.

On the other hand, Heino and Gronroos (2016) argue that species with high total abundances and variation across sites can also exhibit high contribution to beta diversity, what was presently confirmed with other diatom species. For instance, *Nitzschia palea* had higher $SCBD_{Total}$ value in summer phytoplankton and higher abundance in the hypereutrophic reservoir (Barra Bonita), confirming its preference for nutrient-rich environments (Trobajo et al. 2009). *Discostella stelligera* was the most representative species in winter phytoplankton and was widely distributed in all reservoirs, but mainly in oligo- and mesotrophic and probably favored by lower temperatures and mixing of the water column (Borges et al. 2008; Padisák et al. 2009). Planktonic *Aulacoseira* species (*Aulacoseira ambigua*, *A. granualata* var. *granulata* and *A. granulata* var. *angustissima*) and *Cyclotella meneghiniana* also showed high $SCBD_{Total}$ values and they were widely distributed in samples, in both surface sediments and phytoplankton, with higher abundance in eu- and hypereutrophic reservoirs (Hedberg and Barra Bonita). Indeed, these *Aulacoseira* and *Cyclotella* species are known to be competitive in nutrient-rich environments (Bradbury et al. 2004; Costa-Böddeker et al. 2012; Bicudo et al. 2016). These results partially confirm our prediction that species more closely related to oligotrophic conditions would have higher contribution to beta diversity, since species with preference for nutrient-rich environments also accounted for beta diversity.

In conclusion, our main findings demonstrated that diatom beta diversity was primarily determined by the trophic gradient (TP, TN and PC1), and that $Repl_{LCBD}$ values were negatively related to these indicators of productivity. Furthermore, surface sediment diatoms exhibited a more sensitive response to these predictors, reinforcing the potential of these assemblages in biodiversity studies (e.g. to access species richness and patterns of species distribution). We did not verify a clear pattern between planktonic winter diatoms and our predictor variables, indicating that other important factors governing planktonic beta diversity are missing in our models. We also found that oligotrophic sites and species associated to such conditions were important for total beta diversity, mainly in the surface sediment. However, we highlight that species widely distributed in samples and mainly related to nutrient-rich conditions also showed high $SCBD_{Total}$ values for both surface sediments and plankton assemblages (summer and winter) indicating, therefore, that they are important species for beta diversity. Considering that sites with high $Repl_{LCBD}$ values have higher degree in uniqueness of species composition than others, our study indicates that this approach can be useful to determine important sites for conservation (high $Repl_{LCBD}$ values) and restoration purposes (low $Repl_{LCBD}$ values). Finally, we highlight the importance of considering surface sediments in biodiversity studies, since they provided consistent information about the environmental conditions in this set of tropical reservoirs.

Acknowledgements

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Electronic Supplementary Material

Table S1 Repl$_{LCBD}$ selected models using abundance-based data for surface sediment, summer and winter phytoplankton diatoms explained by environmental variables.

	Estimate	*SE*	*Z*	*P*	*AIC*
Surface sediment					
Intercept	-2.10	0.13	-16.32	0.00000	-126.6
PT(log)	-0.20	0.03	-6.16	0.00000	
Intercept	-1.95	0.16	-12.48	0.00000	-125.7
TP(log)	-0.22	0.03	-6.73	0.00000	
Richness	0.00	0.00	-1.52	0.12900	
Intercept	-2.75	0.07	-38.58	0.00000	-124.6
PC1	-0.28	0.04	-6.43	0.00000	
Richness	-0.01	0.00	-2.48	0.01310	
Summer phytoplankton					
Intercept	-2.64	0.08	-35.11	0.00000	-127.7
PC1	-0.15	0.05	-3.26	0.00113	
Richness	-0.01	0.00	-3.53	0.00042	
Intercept	-1.99	0.33	-6.12	0.00000	-124.9
TN(log)	-0.10	0.04	-2.54	0.01117	
Richness	-0.01	0.00	-2.88	0.00401	
Summer phytoplankton					
Intercept	-2.89	0.05	-63.74	0.00000	-114.6
PC1	-0.10	0.05	-1.86	0.06240	
Intercept	-2.57	0.19	-13.23	0.00000	-114.1
TP(log)	-0.08	0.05	-1.71	0.08820	
Intercept	-2.20	0.45	-4.86	0.00000	-113.6
TN(log)	-0.09	0.06	-1.53	0.12500	
Intercept	-2.24	0.47	-4.72	0.00000	-113.3
IET	-0.01	0.01	-1.38	0.16800	
Intercept	-2.74	0.12	-23.19	0.00000	-113.2
Chl(log)	-0.06	0.04	-1.35	0.17600	
Intercept	-2.73	0.25	-10.85	0.00000	-111.9
TP(log)	-0.07	0.05	-1.31	0.18900	
Richness	0.00	0.00	0.96	0.33600	
Intercept	-2.96	0.12	-23.92	0.00000	-111.7
PC1	-0.08	0.06	-1.24	0.21500	
Richness	0.00	0.01	0.55	0.58000	
Intercept	-2.49	0.55	-4.54	0.00001	-111.2
TN(log)	-0.07	0.07	-1.01	0.31300	
Richness	0.00	0.00	0.87	0.38500	
Intercept	-2.57	0.58	-4.44	0.00001	-110.9
IET	-0.01	0.01	-0.81	0.42000	
Richness	0.00	0.01	0.89	0.37300	
Intercept	-2.90	0.20	-14.17	0.00000	-110.7
Chl(log)	-0.03	0.05	-0.73	0.46400	
Richness	0.00	0.01	0.87	0.38600	

Table S2 Repl$_{LCBD}$ selected models using presence-absence data for surface sediment, summer and winter phytoplankton diatoms explained by environmental variables.

	Estimate	*SE*	*Z*	*P*	*AIC*
Surface sediment					
Intercept	-1.18	0.30	-3.90	0.00010	-102.4
TP(log)	-0.39	0.06	-6.08	0.00000	
Richness	-0.01	0.01	-1.80	0.07240	
Intercept	-2.61	0.14	-18.65	0.00000	-101.7
PC1	-0.52	0.09	-5.89	0.00000	
Richness	-0.01	0.01	-2.63	0.00866	
Intercept	-1.52	0.26	-5.91	0.00000	-101.9
TP(log)	-0.36	0.07	-5.26	0.00000	
Summer phytoplankton					
Intercept	-2.34	0.14	-16.27	0.00000	-104.9
PC1	-0.24	0.09	-2.81	0.00504	
Richness	-0.03	0.01	-3.98	0.00007	
Intercept	-1.37	0.60	-2.27	0.02314	-102.4
TN(log)	-0.15	0.07	-2.09	0.03711	
Richness	-0.02	0.01	-3.39	0.00070	
Winter phytoplankton					
Intercept	-2.91	0.11	-27.25	0.00000	-84.8
PC1	-0.23	0.13	-1.81	0.06990	
Intercept	-2.16	0.44	-4.93	0.00000	-84.6
TP(log)	-0.19	0.11	-1.69	0.09020	
Intercept	-2.52	0.25	-9.96	0.00000	-84.5
Chl(log)	-0.15	0.09	-1.56	0.11800	
Intercept	-1.31	1.04	-1.26	0.20900	-84.3
IET	-0.03	0.02	-1.52	0.12800	
Intercept	-1.31	1.04	-1.27	0.20500	-84.1
TN(log)	-0.22	0.14	-1.53	0.12700	
Intercept	-2.57	0.55	-4.70	0.00000	-82.8
TP(log)	-0.15	0.11	-1.30	0.19200	
Richness	0.01	0.01	1.12	0.26300	
Intercept	-3.10	0.27	-11.37	0.00000	-82.3
PC1	-0.16	0.14	-1.09	0.27500	
Richness	0.01	0.01	0.76	0.44600	
Intercept	-2.07	1.21	-1.71	0.08800	-82.1
TN(log)	-0.15	0.15	-0.96	0.33600	
Richness	0.01	0.01	1.02	0.30800	
Intercept	-2.09	1.25	-1.67	0.09530	-82.0
IET	-0.02	0.02	-0.90	0.36750	
Richness	0.01	0.01	0.93	0.35190	
Intercept	-2.85	0.44	-6.46	0.00000	-82.0
Chl(log)	-0.09	0.10	-0.89	0.37300	
Richness	0.01	0.01	0.82	0.41300	

Table S3 Values (from higher to smaller) of Local Contributions to Beta Diversity calculated for the species replacement component (Rep$_{LCBD}$). SH: Santa Helena reservoir (oligotrophic), IT: Itupararanga reservoir (mesotrophic), IP: Ipaneminha reservoir (mesotrophic), HB: Hedberg reservoir (eutrophic), BB: Barra Bonita reservoir (hypereutrophic).

Surface sediment	Rep$_{LCBD}$	Summer phytoplankton	Rep$_{LCBD}$	Winter phytoplankton	Rep$_{LCBD}$
SH1	0.072	IP3	0.070	HB3	0.061
IP1	0.071	IP2	0.067	HB2	0.061
SH2	0.068	BB5	0.065	IP2	0.060
SH3	0.068	IP1	0.064	IP1	0.060
IP3	0.064	IT2	0.055	IT5	0.060
IT2	0.062	IT1	0.054	IP3	0.060
IP2	0.056	BB4	0.054	IT1	0.060
IT3	0.055	HB3	0.054	IT4	0.056
IT4	0.053	IT3	0.052	SH1	0.056
HB3	0.052	BB3	0.051	BB3	0.054
IT1	0.052	IT4	0.051	IT2	0.054
IT5	0.050	HB2	0.050	SH3	0.052
BB3	0.044	SH3	0.050	BB2	0.052
HB2	0.043	IT5	0.048	IT3	0.050
BB2	0.042	SH1	0.047	SH2	0.045
BB1	0.040	BB1	0.047	BB4	0.045
BB4	0.038	SH2	0.042	HB1	0.045
HB1	0.035	HB1	0.040	BB1	0.044
BB5	0.031	BB2	0.038	BB5	0.022
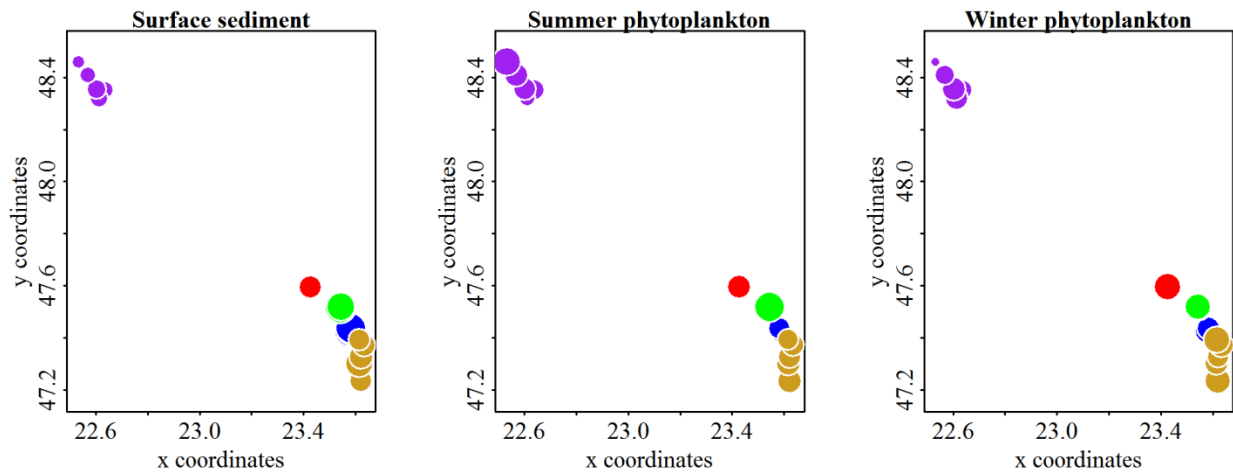
Fig. S1 Maps showing sampling sites according to the values of Local Contribution to Beta Diversity calculated for the species replacement component (Rep$_{LCBD}$). Size of the circles is proportional to the LCBD values. Blue: Santa Helena reservoir (oligotrophic), golden: Itupararanga reservoir (mesotrophic), green: Ipaneminha reservoir (mesotrophic), red: Hedberg reservoir (eutrophic), purple: Barra Bonita reservoir (hypereutrophic).

Table S4 SCBD$_{Total}$ models using abundance-based data for surface sediment, summer and winter phytoplankton diatoms explained by frequency in samples and total abundance (TotalAbund).

	Estimate	*SE*	*Z*	*P*	*AICc*
Surface sediment					
Intercept	-5.98	0.12	-49.54	0.00000	-1305.6
Frequency	0.03	0	18.28	0.00000	
Intercept	-5.34	0.11	-47.53	0.00000	-1264.8
TotalAbund	0.01	0	15.14	0.00000	
Summer phytoplankton					
Intercept	-5.74	0.15	-36.75	0.00000	-1400.7
Frequency	0.03	0.01	11.34	0.00000	
Intercept	-5.77	0.11	-49.91	0.00000	-1341.0
TotalAbund	0.01	0	25.49	0.00000	
Winter phytoplankton					
Intercept	-6.21	0.12	-50.52	0.00000	-1178.6
Frequency	0.04	0	24.06	0.00000	
Intercept	-5.41	0.11	-46.77	0.00000	-1139.9
TotalAbund	0.01	0	19.85	0.00000	

Table S5 SCBD$_{Total}$ models using presence-absence data for surface sediment, summer and winter phytoplankton diatoms explained by frequency in samples and total abundance (TotalAbund).

	Estimate	*SE*	*Z*	*P*	*AICc*
Surface sediment					
Intercept	-5.34	0.08	-67.55	0.00000	-1186.7
Frequency	0.02	0	9.57	0.00000	
Intercept	-5.01	0.07	-67.27	0.00000	-1134.4
TotalAbund	0	0	4.07	0.00005	
Summer phytoplankton					
Intercept	-5.46	0.07	-76.16	0.00000	-1201.6
Frequency	0.02	0	14.45	0.00000	
Intercept	-5.07	0.07	-72.03	0.00000	-1137.8
TotalAbund	0	0	8.84	0.00000	
Winter phytoplankton					
Intercept	-5.08	0.07	-70.78	0.00000	-1026.2
Frequency	0.01	0	6.53	0.00000	
Intercept	-4.86	0.06	-75.38	0.00000	-994.8
TotalAbund	0	0	2.47	0.01360	

CAPÍTULO 2

Environmental and spatial drivers of surface sediment and water column diatoms in tropical reservoirs

Environmental and spatial drivers of surface sediment and water column diatoms in tropical reservoirs

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Abstract

The relative contribution of environmental and spatial drivers has been focused by ecologists to understand community structure. In the context of metacommunity theory, diatoms are mainly associated to local environmental factors. However, space has been recorded as an important driver as well. This study aimed at determining the relative importance of environmental and spatial predictors as drivers of surface sediment and water column diatom assemblages in tropical reservoirs. Samplings were carried out in 31 reservoirs ranging from oligo- to hypereutrophic conditions from five hydrological basins. To identify the main environmental drivers of diatom communities, we performed a partial RDA between the predictor matrixes (environmental and spatial predictors) and response matrix (surface sediment and water column diatoms). Variation partitioning was used to assess the relative contribution of environmental and spatial predictors in structuring the diatoms community. In general, diatom assemblages were structured by a combination of environmental and spatial drivers. Our results further suggested that surface sediment and water column diatoms were structured by similar environmental variables (productivity-related variables, such as total phosphorus, water transparency and pH) and by a similar set of diatom species (mainly centric diatoms like *Aulacoseira granulata* var. *granulata*, *A. tenella*, *Discostella stelligera* and *Spicaticribra kingstonii*). Surface sediment diatoms presented slightly higher relative response than water column diatoms to the predictors, confirming that this assemblage may be more sensible to capture information from the environment. These findings reinforced that, despite the strong spatial influence, diatoms are also

strongly associated with environmental predictors and thus suitable organisms for biomonitoring purposes.

Keywords: diatoms, environmental predictors, metacommunity, spatial predictors.

Introduction

Patterns of biodiversity have fascinated ecologists for centuries, but recent theoretical developments have emphasized the idea that community structure is the result of processes occurring at many spatial scales (Heino et al. 2010, Comte et al. 2015). At the cornerstone of these ideas is the framework of metacommunity ecology, defined as "a set of local communities linked by dispersal" that are influenced by both environmental and spatial processes (Leibold et al. 2004, Heino et al. 2015). There are four main paradigms of metacommunity ecology, differing in the degree to which local processes and regional dispersal affect the community structure: neutral perspective, species sorting, patch dynamics and mass effects (Leibold et al. 2004). However, the boundaries distinguishing each of these paradigms are not discrete, as communities differ along gradients of environmental and dispersal control (Heino et al. 2015). A key goal of metacommunity studies is to disentangle the relative influence of environmental and dispersal factors (the latter of which spatial variables are often used as proxies; Heino et al. 2015).

Traditionally, environmental heterogeneity has been recognized as one of the main determinants of freshwater community structure (Soininen 2007), and several studies have been demonstrated that nutrient availability (e.g. phosphorus) as among the principal drivers of species distribution (Donohue et al. 2009, Levi et al. 2014, Vilar et al. 2014). However, depending on the scale of study, environmental variation may not be sufficient to determine how species are structured in space (Peres-Neto & Legendre 2010), since communities might be under both local and regional control (Soininen 2007). Geographical distances and the physical structure of the landscape may be described by incorporating spatial coordinates in analyses. It is expected that with increasing distances, spatial factors will explain a greater proportion of community structure (Declerck et al. 2011).

Over the last few decades, the importance of spatial scale has increasingly been recognized in community ecology and several methods based on variables describing spatial structures were developed (Borcard et al. 2004, Legendre & Legendre 2012). Spatial

eigenfunction analysis, such as distance based Moran's eigenvector maps (dbMEM), are important tools to study spatial structures and they can be used as an approximation to species movement between sites (Astorga et al. 2012). Thus, integrated environmental and spatial analysis have been carried out to assess the patterns and main drivers of different aquatic assemblages, such as bacterioplankton (Comte et al. 2015), zooplankton (Declerck et al. 2011), aquatic insects (Heino & Mendoza 2016), macrophytes (Alahuhta et al. 2014) and phytoplankton and fishes (Beisner et al. 2006, Padial et al. 2014). In general, studies that have considered multiple trophic levels that vary in dispersal ability across the same network of sites have identified that environmental factors are most important for organisms that easily disperse like bacteria and algae (Beisner et al. 2006; Astorga et al. 2012). However, only a limited amount of this kind of work has been conducted in tropical ecosystems, and thus it is unclear how applicable are the findings from temperate studies.

Tropical ecosystems contrast strongly from temperate ones in that they often have much high diversity, muted seasonal temperature differences and a longer history of evolution (Mittelbach et al. 2007). Similarly to temperate ecosystems, some previous studies carried out in tropical freshwater ecosystems have shown that environmental conditions were the most important drivers of periphytic and planktonic microalgae assemblages (Padial et al. 2014, Moresco et al. 2017). Furthermore, a preliminary work by Zorzal-Almeida et al. (2017a) found that diatom communities were primarily constrained by a trophic gradient and secondarily by connectivity in a set of connected tropical reservoirs. Here we build on this earlier study by using a much larger set of data set (i.e. 113 sites spread across 31 reservoirs distributed in five basins, instead of 31 sites from seven reservoirs) to further elucidate the relative contribution of environmental and spatial predictors of diatom assemblages. More specifically, we want to determine (a) what is the relative importance of environmental and spatial drivers in surface sediment and water column diatom assemblages, (b) what are the major environmental variables driving the diatom assemblages across the reservoirs and (c) whether surface sediment and water column assemblages respond similarly to the same variables. Since we sampled a reservoirs that spanned a wide trophic gradient (from oligo- to hypereutrophic conditions), we hypothesized that productivity-related variables would explain a larger proportion of variation in diatom assemblages relative to spatial variables for both surface sediment and water column assemblages. However, given that surface sediments integrate information through time and across the basin (Smol 2008), we predicted that subfossil assemblages would be less noisy and show stronger associations with the measured environmental gradients.

Material and methods

Study area and field work

The study area includes five drainage basins in the state of São Paulo, southeastern region of Brazil (Fig. 1). The drainage basins include protected and highly urbanized reservoirs ranging from oligo to hypereutrophic conditions. This study was conducted across 31 reservoirs with different uses (public water supply, electric generation, recreational and navigation). They range from shallow to deep (maximum depth ranging from 0.5 to 46 m) and from small to large (surface area from 0.2 to 241.3 km²) waterbodies. There were from one to seven sampling sites per reservoir depending on size, main water inputs (main streams) and deepest region of the reservoirs. A total 113 sites were sampled during austral winter and summer from 2009 to 2014, totaling 226 samples.
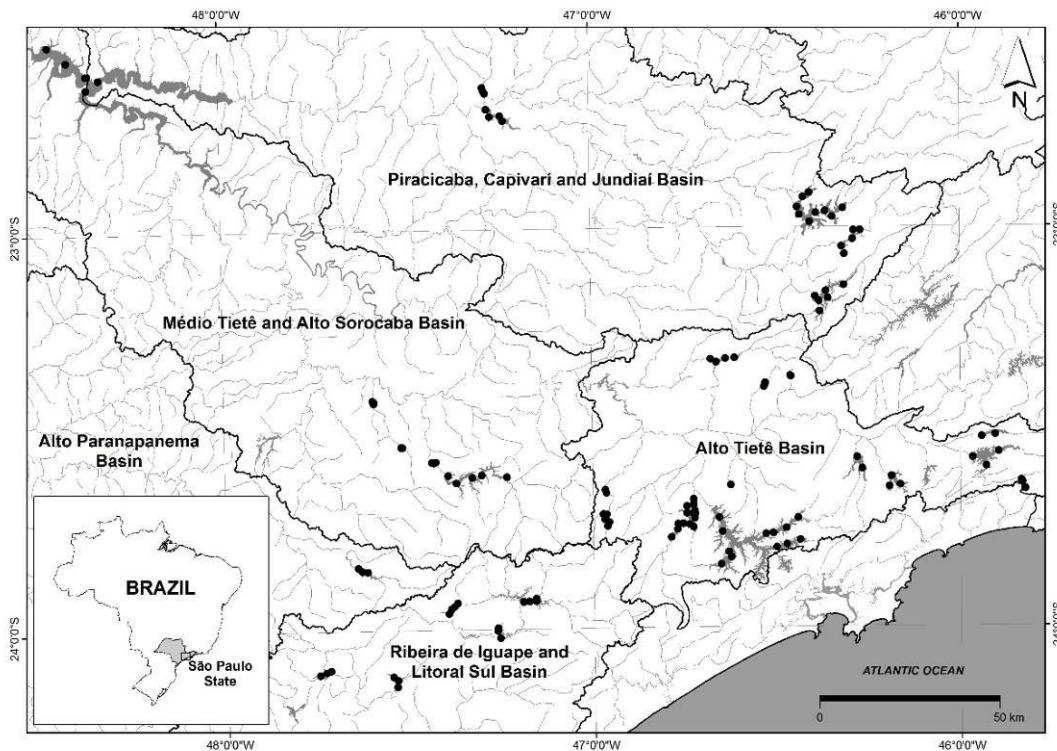
Figure 1. Geographic location of the study area showing the 31 reservoirs distributed in the five drainage basins. Modified from Bicudo et al. (2016).

Integrated water samples were collected with a van Dorn bottle along the reservoir vertical profile (subsurface, mean depth and 1 m above the sediments). Surface sediments were sampled only in winter using a UWITEC gravity corer, since they integrate a larger temporal

scale (Smol 2008). Each sediment sampling site was sampled in triplicate to collect a representative subsample; the first two centimeters of each sediment core was extruded and then pooled and homogenized together with the other replicate surface sediments from that site.

Environmental variables were also measured at three different depths and mean water column values were used in the analysis. Water temperature (ºC), pH and conductivity (μS cm^{-1}) were measured *in situ* using standard electrodes (Horiba U-50). The analytical procedure for dissolved oxygen (DO, mg L^{-1}), ammonium (N-NH$_4$, μg L^{-1}), nitrite (N-NO$_2$, μg L^{-1}), nitrate (N-NO$_3$, μg L^{-1}), soluble reactive silica (SRS, mg L^{-1}), total nitrogen (TN, μg L^{-1}) and total phosphorus (TP, μg L^{-1}) followed Standard Methods (APHA 2005). Chlorophyll-*a* (μg L^{-1}), corrected for phaeophytin, was measured using 90% ethanol (Sartory & Grobbelaar 1984). The Trophic State Index (TSI) was calculated following an adapted Carlson's TSI to tropical reservoirs (Zorzal-Almeida et al. 2017b).

Surface sediment and water column diatom samples were oxidized according to Battarbee et al. (2001), using concentrated hydrogen peroxide (H$_2$O$_2$ 35%) and hydrochloric acid (HCl 37%). Permanent slides were prepared using Naphrax as a mounting medium. Diatoms were identified and quantified at a magnification of 1000× using a Zeiss Axioskop 2 microscope. A minimum of 400 valves were counted per slide and until reaching at least 90% in counting efficiency (Pappas & Stoermer 1996). Species abundances were expressed as a percentage of the total diatom counts in each sample. Diatom analysis was performed on species that achieved relative abundances of greater than or equal to 2% at least one sampling station.

Numerical analysis

To identify the main drivers of surface sediment and water column diatoms assemblages we performed partial redundancy analysis (partial RDA) between the predictor matrices (environmental and spatial matrices) and response matrices (diatoms from surface sediment or water column in summer or winter). For the analysis of surface sediment diatoms assemblages, we used mean values of environmental variables measured in summer and winter as possible predictors. For the water column data set, the analyses were run separately for summer and winter to enable comparisons with the surface sediment data set. With each partial RDA, we first log transformed (logx+1) environmental variables (except pH) to improve normality and then screened variables that were highly collinear (r $\geq$ 0.7) based on a Pearson correlation matrix. We then applied forward selection as proposed by Blanchet et al. (2008) in our partial RDAs to

identify the most parsimonious set of predictors. For all partial RDAs, the diatom species matrices were Hellinger-transformed.

Spatial variables were obtained using distance based Moran's eigenvector maps (db MEM), formerly called principal coordinates of neighbour matrices (PCNM). A full description of the method is given by Dray et al. (2006), which is an improvement of the original approach proposed by Borcard & Legendre (2002). We used the geographic coordinates of each sampling site to calculate Euclidian distances (overland distances) among sites. The resulting variables from PCNM are orthogonal and can be directly used as spatial predictors in our RDAs (Borcard et al. 2011). We used overland distances as spatial predictors because our reservoirs spanned across multiple drainage basins and, therefore, they are not all connected via water courses (Heino et al. 2010). Then, we performed a global test with redundancy analysis (RDA) for each response matrix (diatoms from surface sediment or water column in summer or winter) and tested the significance using the *anova()* function. When the test was significant, we applied the forward selection procedure to obtain the most parsimonious model (Blanchet et al. 2008) with a significance level of 5%. We retained only positive and significant eigenvectors based on Moran`s I and minimum truncation distances in each of the analyses. Therefore, we achieved three different sets of PCNMs, one for each response matrix.

Variation partitioning was used to assess the relative importance of environmental and spatial predictors. This analysis quantifies the amount of variation in community structure that can be explained by environmental alone, space alone, as well as their shared contribution (Peres-Neto & Legendre 2010).

The RV coefficient, which is a multivariate generalization of the Pearson coefficient (Legendre & Legendre 2012), was applied to quantify the correlation between the assemblage data types. We run a Principal Component Analysis (PCA) for each diatom assemblage matrix and computed the RV coefficient between the site scores of the first PCA axis of the surface sediment diatom matrix and water column matrix (summer and winter). It produces values between 0 (no correlation) and 1 (total correlation).

All statistical analyses were performed in R v. 3.3.1 (R Core Team 2016). Forward selection of environmental and spatial variables was executed using *forward.sel()* function from packfor package (Dray et al. 2016). Ordination analysis were performed using *rda()* and tested using *anova()* functions from vegan package (Oksanen et al. 2017). Variation partitioning was performed using the *varpart()* function from vegan package (Oksanen et al. 2017). For computing RV coefficients we used function *coeffRV()* from package FactoMineR (Husson et al. 2016).

Results

The measured environmental variables presented considerable variation among the sampling sites (Table 1). Total nitrogen and total phosphorus, for example, ranged from oligotrophic to hypereutrophic values, and pH values varied from acidic to alkaline. In general, the variation was greater among sites than between seasons, with the exception of water transparency and water temperature which were significant different ($p < 0.05$) between summer and winter.

Table 1. Environmental variables measured in the 31 sampled reservoirs (n=113). Secchi: water transparency, Temp.: water temperature, Cond.: conductivity, Alk.: alkalinity, DO: dissolved oxygen, N-NH$_4$: ammonium, N-NO$_2$: nitrite, N-NO$_3$: nitrate, TN: total nitrogen, PO$_4$: orthophosphate, TDP: total dissolved phosphorous, TP: total phosphorous, SRS: soluble reactive silica, Chl: chlorophyll-*a*.

Variables	Summer		Standard	Winter		Standard
	Range	Mean	deviation	Range	Mean	deviation
Depth (m)	0.5-40.0	11.6	9.6	0.5-46.0	12.3	10.0
Secchi (m)	0.3-3.3	1.4	0.8	0.4-5.3	1.9	1.1
Temp. (˚C)	12.8-28.9	24.3	2.3	12.5-21.08	17.5	1.8
pH	5.2-8.5	6.6	0.7	5.1-8.7	6.7	0.6
Cond. (µS cm^{-1})	10.4-383.0	72.9	77.9	10.4-487.7	97.6	109.7
Alk. (mEq L^{-1})	0-1.5	0.4	0.3	0-1.8	0.4	0.3
CO$_2$ (mg L^{-1})	0.2-180.1	28.9	36.0	0.2-73.7	15.5	13.7
HCO$_3$ (mg L^{-1})	3.1-92.2	26.4	18.3	3.1-113.4	27.2	21.1
CO$_3$ (mg L^{-1})	0-2.6	0.1	0.4	0-8.8	0.2	0.9
DO (mg L^{-1})	0.7-14.4	4.6	1.6	2.4-10.8	6.6	1.4
N-NH$_4$ (µg L^{-1})	10.0-3460.0	253.6	489.6	10.0-5865.3	269.1	676.1
N-NO$_2$ (µg L^{-1})	5.0-398.6	26.6	61.7	5.0-196.0	21.4	39.7
N-NO$_3$ (µg L^{-1})	8.0-2463.6	162.7	409.5	8.0-1833.5	218.2	402.4
TN (µg L^{-1})	88.5-10652.1	969.1	1500.2	109.1	9767.0	1309.3
PO$_4$ (µg L^{-1})	4.0-163.6	13.0	24.4	4.0-446.0	15.8	48.4
TDP (µg L^{-1})	4.0-209.6	17.2	30.5	4.0-477.2	20.8	53.7
TP (µg L^{-1})	4.0-381.3	37.6	56.5	4.0-502.9	36.1	62.1
SRS (mg L^{-1})	1.1-6.5	3.1	1.2	0.6-6.2	3.2	1.5
Chl (µg L^{-1})	1.7-149.9	13.3	19.4	1.7-175.9	14.5	22.6
Trophic State Index	42.8-72.9	54.6	6.3	44.1-75.2	54.6	6.3

Considering surface sediment and water column (summer and winter) diatom assemblages together, a total of 237 species were present in relative abundance $\geq 2\%$ and were included in the analysis. Using this screening criterion, a comparable number of taxa were observed in the surface sediment diatom assemblage (147) relative to the water column in summer (149 taxa) and winter (150 taxa). *Discostella stelligera* (Cleve & Grunow) Houk & Klee, *Aulacoseira ambigua* (Grunow) Simonsen and *Aulacoseira tenella* (Nygaard) Simonsen

were the most common species in surface sediments, occurring in 91%, 89% and 81% of the sampling sites, respectively. In the water column *Discostella stelligera*, *Aulacoseira tenella* and *Aulacoseira granulata* var. *granulata* (Ehrenberg) Simonsen were the most common taxa, occurring in 89%, 81% and 76% of summer samples and in 93%, 86% and 85% of winter samples. In general, independently of the assemblage considered, *Aulacoseira ambigua* and *A. granulata* var. *granulata* presented higher relative abundance and frequency in eutrophic samples, while *A. tenella* was more related to oligo- and mesotrophic conditions (Table 2). Furthermore, *Discostella stelligera* was widely distributed in samples, but mainly associated to oligo- and mesotrophic conditions.

Table 2. Ranging (minimum and maximum) of the relative abundance and frequency (Freq. %) in samples of the most frequent diatom species in the surface sediment and water column in summer and winter in relation to the trophic state.

Assemblage	Trophic state	*Aulacoseira ambigua*		*Aulacoseira granulata* var. *granulata*		*Aulacoseira tenella*		*Discostella stelligera*	
		Ranging	Freq.	Ranging	Freq.	Ranging	Freq.	Ranging	Freq.
Surface sediment	Oligotrophic	0-40.0	80.0	0-10.0	67.0	0-67.0	93.3	0-73.0	93.3
	Mesotrophic	0-49.0	95.5	0-22.4	84.0	0-69.0	88.6	0-76.5	91.0
	Eutrophic	0-63.5	87.5	0-51.6	96.0	0-43.0	46.0	0-41.0	87.5
Summer water column	Oligotrophic	0-19.5	74.4	0-33.6	70.0	0-59.0	95.3	0-88.0	93.0
	Mesotrophic	0-23.7	75.0	0-40.5	75.0	0-43.0	81.3	0-95.0	90.0
	Eutrophic	0-27.0	68.2	0-31.0	91.0	0-14.6	50.0	0-17.0	77.3
Winter water column	Oligotrophic	0-23.7	91.3	0-18.6	72.0	0-84.0	96.0	0-85.0	98.0
	Mesotrophic	0-67.0	71.0	0-59.5	90.2	0-63.0	88.0	0-73.0	88.0
	Eutrophic	0-68.6	88.5	0.4-88.3	100.0	0-19.0	65.4	0-45.0	92.3

After screening for collinearity, 10 out of the original 20 environmental variables were retained by the forward selection procedure to explain the surface sediment diatom assemblages (i.e. Secchi, Temp, pH, CO_2, CO_3, DO, $N-NH_4$, $N-NO_3$, TP and SRS, see Table 1 for codes). A similar set of variables was retained when either of the water column data sets (summer and winter) were used as the response matrix. Forward selection retained 11 environmental variables to explain the diatom community from the water column in summer (i.e. Depth, Secchi, Temp, pH, DO, $N-NH_4$, $N-NO_3$, $P-PO_4$, TP, SRS and Chl). For the winter water column diatoms 10 environmental variables were retained (Depth, Secchi, Temp, pH, CO_3, DO, $N-NH_4$, $N-NO_3$, TP and SRS).

PCNM revealed a total of 12 significant and positive eigenfunctions. When surface sediment diatoms were used as the response matrix, forward selection retained 11

eigenfunctions. For the water column diatoms data set in summer, forward selection also retained 11 PCNMs eigenfunctions whereas for winter data set, ten PCNMs eigenfunctions were retained.

We then conducted partial RDA, where we controlled for the role of spatial factors by using significant PCNMs as covariables, and found that the with the selected environmental variables and surface sediment diatoms (Fig. 2A and B) explained a total of 50% of the residual community variation (R^2 adj.; p<0.001). The first two axes of partial RDA explained 29.4% of variation. Axis one showed the distribution of the sampling sites along primarily a trophic gradient where productivity-related variables, such as water transparency (-0.58) and total phosphorus (0.49), as well as soluble reactive silica availability (-0.60) were important. Axis two ordered the sampling sites along a gradient of pH (-0.64) and total phosphorus (-0.40). The species related to the oligotrophic sampling sites were *Aulacoseira tenella* (AUTL), *Discostella stelligera* (DSTE) and *Spicaticribra kingstonii* Johansen, Kociolek & Lowe (SKIN). On the other hand, *Aulacoseira ambigua* (AAMB), *Aulacoseira granulata* var. *granulata* (AUGR), *A. granulata* var. *angustissima* (O. Müller) Simonsen (AUGA) and *Cyclotella meneghiniana* Kützing (CMEN) were mainly associated to eutrophic sampling sites. *Navicula notha* Wallace (NNOT) and *Frustulia crassinervia* (Brébisson ex W.Smith) Lange-Bertalot & Krammer (FCRS) seem to be in an intermediate position been related to oligo to mesotrophic sites.

For summer water column assemblages, we found that selected environmental variables in the partial RDA (with significant PCNMS used as covariables) explained 45% (R^2 adj.; p<0.001) of the residual variation. The biplots also indicated the trophic gradient and depth were the main drivers of species distribution (Fig. 2C and D). The first two axes explained 21.7% of residual variation and axis one was mostly explained by Chlorophyll-*a* (0.68), water transparency (-0.51) and depth (-0.51), while axis two was mostly explained by soluble reactive silica availability (-0.60) and depth (0.51). Two species were mainly fitted with oligotrophic sampling sites, *Discostella stelligera* (DSTE) and *Spicaticribra kingstonii* (SKIN), meanwhile *Aulacoseira granulata* var. *granulata* (AUGR) was more related to eutrophic sites.

In winter, we found that selected environmental variables in the partial RDA (with significant PCNMS used as covariables) explained 46% (R^2 adj.; p<0.001) of residual variation in diatom assemblages. Similar to the surface sediment and summer water column assemblages, the trophic gradient was the main driver of diatoms distribution (Fig. 2E and F). The first two axes explained 25.4% of residual variation and axis one was mainly explained by soluble reactive silica availability (-0.66), water transparency (-0.58), total phosphorus (0.56), depth (-0.50) and pH (0.48), while axis two was mainly explained by depth (-0.50), pH (-0.40) and N-NO_3 (-0.39). As observed with the surface sediment assemblages, *Aulacoseira tenella* (AUTL),

Discostella stelligera (DSTE) and *Spicaticribra kingstonii* (SKIN) were mainly associated to oligotrophic sites, while *Achnanthidium catenatum* (Bily & Marvan) Lange-Bertalot (ADCT), *Achnanthidium minutissimum* (Kützing) Czarnecki (ADMI), *Aulacoseira granulata* var. *granulata* (AUGR), *A. granulata* var. *angustissima* (AUGA) and *Cyclotella meneghiniana* (CMEN) were related to eutrophic sites.
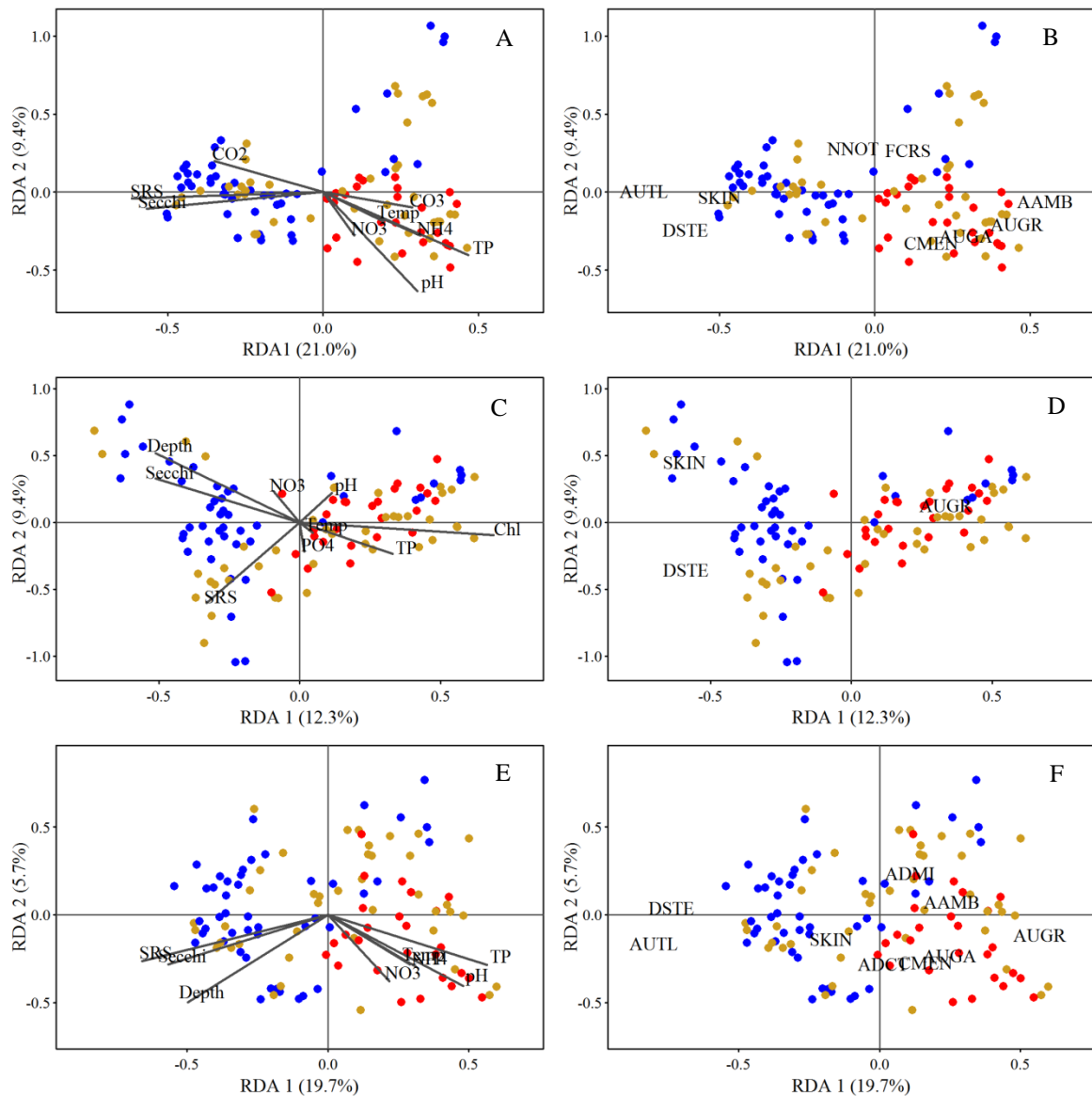
Figure 2. Partial RDA biplots of surface sediment diatom species (A and B), summer water column diatoms (C and D) and winter water column diatom species (E and F). Environmental variables codes are available in Table 1. Species shown in the partial RDA biplots are those with vectors greater than 0.2 units. Species codes according to OMNIDIA and available in the text. Blue: oligotrophic sites, golden: mesotrophic sites, red: eu- and hypereutrophic sites.

According to the variation partitioning analysis, the pure effect of the environmental and spatial predictors on diatom assemblages structure was highly significant ($p < 0.001$). The pure effect of environment was substantially larger than space with the diatom assemblages from surface sediment or water column in winter (Fig. 3A and C). In summer, the pure effect of space was slightly higher than the environment. The shared variation was low (i.e. $\leq 5\%$) for the three studied communities, suggesting that the effects of associated with spatially-structured environmental variables were small.
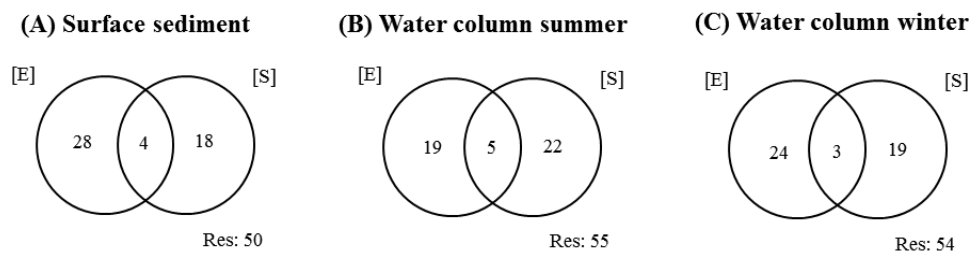
Figure 3. Variation partitioning of the diatom communities between environmental ([E]) and spatial ([S]) components. Res: residuals.

The RV coefficient analyses detected high and significant correlations between the studied assemblages (Table 2). RV coefficient between PCA surface sediment site scores and PCA summer water column site scores was 0.66 ($p < 0.001$), while correlation of surface sediment and PCA winter water column site scores was 0.76 ($p < 0.001$). The correlation was lower, but still strong, between site scores of water column in summer and winter, with an RV coefficient of 0.63 ($p < 0.001$).

Discussion

Our results highlighted that both environmental and spatial predictors were important drivers of diatom assemblages from surface sediment and water column, where there were many similarities across the different studied assemblages. In most ecological communities, these processes are not mutually exclusive, but probably occur together along a continuum (Soininen et al. 2007, Logue et al. 2011). Our results echo the findings from earlier study of temperate lakes and reservoirs (Winegardner et al. 2014), where the strong similarities detected among water column and surface sediment diatom assemblages meant that ecologists would infer the same general conclusions about environmental or spatial predictors across these different sample sets. Similarly, Zorzal-Almeida et al. (2017a) documented strong concordance between surface

sediment and water column diatom communities in a set of connected tropical reservoirs from the same watershed, but here they found stronger effect of spatially structured variables in response to local environmental variables and connectivity.

More specifically, we found that environmental predictors presented slightly higher contribution to surface sediment and winter water column diatom communities than spatial predictors, while for summer water column diatoms spatial predictors were slightly stronger than environment factors. According to Heino et al. (2015), the relative contribution of environmental and spatial predictors in community structure depends on the spatial scale of study, range of environmental gradients and dispersal ability of the biological group. Relative to the earlier study by Zorzal-Almeida et al. (2017a), we widened substantially the study area from one to five watersheds. Therefore, the wide environmental gradient associated with the larger study area likely favored the relative contribution of environmental over spatial drivers (Heino et al. 2015). Additionally, our results agree with previous studies that have demonstrated that diatoms primarily respond to environmental drivers in the presence of broad environmental gradients (Astorga et al. 2012, Vilar et al. 2014), while in near-pristine environments, spatial predictors are often the main drivers of diatom communities for both streams (Heino et al. 2010) and tropical reservoirs (Marquardt et al. 2017). Other previous studies with microorganisms also showed the environmental component as the most important driver of phytoplanktonic communities (Beisner et al. 2006, Padial et al. 2014) and bacteria (Beisner et al. 2006). Since diatoms and microorganisms in general are considered good dispersers, larger environmental control might be expected (Padial et al. 2014).

In relation to the little higher response of space for summer water column diatoms, a possible reason is that in summer, which represents the rainy season in our study area, the aquatic systems are subject to higher precipitation, which can lead to a homogenization of environmental variables (Thomaz et al. 2007); in our case, several of the key trophic variables (e.g. TP and Chl$a$) became truncated in summer relative to winter. In addition, the greater amount of rain might also lead to more water movement within connected reservoirs. Consequently, the greater amount of mixing of water in summer along the length of the reservoirs might explain the enhanced contribution of the spatial component. In contrast, the reservoirs become more isolated due to the lower precipitation and lower water flow in winter, enhancing limnological differences in stations along the reservoirs and, consequently, a higher contribution of the environmental component. These different climatic conditions between summer and winter might have accentuated variations in environmental variables and, therefore, in planktonic diatom composition.

Interestingly, we found high percentage of explanation in our analysis, independently of the assemblage considered, when compared to other previous studies (e.g. Heino et al. 2010, Winegardner et al. 2014). We believe that these results are owing to the large environmental gradient and high spatial extent encompassed by our study, which mean that important key environmental and spatial drivers were included in our analysis. Furthermore, these findings reinforce diatoms as suitable organisms in ecological studies (Bennet et al. 2010). Our comparison of the diatom assemblages from different matrices also demonstrated that a slightly higher amount of variation (50%) was explained in the surface sediment assemblages relative to water column diatoms (~45%), as we predicted. Surface sediments are considered an important record of freshwater ecosystems because they integrate environmental information across the basin and over time (Smol 2008, Gregory-Eaves & Beisner 2011). This means that surface sediment diatom assemblages can incorporate benthic and water column species, and may result in more complete species sorting through environmental gradients (Winegardner et al. 2014).

In our study both surface sediment and water column assemblages were dominated by centric planktonic diatoms such as *Aulacoseira* species, *Cyclotella meneghiniana*, *Discostella stelligera* and *Spicaticribra kingstonii*. Similar to numerous other studies of surface sediments and water samples, we found that *Aulacoseira ambigua*, *A. granulata* var. *granulata*, *A. granulata* var. *angustissima* and *Cyclotella meneghiniana* were mainly associated to eutrophic sampling sites (Potapova et al. 2004, Dong et al. 2008, Bicudo et al. 2016, Zorzal-Almeida et al. 2017a). Most of the species that we found associated to oligo- and mesotrophic conditions (i.e. *Aulacoseira tenella*, *Discostella stelligera* and *Spicaticribra kingstonii*) have been reported to occur in these environments (Bicudo et al. 2016, Zorzal-Almeida et al. 2017a). The exception is *D. stelligera*, which has also been documented to occur in sites with intermediate to high nutrient concentrations (Potapova et al. 2004, Becker et al. 2009), but also has been reported to occur in low TP conditions (Cumming et al. 2015). Overall, these centric taxa seem to be key diatom species in this set of reservoirs, and thus have potential to be used as bioindicators.

In summary, it is clear that to understand diatoms distribution it is important to identify whether species distribution are mainly constrained by environmental or spatial drivers. Our findings indicated that diatom communities were structured by a combination of both predictors in our study area, showing the complexity of conditions shaping these organisms. Furthermore, we found that both surface sediment and planktonic assemblages were constrained by similar environmental drivers, mainly related to productivity. However, more variation could be explained in the surface sediment assemblages relative to those sampled in the water column, possibly because surface sediments capture information from the whole ecosystem and over time

(Smol 2008, Gregory-Eaves & Beisner 2011). Most of the work considering the relative roles of spatial and environmental variables on diatom assemblages has come from analyses of periphyton, which typically come from streams and rivers that have a clear linear structure (e.g. Soininen et al. 2004, Heino et al. 2010, Heino et al. 2012, Dong et al. 2016). However, our study contributes to a growing pool of literature on lakes and reservoirs that have considered both kinds of predictors and is leading to a better understanding on the structure of diatom communities from surface sediment and water column (e.g. Bennett et al. 2010, Winegardner et al. 2014, Zorzal-Almeida et al. 2017a). To our knowledge, Winegardner et al. (2014) and Zorzal-Almeida et al. (2017a) represent the only studies whereby diatom assemblages from both the water column and surface sediments are contrasted in terms of the spatial and environmental drivers, and our study is the largest of its kind to consider these diatom responses in tropical reservoirs. Our findings, combined with these earlier works, show that there are strong similarities with respect to drivers of diatom assemblages across these different matrices. In conclusion, despite the strong spatial influence, our results demonstrated that diatoms are also strongly associated with environmental predictors and thus suitable organisms for biomonitoring purposes.

Acknowledgments

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CAPÍTULO 3

Surface sediment and phytoplankton diatoms along a trophic gradient in tropical reservoirs: new records for Brazil and São Paulo state

Surface sediment and phytoplankton diatoms along a trophic gradient in tropical reservoirs: new records for Brazil and São Paulo state

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Shortened Title: New diatom records for Brazil and São Paulo state

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ABSTRACT **-** (Surface sediment and phytoplankton diatoms along a trophic gradient in tropical reservoirs: new records for Brazil and São Paulo state). We aimed to inventory the diatom flora of tropical reservoirs ranging from oligo- to hypereutrophic conditions from southeastern region of Brazil, highlighting the new records for Brazil and São Paulo state, as well as to improve the knowledge about the ecology and distribution of diatom species. We collected diatom samples from surface sediment and phytoplankton (summer and winter) in 41 sites (10 reservoirs). Seventy-eight taxa, distributed in 28 genera, were identified in the surface sediment and phytoplankton samples. *Nizschia* was the most representative genera, with a total of nine species. Seven taxa represent new records from Brazil and five for São Paulo state. Additionally, eleven taxa were identified in genus level and probably represent new species. We contributed to the increasing of information on the ecology of these species and highlight the need of floristic surveys to improve the knowledge of diatom tropical biodiversity.

Key-words: biodiversity, diatom flora, ecology, *Nitzschia*

RESUMO - (Diatomáceas de sedimentos superficiais e fitoplanctônicas ao longo de um gradiente trófico em reservatórios tropicais: novos registros para o Brasil e Estado de São Paulo). Este estudo visou inventariar a flora diatomológica de represas tropicais oligo- a hipereutróficas da região sudeste do Brasil, destacando os novos registros para o Brasil e para o Estado de São Paulo, bem como aumentar o conhecimento sobre a ecologia e distribuição das espécies. As amostras abrangeram diatomáceas do sedimento superficial e fitoplâncton (verão e inverno) em 41 locais (10 represas). Setenta e oito táxons, distribuídos em 28 gêneros, foram identificados nas amostras de sedimento superficial e fitoplanctônicas. *Nitzschia* foi o gênero mais representativo, com um total de nove espécies. Sete táxons representam novas citações para o Brasil e cinco para o Estado de São Paulo. Onze táxons foram identificados em nível de gênero e provavelmente representam novas espécies. Adicionalmente, este estudo contribuiu com

informações sobre a ecologia dessas espécies e permite enfatizar a necessidade de estudos florísticos para ampliar o conhecimento da biodiversidade de diatomáceas tropicais.

Palavras-chave: biodiversidade, ecologia, flora diatomológica, *Nitzschia*

Introduction

Evidences show that recent species extinctions rates are exceptionally high, suggesting a probably new event of mass extinction due the environmental crisis caused by mankind (Ceballos *et al.* 2015). Despite the efforts on taxonomic and ecological studies, many species are extinct even before they can be described. The biota of freshwater ecosystems has been highly neglected in studies about biodiversity, especially invertebrates and microorganisms at the tropical region (Dudgeon *et al.* 2006). Freshwater ecosystems support a high diversity despite their reduced superficial area, therefore being considered hot spots for biodiversity (Strayer & Dudgeon 2010).

Diatoms are among the most species-rich group of algae and the number of species is around 100,000, including fossil species (Mann & Vanormelingen 2013). They are an abundant component of primary producers in plankton and benthos, both in marine and freshwaters (Round *et al.* 1990). Due to their high richness and abundance in aquatic ecosystems, diatoms represent an important account to local and regional biodiversity, which can be accessed by floristic surveys. Furthermore, ecological preferences of many species are relatively well know, making these group widely used to evaluate environmental conditions (*e.g.*, Passy 2007, Bennion *et al.* 2014, Blanco *et al.* 2014). However, just about 12% of estimated diatom flora is currently described (Julius & Theriot 2010).

In recent years, the number of studies about the diatom flora in Brazil has been increasing (*e.g.*, Souza & Senna 2009, Bertolli *et al.* 2010, Silva *et al.* 2010, Bartozek *et al.* 2013). However the inclusion of surface sediment diatoms is still scarce (Fontana & Bicudo 2009, 2012, Almeida & Bicudo 2014, Faustino *et al.* 2016), and all of them were carried out in the state of São Paulo. Such studies have added several new records to the Brazilian diatom flora and new species to Science (Almeida *et al.* 2015, Almeida *et al.* 2016, Marquardt *et al.* 2016), demonstrating the importance of floristic survey of sediments. Other studies about the diatom flora encompassing

lotic and lentic environments have been carried out in the state of São Paulo (Carneiro & Bicudo 2007, Bere & Tundisi 2010, Marquardt & Bicudo 2014, Ferreira & Bicudo 2017). The present study was carried out in ten reservoirs from three watersheds of São Paulo state (Brazil). To our knowledge, this is a pioneer diatom floristic survey to the study area, except for the unpublished study carried out by Silva (2017). We aimed at improving the knowledge of the diatom flora from surface sediments and phytoplankton, highlighting the new records for Brazil and São Paulo state. Furthermore, this study contributes to the increase of knowledge about biodiversity and ecology of tropical diatoms.

Material and methods

This study was carried out in the southeastern region of Brazil and comprises three drainage basins in the state of São Paulo (Figure 1, Table 1). We selected 10 reservoirs located in protected and highly urbanized areas, ranging from oligo- to hypereutrophic conditions and with different uses (recreational, power generation, navigation and public water supply). The reservoirs range from shallow to deep (maximum depth from 2 to 33 m) and from small to large (surface area from 0.2 to 241.3 km²). We selected three to six sampling sites (Table 1) per reservoir depending on size, the main water inputs (main streams) and deepest region of the reservoirs.
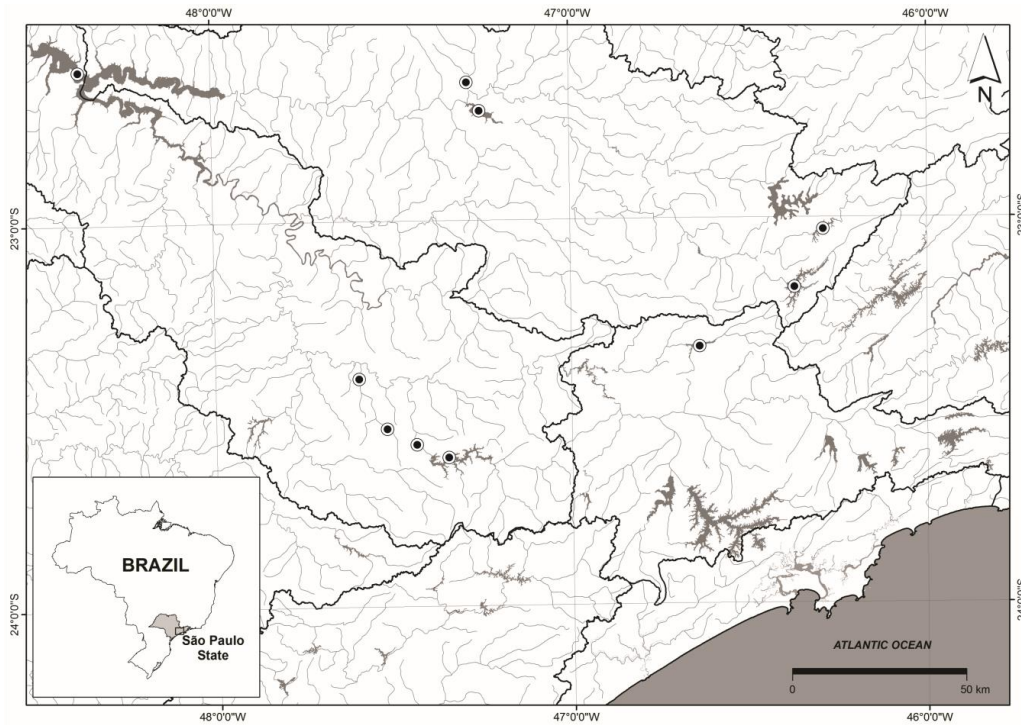
Figure 1. Location of the 10 studied reservoirs in southeastern region of Brazil. Black lines are the boundaries of the basins. Modified from Bicudo *et al.* (2016).

We sampled a total of forty-one sites (Table 1) during two climatic periods (austral winter and summer) in 2013 and 2014. Water column samples were taken with a van Dorn bottle along the reservoir vertical profile (subsurface, mean depth and 1 m above the sediments), and mean results of water column were used to characterize each sampling site. Conductivity, pH and water temperature were measured in field using standard electrodes (Horiba U-50). The analytical methods for dissolved oxygen, dissolved inorganic nitrogen, total nitrogen, orthophosphate, total phosphorus and soluble reactive silica followed Standard Methods (APHA 2005). The reservoirs Trophic State Index (TSI) was calculated according to Lamparelli (2004) based on values of chlorophyll-*a* (Sartory & Grobbelaar 1984) and total phosphorus. Integrated water column samples were used to describe the phytoplankton diatom community. Surface sediment diatoms (top 2 cm) were sampled only in winter (41 samples) using a UWITEC gravity corer. Each sampling site was sampled in triplicate to compound the site spatial heterogeneity.

Table 1. Watersheds, reservoirs, number and codes of sampling sites and number of samples collected from surface sediments (SS) and phytoplankton (P) in each reservoir.

Watershed	Reservoirs	Sampling sites	Coordinates	Number of samples
Alto Tietê	Paiva Castro (oligotrophic)	PC1	S 23° 19' 30" W 46° 36' 03"	01 SS 02 P
		PC2	S 23° 19' 44" W 46° 38' 12"	01 SS 02 P
		PC3	S 23° 20' 08 W 46° 39' 39"	01 SS 02 P
		PC4	S 23° 19' 55" W 46° 40' 35"	01 SS 02 P
Médio Tietê and Alto Sorocaba	Santa Helena (oligotrophic)	SH1	S 23º 34' 50" W 47º 25' 32"	01 SS 02 P
		SH2	S 23º 34' 58" W 47º 25' 50"	01 SS 02 P
		SH3	S 23º 34' 54" W 47º 26' 12"	01 SS 02 P
	Itupararanga (mesotrophic)	IT1	S 23º 37' 11" W 47º 13' 59"	01 SS 02 P
		IT2	S 23º 36' 52" W 47º 18' 5"	01 SS 02 P
		IT3	S 23º 37' 13" W 47º 19' 37"	01 SS 02 P
		IT4	S 23º 38' 0.3" W 47º 22' 14"	01 SS 02 P
		IT5	S 23º 36' 53" W 47º 23' 35"	01 SS 02 P
	Ipaneminha (mesotrophic)	IP1	S 23º 32' 34" W 47º 30' 57"	01 SS 02 P
		IP2	S 23º 32' 38" W 47º 31' 4"	01 SS 02 P
		IP3	S 23º 32' 34" W 47º 31' 9"	01 SS 02 P
	Hedberg (eutrophic)	HB1	S 23º 25' 56" W 47º 35' 33"	01 SS 02 P
		HB2	S 23º 25' 41" W 47º 35' 31"	01 SS 02 P
		HB3	S 23º 25' 34" W 47º 35' 42"	01 SS 02 P
	Barra Bonita (hypereutrophic)	BB1	S 22º 38' 9" W 48º 21' 11"	01 SS 02 P
		BB2	S 22º 36' 42" W 48º 19' 15"	01 SS 02 P
		BB3	S 22º 36' 9" W 48º 21' 16"	01 SS 02 P
		BB4	S 22º 34' 9" W 48º 24' 31"	01 SS 02 P
		BB5	S 22º 31' 56" W 48º 27' 37"	01 SS 02 P

Continues

Table 1 (*Continuation*)

Watershed	Reservoirs	Sampling sites	Coordinates	Number of samples
Piracicaba, Capivari and Jundiaí	Atibainha (oligotrophic)	AT1	S 23° 08' 50" W 46° 18' 50"	01 SS 02 P
		AT2	S 23° 09' 42" W 46° 21' 44"	01 SS 02 P
		AT3	S 23° 11' 11" W 46° 22' 51"	01 SS 02 P
		AT4	S 23° 10' 31" W 46° 23' 29"	01 SS 02 P
		AT5	S 23° 12' 46" W 46° 22' 54"	01 SS 02 P
		AT6	S 23° 10' 46" W 46° 21' 25"	01 SS 02 P
	Cachoeira (oligotrophic)	CA1	S 23° 00' 06" W 46° 16' 05"	01 SS 02 P
		CA2	S 23° 00' 37" W 46° 17' 11"	01 SS 02 P
		CA3	S 23° 01' 56" W 46° 17' 20"	01 SS 02 P
		CA4	S 23° 03' 00" W 46° 19' 07"	01 SS 02 P
		CA5	S 23° 04' 11" W 46° 18' 41"	01 SS 02 P
	Tatu (mesotrophic)	TU1	S 22° 38' 45" W 47° 17' 09"	01 SS 02 P
		TU2	S 22° 39' 17" W 47° 17' 01"	01 SS 02 P
		TU3	S 22° 39' 36" W 47° 16' 45"	01 SS 02 P
	Salto Grande (eutrophic)	SG1	S 22° 43' 43" W 47° 13' 56"	01 SS 02 P
		SG2	S 22° 42' 59" W 47° 14' 26"	01 SS 02 P
		SG3	S 22° 43' 05" W 47° 16' 02"	01 SS 02 P
		SG4	S 22° 42' 04" W 47° 16' 51"	01 SS 02 P

For diatom analyses, samples were digested using hydrogen peroxide (H_2O_2 35%) and hydrochloric acid (HCl 37%) according to Battarbee *et al.* (2001). Permanent slides were prepared using Naphrax® as inclusion medium. Optical observations, measurements and micrographs were taken at a magnification of 1000× with a Zeiss Axioskop 2 plus microscope equipped with phase contrast and Axiocam ERc5s high-resolution digital camera. Taxonomy and nomenclature followed specific publications (*e.g.*, Lange-Bertalot 1993, Metzeltin *et al.* 1998, Lange-Bertalot *et al.* 2011) and the on-line catalogue of valid names (site of California Academy

of Sciences 2012). The classification systems followed Medlin & Kaczmarska (2004) for supra-ordinal taxa and Round *et al.* (1990) for subordinal taxa, except for genera published after to this work.

Diatoms were quantified at a magnification of 1000× and until reaching a minimum of 400 valves per slide (Battarbee *et al.* 2001), and at least 90% in counting efficiency (Pappas & Stoermer 1996). We included those taxa with relative abundance ≥2% in at least one sampling site and indicated the new records for Brazil and São Paulo state after consulting the published literature (books and articles). Descriptions, relevant taxonomical and ecological comments were provided for taxa identified in genus level. Morphometric information is provided for the new records for Brazil and São Paulo State and for genus level taxa (L: length; W: width; S: striae; A: areolae; F: fibulae). Samples were deposited at the "Herbário Científico do Estado Maria Eneyda P. Kauffmann Fidalgo" (SP), Brazil (SP469229 to SP467313, SP469453, SP469454 and SP456488 to SP469523).

Results and discussion

The main environmental features of the study area are available in Table 2. A total of seventy-eight taxa presented relative abundance ≥2% were identified, including two non-typical varieties, distributed in 28 genera (Table 3). Surface sediment and phytoplankton contributed, respectively, with 60 and 70 taxa. *Nitzschia* Hassal was the genera with higher number of taxa (nine species) followed by *Achnanthidium* Kützing (eight species), *Aulacoseira* Thwaites (eight species) and *Fragilaria* Lyngbye (eight species). *Aulacoseira ambigua* and *A. granulata* var. *angustissima* were the most spread species in the surface sediment, occurring in 100% of samples and with the highest abundance in eutrophic conditions (63.6% and 63.7%, respectively). The most frequent species in the phytoplankton were *Aulacoseira ambigua* and *Discostella stelligera*, both with an occurrence of 90.2% in samples and higher abundances in

oligo- and mesotrophic and meso- eutrotrophic conditions, respectively (63.6% and 92.0%). All inventoried taxa and their relative abundances according to the trophic state are presented in Table 3. Taxa relative abundance according to surface sediment and phytoplankton assemblages are available in Table 4. Seven taxa are new records for Brazil and five for São Paulo state. They are marked with one and two asterisks, respectively. Eleven taxa were identified in genus level because they were not found in literature, and probably represent undescribed species. Those taxa are presented below.

Table 2. Mean and standard deviation of environmental variables measured in the 10 sampled reservoirs (n=41) in summer and winter. Secchi: water transparency, Temp: water temperature, Cond: conductivity, DO: dissolved oxygen, DIN: dissolved inorganic nitrogen, TN: total nitrogen, PO$_4$: orthophosphate, TP: total phosphorous, SRS: soluble reactive silica, Chl-*a*: chlorophyll-*a*.

Variables	Summer		Standard deviation	Winter		Standard deviation
	Range	Mean		Range	Mean	
Depth (m)	2.0-24.0	10.7	5.8	1.5-25.2	11.0	6.3
Secchi (m)	0.3-3.2	1.2	0.8	0.4-2.9	1.5	0.6
Temp (˚C)	21.0-29.7	25.7	1.9	11.4-26.1	17.8	3.7
pH	5.8-9.6	7.2	1.0	6.2-9.5	7.2	0.9
Cond (μS cm^{-1})	18.0-361.0	114.1	98.5	38.0-481.0	151.3	139.9
DO (mg L^{-1})	3.7-12.7	6.3	1.7	2.4-12.2	7.6	1.8
DIN (μg L^{-1})	23.0-4968.0	536.6	1066.0	69.5-7548.2	811.8	1362.1
TN (μg L^{-1})	67.0-9859.1	1337.9	2262.5	145.9-8136.6	1307.5	1500.1
PO$_4$ (μg L^{-1})	4.0-90.0	12.8	17.6	4.0-428.1	32.3	74.7
TP (μg L^{-1})	6.9-567.7	68.4	124.8	6.5-590.6	77.3	124.9
SRS (mg L^{-1})	2.6-6.6	3.8	0.9	1.0-5.7	3.5	1.6
Chl-*a* (μg L^{-1})	0.9-363.9	32.2	66.5	0.5-518.5	38.9	92.9
Trophic State Index (TSI)	48.2-72.8	56.0	7.1	45.7-75.3	55.8	8.2

Fragilariaceae Greville

    Fragilaria Lyngbye

*Fragilaria grunowii Lange-Bertalot & Ulrich *In* Lauterbornia 78, p. 22-27, pl. 9, fig. 1-12, pl. 10, fig. 1-10, 2014.

Figs. 2-4

L: 68.5-178.0 μm; W: 2.5-3.4 μm; S: 13-17 in 10 μm.

Short and narrow specimens of *F. grunowii* may be mistaken with large specimens of *Fragilaria tenuissima* Lange-Bertalot & Ulrich. However, the specimens found in this study are wider than the type population of *F. tenuissima* (W: 1.6-2.8 μm; Lange-Bertalot & Ulrich 2014). Specimens shorter than *F. grunowii* type population (L: 100.0-380.0 μm) were presently found, increasing the length range for this species. Silva (2017) recorded this species in surface sediment and planktonic samples in six of the reservoirs included in this study. This author estimated that this species has preference for slightly acid (pH: 6.8) and low nutrient content waters (total nitrogen: 417.7 μg L^{-1} and total phosphorus: 15.0 μg L^{-1}). In this study, considering surface sediment samples, *F. grunowii* was found in one mesotrophic reservoir (Itupararanga, maximum abundance: 2.7%), and, considering planktonic samples, it was found in three reservoirs ranging from oligo- to eutrophic conditions (Santa Helena, Itupararanga and Hedberg, maximum abundance: 2.9%), but with higher frequency of occurrence in mesotrophic waters (37.1% of samples). This is the second register of the species in Brazil and the first published taxonomical register of this species.

Examined material: BRASIL, SÃO PAULO: Sorocaba, Itupararanga, 29-VIII-2014, *E. Bartozek & D.C. Bicudo* (surface sediment: SP469233, SP469234, SP469235, SP469236); Sorocaba, Itupararanga, 21-II-2014, *E. Bartozek & D.C. Bicudo* (phytoplankton: SP469492, SP469493, SP469494, SP469495, SP469499, SP469500, SP469501); Votorantim, Santa Helena, 27-II-2014, *E. Bartozek & D.C. Bicudo* (phytoplankton: SP469453, SP469454, SP469488); Ibiúna, Hedberg, 26-VIII-2014, *E. Bartozek & D.C. Bicudo* (phytoplankton: SP469513).

Fragilaria tenera var. **nanana (Lange-Bertalot) Lange-Bertalot & Ulrich *In* Lauterbornia 78, p. 7-8, pl. 2, fig. 1-6, pl. 4, fig. 1-6, 2014.

Figs. 5-10

L: 34.1-66.1 µm; W: 2.4-3.0 µm; S: 17-20 in 10 µm.

Lange-Bertalot & Ulrich (2014) provided new illustrations of *F. tenera* from the lectotype slide and presented three varieties: *F. tenera* (Smith) Lange-Bertalot var. *tenera*, *F. tenera* var. *nanana* (Lange-Bertalot) Lange-Bertalot & Ulrich and *F. tenera* var. *lemanensis* Druart, Lavigne & Robert. *F. tenera* var. *nanana* presents lanceolate valves, inflated and capitated ends and shorter measures (L: 50.0-70.0 µm; W: 2.0 µm), while *F. tenera* var. *tenera* presents valves (sub)linear, mainly in the proximal region, slightly inflated ends, larger length (L: 60.0-120.0 µm) and shorter width (W: 1.8-2.5 µm). *F. tenera* var. *lemanensis* is characterized by longer (L: 97.0-102.0 µm) and narrower valves (W: 1.5-1.7 µm). This taxon was registered by Silva (2017) as *Fragilaria tenera* (Smith) Lange-Bertalot in the surface sediment and phytoplankton in seven of the studied reservoirs, with preferences for slightly acid to neutral waters (pH: 6.6-7.5) and low to moderate nutrients content (total nitrogen: 284.0-957.6 µg L^{-1} and total phosphorus: 0.1-52.7 µg L^{-1}). In this study, it was observed in mesotrophic conditions in the surface sediment of one reservoir (Ipaneminha, maximum abundance: 3.9%) and in phytoplankton of three meso- and hypereutrophic reservoirs (Itupararanga, Ipaneminha and Barra Bonita, maximum abundance: 30.4%), but with higher frequency in mesotrophic conditions (25.7%), corroborating previous information. This is the second register of the species in Brazil and the first published taxonomical register of this species.

Examined material: BRASIL, Sᾶo Paulo: Barra Bonita, Barra Bonita, 20-III-2014*, E. Bartozek & D.C. Bicudo* (phytoplankton: SP469517); Sorocaba, Ipaneminha, 25-II-2014, *E. Bartozek & D.C. Bicudo* (phytoplankton: SP469502, SP469503, SP469504); Sorocaba, Ipaneminha, 21-VIII-2014, *E. Bartozek & D.C. Bicudo* (phytoplankton: SP469505, SP469506, SP469507); Sorocaba, Ipaneminha, 21-VIII-2014, *E. Bartozek & D.C. Bicudo* (surface sediment:

SP469237, SP469238, SP469239); Sorocaba, Itupararanga, 25-VIII-2017, *E. Bartozek & D.C. Bicudo* (phytoplankton: SP469501); Sorocaba, Itupararanga, 25-VIII-2017, *E. Bartozek & D.C. Bicudo* (surface sediment: SP469232).

Fragilaria sp.

Figs. 11-14

Valves linear with weakly convex margin; ends subcapitate; axial area narrow and linear; central area bilaterally swelling and with "ghost" striae; striae parallel. L: 27.0-59.0 µm; W: 2.0-4.0 µm; S: 14-16 in 10 µm.

This taxon resembles *F. parva* (Grunow) Tuji & Williams, which however presents more pronounced swellings and capitate ends (Tuji & Williams 2008) than *Fragilaria* sp. This species was recorded in the surface sediment of one mesotrophic reservoir (Tatu, maximum abundance: 5.0%), and in phytoplankton of four reservoirs ranging from oligo- to mesotrophic conditions (Atibainha, Paiva Castro, Cachoeira and Tatu, maximum abundance: 18.3%). The highest frequency in samples was in oligotrophic conditions (22.0%).

Examined material: BRASIL, São Paulo: Limeira, Tatu, 18-IV-2013, *S. Zorzal-Almeida & D.C. Bicudo* (phytoplankton: SP469289, SP469290, SP469291); Limeira, Tatu, 18-VII-2013, *S. Zorzal-Almeida & D.C. Bicudo* (phytoplankton: SP469311, SP469312, SP469313; surface sediment: SP469269); Mairiporã, Paiva Castro, 18-I-2013, *S. Zorzal-Almeida & D.C. Bicudo* (phytoplankton: SP469281, SP469282, SP469283, SP469284); Mairiporã, Paiva Castro, 19-VII-2013, *S. Zorzal-Almeida & D.C. Bicudo* (phytoplankton: SP469303, SP469304, SP469305, SP469306); Nazaré Paulista, Atibainha, 24-I-2013, *S. Zorzal-Almeida & D.C. Bicudo* (phytoplankton: SP469275, SP469278); Piracaia, Cachoeira, 26-VII-2013, *S. Zorzal-Almeida & D.C. Bicudo* (phytoplankton: SP469292).

Pseudostaurosira Williams & Round

Pseudostaurosira sp.

Figs. 15-24

Valves elliptical to elliptical-lanceolate, sternum following the valve shape; striae short, parallel in the center becoming slightly radiate toward the ends. L: 5.3-8.9 µm; W: 2.5-3.3 µm; S: 16-17 in 10 µm.

This taxon was identified as belonging to the genus *Pseudostaurosira* due to the uniseriate striae composed by several areolae and wide axial area. Other features, such as presence of spines and apical pore fields absent or reduced, are only visible in SEM (Morales 2001). It can be misidentified as *Staurosirella* sp. (see taxon bellow), however, *Pseudostaurosira* sp. presents shorter striae and wider axial area. This is probably a new diatom species for science. The species was documented in the surface sediment of four reservoirs with trophic state ranging from oligo- to eutrophic (Santa Helena, Itupararanga, Ipaneminha, and Hedberg, maximum abundance: 3.0%), and in the phytoplankton of four reservoirs ranging from oligo- to eutrophic conditions (Santa Helena, Itupararanga, Ipaneminha and Hedberg, maximum abundance: 3.8%). The highest frequency occurred in mesotrophic conditions (37.1%).

Examined material: BRASIL, São Paulo: Iperó, Hedberg, 12-III-2014, *E. Bartozek & D.C. Bicudo* (phytoplankton: SP469508, SP469509, SP469510); Iperó, Hedberg, 26-VIII-2014, *E. Bartozek & D.C. Bicudo* (phytoplankton: SP469511, SP469512, SP469513; surface sediment: SP469240, SP469241, SP469242); Sorocaba, Ipaneminha, 21-VIII-2014, *E. Bartozek & D.C. Bicudo* (phytoplankton: SP469505, SP469507; surface sediment: SP469238, SP469239); Sorocaba, Itupararanga, 25-VIII-2014, *E. Bartozek & D.C. Bicudo* (phytoplankton: SP469500; surface sediment: SP469235, SP469236); Sorocaba, Itupararanga, 29-VIII-2014, *E. Bartozek & D.C. Bicudo* (phytoplankton: SP469499; surface sediment: SP469233, SP469234); Votarantim, Santa Helena, 27-II-2014, *E. Bartozek & D.C. Bicudo* (phytoplankton: SP469453); Votarantim,

Santa Helena, 21-VIII-2014, *E. Bartozek & D.C. Bicudo* (surface sediment: SP469230, SP469231).

Rimoneis Garcia

Rimoneis sp.

Figs. 31-39

Valves linear-lanceolate and hyaline; valve face with wide sterna occupying almost all the valve face; rounded ends. L: 9.2-16.1 µm; W: 1.5-3.0 µm; inconspicuous striae.

The species resembles *Rimoneis inanis* Garcia in relation to the valve shape. However, *R. inanis* presents larger valve length (L: 17.0-25.0 µm, Garcia 2010). This author points out that *R. inanis* presented restricted distribution to freshwater/brackish water of the Lagoa dos Patos lagoon. *Rimoneis* sp. is described as a new species in the revision carried out by (Silva 2017) and mainly associated to low nutrient content environments. In this study, it occurred in the surface sediment of five reservoirs ranging from oligo- to mesotrophic conditions (Santa Helena, Atibainha, Cachoeira, Paiva Castro and Itupararanga, maximum abundance: 7.0%) and in the phytoplankton of mesotrophic reservoir Itupararanga (maximum abundance: 1.4%). Nevertheless, highest frequency in samples was observed in mesotrophic conditions (20.0%).

Examined material: BRASIL, São Paulo: Mairiporã, Paiva Castro, 19-VII-2013, *S. Zorzal-Almeida & D.C. Bicudo* (surface sediment: SP469262); Nazaré Paulista, Atibainha, 25-VII-2013, *S. Zorzal-Almeida & D.C. Bicudo* (surface sediment: SP469253); Piracaia, Cachoeira, 26-VII-2013, *S. Zorzal-Almeida & D.C. Bicudo* (surface sediment: SP469250); Sorocaba, Itupararanga, 21-II-2014, *E. Bartozek & D.C. Bicudo* (phytoplankton: SP469493); Sorocaba, Itupararanga, 25-VIII-2014, *E. Bartozek & D.C. Bicudo* (phytoplankton: SP469500, SP469501; surface sediment: SP469235, SP469236); Sorocaba, Itupararanga, 29-VIII-2014, *E. Bartozek &*

D.C. Bicudo (phytoplankton: SP469498; surface sediment: SP469233, SP469234); Votorantim, Santa Helena, 21-VIII-2014, *E. Bartozek & D.C. Bicudo* (surface sediment: SP469231).

Staurosirella Williams & Round

***Staurosirella* sp.**

Figs. 25-30

Valves oval to elliptic; ends rounded; axial area linear and narrow; striae alternated and slightly radiate; central area absent. L: 4.7-7.3 µm; W: 3.4-4.3 µm; S: 12 in 10 µm.

This taxon resembles *Staurosira altiplanensis* Lange-Bertalot & Rumrich due to the overlapping measures (L: 4.5 µm; W: 2.8-3.6 µm) and similar valve outline. However, *S. altiplanensis* presents valves strictly elliptical and was described for the high altitude of the Altiplano of South America (Lange-Bertalot 2000). Furthermore, *Staurosirella* sp. was identified as *Staurosirella pinnata* (Ehrenberg) Williams & Round by Ribeiro *et al.* (2008) and Nardelli *et al.* (2014). However, Morales *et al.* (2013) demonstrated that *S. pinnata* type material, originally described as *Fragilaria pinnata* Ehrenberg, represents a species of the genus *Denticula* Kützing. Therefore, for these authors, a prior careful taxonomical and ecological analysis of this species is necessary. It was presently found in the surface sediment of four reservoirs with trophic states from oligo- to eutrophic conditions (Santa Helena, Itupararanga, Ipaneminha and Hedberg, maximum abundance: 4.0%), and in the phytoplankton of three reservoirs ranging from oligo- to eutrophic conditions (Santa Helena, Itupararanga and Hedberg, maximum abundance: 2.3%), and with higher frequency in mesotrophic waters (34.3%).

Examined material: BRASIL, SÃO PAULO: Iperó, Hedberg, 12-III-2014, *E. Bartozek & D.C. Bicudo* (phytoplankton: SP469508, SP469509, SP469510); Iperó, Hedberg, 26-VIII-2014, *E. Bartozek & D.C. Bicudo* (phytoplankton: SP469511, SP469512; surface sediment: SP469240, SP469241, SP469242); Sorocaba, Ipaneminha, 21-VIII-2014, *E. Bartozek & D.C. Bicudo*

(surface sediment: SP469237, SP469238); Sorocaba, Itupararanga, 21-II-2014, *E. Bartozek & D.C. Bicudo* (phytoplankton: SP469496); Sorocaba, Itupararanga, 25-VIII-2014, *E. Bartozek & D.C. Bicudo* (phytoplankton: SP469500; surface sediment: SP469235, SP469236); Sorocaba, Itupararanga, 29-VIII-2014, *E. Bartozek & D.C. Bicudo* (surface sediment: SP469234); Votorantim, Santa Helena, 27-II-2014, *E. Bartozek & D.C. Bicudo* (phytoplankton: SP469454, SP469488); Votorantim, Santa Helena, 21-VIII-2014, *E. Bartozek & D.C. Bicudo* (surface sediment: SP469229, SP469231).

Cymbellaceae Greville

  Cymbella Agardh

Cymbella excisa Kützing var. ***procera* Krammer *In* Diatoms of Europe 3, p. 28, pl. 9, fig. 1-7, pl. 10, fig. 10-13, pl. 12, fig. 7, 2002.

Figs. 45-48

  L: 34.5-39.4 µm; W: 9.4-11.3 µm; S: 9-11 in 10 µm.

  C. excisa var. *procera* is the synonymous of *Cymbella affinis* var. *neoprocera* W. Silva. This taxon was recorded in the Paraná State by Ludwig et al. (2005) as *Cymbella affinis* Kützing. According to Krammer (2002), this variety is more robust than its typical variety and usually abundant in eutrophic waters. In this study, it occurred in oligo- to eutrophic conditions in three reservoirs (Santa Helena, Ipaneminha and Hedberg) for both surface sediment and phytoplankton (maximum abundance: 7.0% and 0.5%, respectively), with higher frequency in eutrophic waters (10.5%), corroborating previous finding.

  Examined material: BRASIL, SÃO PAULO: Iperó, Hedberg, 12-III-2017, *E. Bartozek & D.C. Bicudo* (phytoplankton: SP469508); Iperó, Hedberg, 26-VIII-2017, *E. Bartozek & D.C. Bicudo* (phytoplankton: SP469512, SP469513; surface sediment: SP469240, SP469241); Sorocaba, Ipaneminha, 21-VIII-2014, *E. Bartozek & D.C. Bicudo* (phytoplankton: SP469505,

SP469506, SP469507; surface sediment: SP469237, SP469238); Votorantim, Santa Helena, 27-II-2014, *E. Bartozek & D.C. Bicudo* (phytoplankton: SP469454, SP469488); Votorantim, Santa Helena, 27-II-2014, *E. Bartozek & D.C. Bicudo* (surface sediment: SP469231).

Encyonema Kützing

Encyonema sp.

Figs. 49-55

Valve strongly dorsiventral, semi-lanceolate, with dorsal margin strongly convex and ventral margin straight to slightly concave and expanded in the middle portion; ends ventrally bent; axial area straight and linear; raphe straight, external ends deflected to the ventral side and proximal ends deflected to the dorsal side. L: 11.0-22.2 µm; W: 4.0-5.8 µm; S: 10-13 in 10 µm.

This taxon resembles *E. simile* Krammer in valve shape and measures (L: 16.0-25.5 µm; W: 5.1-6.0 µm; S: 10-13 in 10 µm; Krammer 1997), however *Encyonema* sp. presents thinner and slightly more capitate ends. Further analysis (*e.g.*, MEV) are required to confirm if this taxon is a new species. In this study, it was found in the surface sediment of three oligotrophic reservoirs (Atibainha, Cachoeira and Paiva Castro, maximum abundance: 2.2%), and in the phytoplankton of three reservoirs ranging from oligo- to mesotrophic conditions (Cachoeira, Paiva Castro and Tatu, maximum abundance: 4.8), and presented higher frequency of occurrence in oligotrophic conditions (26.0%).

Examined material: BRASIL, SÃO PAULO: Limeira, Tatu, 18-IV-2013, *S. Zorzal-Almeida & D.C. Bicudo* (phytoplankton: SP469290); Mairiporã, Paiva Castro, 19-VII-2013, *S. Zorzal-Almeida & D.C. Bicudo* (phytoplankton: SP469304; surface sediment: SP469259, SP469260, SP469261, SP469262); Nazaré Paulista, Atibainha, 25-VII-2013, *S. Zorzal-Almeida & D.C. Bicudo* (surface sediment: SP469253, SP469254); Piracaia, Cachoeira, 21-II-2013, *S. Zorzal-Almeida & D.C. Bicudo* (phytoplankton: SP469271, SP469272, SP469273); Piracaia, Cachoeira,

26-VII-2013, *S. Zorzal-Almeida & D.C. Bicudo* (phytoplankton: SP469292; surface sediment: SP469248; SP469249, SP469250).

Encyonopsis Krammer

*Encyonopsis thienemannii (Hustedt) Krammer *In* Bibliotheca Diatomologica 37, p. 106, pl. 149, fig. 28-33, 1997.

Figs. 40-44

L: 13.2-21.1; W: 4.0-4.7; S: 25-29 in 10 μm.

E. thienemannii resembles *E. minuta* Krammer & Reichardt in relation to valve outline. However, the second species shows more detached apices, narrower width and lower striae density in 10 μm (W: 2.8-3.5, S: 24-25 in 10 μm; Krammer 1997) than *E. thienemannii*. According to Krammer (1997) this species is found in springs and falls. In this study, it was recorded exclusively in the phytoplankton of two oligo- and mesotrophic reservoirs (Santa Helena and Itupararanga, maximum abundance: 3.6%), with higher frequency in mesotrophic conditions (5.7%).

Examined material: BRASIL, SÃO PAULO: Sorocaba, Itupararanga, 21-II-2014, *E. Bartozek & D.C. Bicudo* (phytoplankton: SP469493); Votorantim, Santa Helena, 21-VIII-2014, *E. Bartozek & D.C. Bicudo* (phytoplankton: SP469489, SP469490, SP469491).

Gomphonema Ehrenberg

**Gomphonema naviculoides Smith *In* A synopsis of the British Diatomaceae, v. 2 pp. [i-vi] - xxix, 1-107, pls. 32-60, 61-62, A-E, 1856.

Figs. 56-58

L: 22.0-55.0 μm; W: 5.0-8.2 μm; S: 10-15 in 10 μm.

Gomphonema naviculoides belongs to *Gomphonema gracile* complex sensu Grunow et sensu auct, and according to Reichardt (2015) both species can be easily mistaken. However, this author highlights that *G. naviculoides* presents valves lanceolate to rhombic-lanceolate and almost naviculoid-symmetrical, while *G. gracile* presents valves lanceolate, gomphonemoid-clavate shaped with bluntly rounded poles. In this study, the species occurred in the surface sediment of two oligo- and mesotrophic reservoirs (Paiva Castro and Tatu, maximum abundance: 3.0%), and in the phytoplankton of three oligo- and mesotrophic reservoirs (Cachoeira, Paiva Castro and Tatu, maximum abundance: 2.3%), and with higher frequency in mesotrophic conditions (14.3%).

Examined material: BRASIL, SãO PAULO: Limeira, Tatu, 18-IV-2013, *S. Zorzal-Almeida & D.C. Bicudo* (phytoplankton: SP469289, SP469290, SP469291); Limeira, Tatu, 18-VII-2013, *S. Zorzal-Almeida & D.C. Bicudo* (phytoplankton: SP469313; surface sediment: SP469267, SP469269); Mairiporã, Paiva Castro, 19-VII-2013, *S. Zorzal-Almeida & D.C. Bicudo* (phytoplankton: SP469303; surface sediment: SP469260); Piracaia, Cachoeira, 21-II-2013, *S. Zorzal-Almeida & D.C. Bicudo* (phytoplankton: SP469271); Piracaia, Cachoeira, 26-VII-2013, *S. Zorzal-Almeida & D.C. Bicudo* (phytoplankton: SP469295).

Placoneis Mereschkovsky

*Placoneis exigua (Gregory) Mereschkovsky *In* Beihefte zum Botanischen Centralblatt 15(1), p. 1-30, pl.1, 1903.
Figs. 59-61

L: 24.2-33.8 μm; W: 9.7-11.2 μm; S: 10-14 in 10 μm.

This taxon resembles *Placoneis constans* (Husted) Cox var. *symmetrica* (Hustedt) Kobayasi due to their lanceolate valves and rostrate ends. However, the second species is smaller (L: 19.3-25.6 μm, W: 8.1-9.3 μm) than *P. exigua* and the first species presents a central area with

a longer striae surrounded by shorter striae (Marquardt & Bicudo 2014). *Placoneis exigua* is reported as an indicator of eutrophic conditions (Van Dam *et al.* 1994, Besse-Lototskaya *et al.* 2011). In this study it occurred in surface sediment of eu- and hypereutrophic reservoirs (Hedberg and Barra Bonita, maximum abundance: 3.7%), and in the phytoplankton of eutrophic reservoir Hedberg (maximum abundance: 0.5%), with 5.7% frequency in samples, corroborating previous finding.

Examined material: BRASIL, São Paulo: Barra Bonita, Barra Bonita, 29-VII-2014, *E. Bartozek & D.C. Bicudo* (surface sediment: SP469245); Iperó, Hedberg, 12-III-2014, *E. Bartozek & D.C. Bicudo* (phytoplankton: SP469508, SP469510); Iperó, Hedberg, 26-VIII-2014, *E. Bartozek & D.C. Bicudo* (surface sediment: SP469240).

Achnanthidiaceae Mann

Achnanthidium Kützing

*Achnanthidium jackii Rabenhorst *In* Die Algen Europas, Fortsetzung der Algen Sachsens, resp. Mittel-Europas. Decades I-CIX, numbers 1-1600 (or 1001-2600), 1861.
Figs. 62-67

L: 7.3-15.0 μm; W: 3.4-3.7 μm; inconspicuous striae.

This taxon can be misidentified as *A. minutissimum* (Kützing) Czarnecki since they have similar valve shape. However, *A. jackii* is usually wider than *A. minutissimum* (W: 2.5-3.0 μm, Wojtal *et al.* 2011). It is mostly found in neutral environments with low organic matter concentrations (Van Dam *et al.* 1994, Wojtal *et al.* 2011). In this study, it occurred in the surface sediment of seven reservoirs ranging from oligo- to eutrophic conditions (Atibainha, Cachoeira, Itupararanga, Paiva Castro, Tatu, Hedberg and Salto Grande, maximum abundance: 5.6%), and in the phytoplankton of six reservoirs ranging from oligo- to eutrophic conditions (Atibainha,

Cachoeira, Santa Helena, Paiva Castro, Tatu and Salto Grande, maximum abundance: 24.7%),

showing higher frequency in oligotrophic samples (76.0%).

Examined material: BRASIL, SÃO PAULO: Americana, Salto Grande, 09-III-2013, *S. Zorzal-Almeida & D.C. Bicudo* (phytoplankton: SP469285, SP469286, SP469287, SP469288); Americana, Salto Grande, 20-IX-2013, *S. Zorzal-Almeida & D.C. Bicudo* (phytoplankton: SP469307, SP469308, SP469309, SP469310; surface sediment: SP469264); Iperó, Hedberg, 26-VIII-2014, *E. Bartozek & D.C. Bicudo* (phytoplankton: SP469512, SP469513; surface sediment: SP469240, SP469241, SP469242); Limeira, Tatu, 18-IV-2013, *S. Zorzal-Almeida & D.C. Bicudo* (phytoplankton: SP469289, SP469290, SP469291); Limeira, Tatu, 18-VII-2013, *S. Zorzal-Almeida & D.C. Bicudo* (phytoplankton: SP469311, SP469312, SP469313; surface sediment: SP469267); Mairiporã, Paiva Castro, 18-I-2013, *S. Zorzal-Almeida & D.C. Bicudo* (phytoplankton: SP469281, SP469282, SP469283, SP469284); Mairiporã, Paiva Castro, 19-VII-2013, *S. Zorzal-Almeida & D.C. Bicudo* (phytoplankton: SP469303, SP469304, SP469306; surface sediment: SP469259, SP469260, SP469261, SP469262); Nazaré Paulsita, Atibainha, 24-I-2013, *S. Zorzal-Almeida & D.C. Bicudo* (phytoplankton: SP469275, SP469276, SP469277, SP469278, SP469279, SP469280); Nazaré Paulsita, Atibainha, 25-VII-2013, *S. Zorzal-Almeida & D.C. Bicudo* (phytoplankton: SP469297, SP469298; surface sediment: SP469253, SP469254, SP469255, SP469256, SP469257, SP469258); Piracaia, Cachoeira, 21-II-2013, *S. Zorzal-Almeida & D.C. Bicudo* (phytoplankton: SP469270, SP469271, SP469272, SP469273, SP469274); Piracaia, Cachoeira, 26-VII-2013, *S. Zorzal-Almeida & D.C. Bicudo* (phytoplankton: SP469292, SP469293, SP469295; surface sediment: SP469248, SP469249, SP469251, SP469252); Sorocaba, Itupararanga, 25-VIII-2014, *E. Bartozek & D.C. Bicudo* (surface sediment: SP469232, SP469235, SP469236); Votorantim, Santa Helena, 27-II-2014, *E. Bartozek & D.C. Bicudo* (phytoplankton: SP469488); Votorantim, Santa Helena, 21-VIII-2014, *E. Bartozek & D.C. Bicudo* (phytoplankton: SP469489, SP469490).

Achnanthidium lineare Smith *In* Annals and Magazine of Natural History, series 2 15, pl. 1, fig. 1-9, 1855.

Figs. 73-79

L: 9.0-13.4 μm; W: 2.0-2.8 μm; inconspicuous striae.

Achnanthidium lineare presents linear to narrowly lanceolate valves while in *A. minutissimum* they are lanceolate to elliptic-lanceolate. Furthermore, the first taxon presents rounded to rostrate apices and the second presents rostrate to subcapitate apices (Van de Vijver *et al.* 2011). This species is found mostly in circumneutral waters (Van Dam *et al.* 1994). In the present study, it was found in surface sediment of four reservoirs ranging from oligo- to mesotrophic conditions (Ipaneminha, Itupararanga, Santa Helena and Tatu, maximum abundance: 6.5%), with frequency of 14.3% in mesotrophic samples.

Examined material: BRASIL, SÃO PAULO: Limeira, Tatu, 18-VII-2013, *S. Zorzal-Almeida & D.C. Bicudo* (surface sediment: SP469268, SP469269). Sorocaba, Ipaneminha, 21-VIII-2014, *E. Bartozek & D.C. Bicudo* (surface sediment: SP469237); Sorocaba, Itupararanga, 25-VIII-2014, *E. Bartozek & D.C. Bicudo* (surface sediment: SP469232); Sorocaba, Itupararanga, 29-VIII-2014, *E. Bartozek & D.C. Bicudo* (surface sediment: SP469233, SP469234); Votorantim, Santa Helena, 21-VIII-2014, *E. Bartozek & D.C. Bicudo* (surface sediment: SP469229).

Achnanthidium macrocephalum (Hustedt) Round & Bukhtiyarova *In* Diatom Research 11(2), p. 349, 1996.

Figs. 68-72

L: 9.0-14.0 μm; W: 2.0-3.0 μm; inconspicuous striae.

This taxon can be distinguished from *A. minutissimum* (Kützing) Czarnecki mainly due to its capitate ends (Potapova & Hamilton 2007). According to these authors, this is an alkaliphilous species. In this study, it was found in phytoplankton of five reservoirs ranging from

oligo- to eutrophic conditions (Atibainha, Cachoeira, Paiva Castro, Tatu and Salto Grande, maximum abundance: 17.1%), and with higher frequency in oligotrophic conditions (30.0%).

Examined material: BRASIL, SÃO PAULO: Americana, Salto Grande, 09-III-2013, *S. Zorzal-Almeida & D.C. Bicudo* (phytoplankton: SP469287); Americana, Salto Grande, 20-IX-2013, *S. Zorzal-Almeida & D.C. Bicudo* (phytoplankton: SP469307, SP469308, SP469309, SP469310); Limeira , Tatu, 18-IV-2013, *S. Zorzal-Almeida & D.C. Bicudo* (phytoplankton: SP469289, SP469290, SP469291); Limeira , Tatu, 18-VII-2013, *S. Zorzal-Almeida & D.C. Bicudo* (phytoplankton: SP469311, SP469312, SP469313); Mairiporã, Paiva Castro, 18-I-2013, *S. Zorzal-Almeida & D.C. Bicudo* (phytoplankton: SP469281, SP469282, SP469283, SP469284); Mairiporã, Paiva Castro, 19-VII-2013, *S. Zorzal-Almeida & D.C. Bicudo* (phytoplankton: SP469303, SP469304); Nazaré Paulista, Atibainha, 24-I-2013, *S. Zorzal-Almeida & D.C. Bicudo* (phytoplankton: SP469275); Nazaré Paulista, Atibainha, 25-VII-2013, *S. Zorzal-Almeida & D.C. Bicudo* (phytoplankton: SP469297); Piracaia, Cachoeira, 21-II-2013, *S. Zorzal-Almeida & D.C. Bicudo* (phytoplankton: SP469270, SP469271, SP469272, SP469273, SP469274); Piracaia, Cachoeira, 26-VII-2013, *S. Zorzal-Almeida & D.C. Bicudo* (phytoplankton: SP469292, SP469293, SP469294).

Achnanthidium sp. 1

Figs. 85-92

Valves linear-lanceolate with rounded to subrostrate ends; raphe valves with narrow and linear axial area. L: 11.5-18.0 µm; W: 2.4-2.8 µm; inconspicuous striae.

The principal feature to distinguish this species from *A. minutissimum* is its narrower width measures (Hlúbiková *et al.* 2011; W: 2.5-3.1 µm). Further studies, such as SEM are necessary to a detailed analysis and to investigate whether *Achnanthidium* sp.1 represents a new species. In the present study, this species was recorded in surface sediment of four reservoirs ranging from oligo- to eutrophic conditions (Santa Helena, Itupararanga, Ipaneminha and

Hedberg, maximum abundance: 6.3%), and in the phytoplankton of the mesotrophic reservoir Ipaneminha (maximum abundance: 0.8%), presenting higher frequency in mesotrophic waters (17.1%).

Examined material: BRASIL, SÃO PAULO: Iperó, Hedberg, 26-VIII-2014, *E. Bartozek & D.C. Bicudo* (surface sediment: SP469240, SP469241); Sorocaba, Ipaneminha, 21-VIII-2014, *E. Bartozek & D.C. Bicudo* (phytoplankton: SP469506, SP469507; surface sediment: SP469237); Sorocaba, Itupararanga, 25-VIII-2014, *E. Bartozek & D.C. Bicudo* (surface sediment: SP469236); Sorocaba, Itupararanga, 29-VIII-2014, *E. Bartozek & D.C. Bicudo* (surface sediment: SP469234); Votorantim, Santa Helena, 21-VIII-2014, *E. Bartozek & D.C. Bicudo* (surface sediment: SP469229, SP469230).

Achnanthidium **sp. 2**
Figs. 80-84

Valves rhombic and slender with slightly capitate ends and widen central portion; axial area of both valves narrow and linear. L: 13.8-17.3 μm; W: 3.0-3.3 μm; inconspicuous striae.

This species resembles *A. catenatum* due to its undulated valves (Hlúbiková *et al.* 2011), however, our species is slender than *A. catenatum*. This is probably a new *Achnanthidium* species and further studies are required. It was found in the phytoplankton of two reservoirs with meso- and eutrophic conditions (Itupararanga and Hedberg, maximum abundance: 44.05), with higher frequency in mesotrophic samples (11.4%).

Examined material: BRASIL, SÃO PAULO: Iperó, Hedberg, 12-III-2014, *E. Bartozek & D.C. Bicudo* (phytoplankton: SP469508, SP469509, SP469510); Sorocaba, Itupararanga, 25-VIII-2014, *E. Bartozek & D.C. Bicudo* (phytoplankton: SP469497, SP469500, SP469501); Sorocaba, Itupararanga, 29-VIII-2014, *E. Bartozek & D.C. Bicudo* (phytoplankton: SP469498, SP469499).

Brachysiraceae Mann

    Brachysira Kützing

Brashysira sp.

Figs. 93-96

    Valves rhombic-lanceolate with ends strongly capitate; axial area is narrow and linear, central area is small and rhombic; raphe is filiform; striae are slightly radiated in middle portion becoming parallel toward the ends. L: 13.5-27.0 µm; W: 3.2-5.0 µm; S: 32-35 in 10 µm.

    Brachysira sp. is similar to *Brachysira microcephala* (Grunow) Compère "morphotype 2" presented by Siver *et al.* (2005) due to the distinctly capitate ends. However, *Brachysira* sp. differs due to its shorter width and valves becoming narrower toward the ends. Besides, *Brachysira* sp. maintains the valve shape (capitate) in smaller specimens. In the present study, this taxon was recorded in surface sediment of three reservoirs (Atibainha, Paiva Castro and Tatu, maximum abundance: 5.3%), however, it exhibited higher frequency in oligotrophic samples (16.0%).

Examined material: BRASIL, SÃO PAULO: Limeira, Tatu, 18-VII-2013, *S. Zorzal-Almeida & D.C. Bicudo* (surface sediment: SP469268, SP469269); Mairiporã, Paiva Castro, 19-VII-2013, *S. Zorzal-Almeida & D.C. Bicudo* (surface sediment: SP469260, SP469261, SP469262); Nazaré Paulista, Atibainha, 25-VII-2013, *S. Zorzal-Almeida & D.C. Bicudo* (surface sediment: SP469254, SP469255, SP469256, SP469257, SP469258).

Sellaphoraceae Mereschkowsky

    Sellaphora Mereschkowsky

Sellaphora rostrata (Hustedt) Johansen *In* Archiv für Hydrobiologie Supplement 150 (Algological Studies 111), p. 17-44, 2004.

Figs. 97-98

L: 17.5-29.0 µm; W: 6.3-8.0 µm; S: 19-25 in 10 µm.

This taxon belongs to the *Sellaphora pupula* complex. Nevertheless, *S. rostrata* can be distinguished from *S. pupula* because the first species presents distinct capitate ends (Johansen et al. 2004). It can be found in circumneutral to alkaline and eutrophic environments (Moro & Fürstenberger 1997). In the present study, it was found in the surface sediment of two oligo- and mesotrophic reservoirs (Paiva Castro and Tatu, maximum abundance: 5.4%), and in the phytoplankton of four reservoirs ranging from oligo- to eutrophic conditions (Cachoeira, Paiva Castro, Tatu and Salto Grande, maximum abundance: 2.6%), showing higher frequency in mesotrophic samples (17.1%).

Examined material: BRASIL, SÃO PAULO: Americana, Salto grande, 20-IX-2013, *S. Zorzal-Almeida & D.C. Bicudo* (phytoplankton: SP469308); Limeira, Tatu, 18-IV-2013, *S. Zorzal-Almeida & D.C. Bicudo* (phytoplankton: SP469290); Limeira, Tatu, 18-VII-2013, *S. Zorzal-Almeida & D.C. Bicudo* (phytoplankton: SP469311, SP469312, SP469313; surface sediment: SP469267, SP469268, SP469269); Mairiporã, Paiva Castro, 18-I-2013, *S. Zorzal-Almeida & D.C. Bicudo* (phytoplankton: SP469283); Mairiporã, Paiva Castro, 19-VII-2013, *S. Zorzal-Almeida & D.C. Bicudo* (phytoplankton: SP469303; surface sediment: SP469261, SP469262); Piracaia, Cachoeira, 21-II-2013, *S. Zorzal-Almeida & D.C. Bicudo* (phytoplankton: SP469270); Piracaia, Cachoeira, 26-VII-2013, *S. Zorzal-Almeida & D.C. Bicudo* (phytoplankton: SP469292).

Bacillariaceae Ehrenberg

Nitzschia Hassal

Nitzschia perminuta (Grunow) Peragallo *In* Le Catalogue Général des Diatomées [issued in fascicles at various dates] vol. 2, p. 672, 1903.

Figs. 99-100

L: 17.0-26.0 µm; W: 2.1-4.0 µm; S: 25-26 in 10 µm; F: 10-17 in 10 µm.

N. perminuta can be distinguished from *Nitzchia amphibia* Grunow because the second species presents evident central nodule, which is lacking in *N. perminuta*, and prominent and distinctly punctate striae (Kociolek 2011a). *N. perminuta* has been found in alkaline and eutrophic waters (Van Dam *et al.* 1994). However, *N.* cf. *perminuta* was found in slightly acidic to circumneutral ponds with low nutrients concentration (Siver *et al.* 2005). In the present study, it occurred in the surface sediment of two oligotrophic reservoirs (Atibainha and Paiva Castro, maximum abundance: 2.0%), with a frequency of 8.0% in the samples.

Examined material: BRASIL, SÃO PAULO: Mairiporã, Paiva Castro, 19-VII-2013, *S. Zorzal-Almeida & D.C. Bicudo* (surface sediment: SP469260, SP469261); Nazaré Paulista, Atibainha, 25-VII-2013, *S. Zorzal-Almeida & D.C. Bicudo* (surface sediment: SP469253, SP469254).

*Nitzschia semirobusta Lange-Bertalot *In* Bibliotheca Diatomologica 27, pl. 120, figs. 3-21, pl. 122, fig. 7, pl. 123, figs. 1-7, 1993.

Figs. 101-103

L: 8.0-29.0 µm; W: 3.5-5.0 µm; S: 16-18 in 10 µm.

This species can be confused with *Nitzschia amphibia* Grunow due to the same valve shape. However, *N. semirobusta* can be distinguished by its extended fibulae from one valve margin to another (Lange-Bertalot 1993). In the present study, it was observed in surface sediment of five reservoirs ranging from oligo- to eutrophic conditions (Atibainha, Cachoeira, Paiva Castro, Tatu and Salto Grande, maximum abundance: 4.3%), and in phytoplankton of four reservoirs ranging from oligo- to mesotrophic conditions (Atibainha, Cachoeira, Paiva Castro and Tatu, maximum abundance: 5.0%). Higher frequency occurred in oligotrophic conditions (74.0%).

Examined material: BRASIL, São Paulo: Limeira, Tatu, 18-IV-2013, *S. Zorzal-Almeida & D.C. Bicudo* (phytoplankton: SP469289, SP469290, SP469291); Limeira, Tatu, 18-VII-2013*, S. Zorzal-Almeida & D.C. Bicudo* (phytoplankton: SP469311, SP469312; surface sediment: SP469269); Mairiporã, Paiva Castro, 18-I-2013, *S. Zorzal-Almeida & D.C. Bicudo* (phytoplankton: SP469282, SP469283); Mairiporã, Paiva Castro, 19-VII-2013, *S. Zorzal-Almeida & D.C. Bicudo* (phytoplankton: SP469303, SP469304, SP469305; surface sediment: SP469259, SP469260, SP469261, SP469262); Nazaré Paulista, Atibainha, 24-I-2013, *S. Zorzal-Almeida & D.C. Bicudo* (phytoplankton: SP469275, SP469276, SP469277, SP469278, SP469279, SP469280); Nazaré Paulista, Atibainha, 25-VII-2013, *S. Zorzal-Almeida & D.C. Bicudo* (phytoplankton: SP469297, SP469298, SP469300, SP469302; surface sediment: SP469253, SP469254, SP469255, SP469257, SP469258); Piracaia, Cachoeira, 21-II-2013, *S. Zorzal-Almeida & D.C. Bicudo* (phytoplankton: SP469270, SP469271, SP469272, SP469273, SP469274); Piracaia, Cachoeira, 26-VII-2013, *S. Zorzal-Almeida & D.C. Bicudo* (phytoplankton: SP469292, SP469294, SP469295, SP469296; surface sediment: SP469248, SP469249, SP469250, SP469251, SP469252).

Nitzschia **sp. 1**
Figs. 104-109

Valves lanceolate; apices acutely rounded; striae parallel; fibulae equally spaced; central nodule absent. L: 16.5-32.2 µm; W: 3.8-4.5 µm; S: 17-19 in 10 µm; F: 8-9 in 10 µm.

Nitzschia sp. 1 is similar to *Nitzschia amphibia* Grunow and *N. fonticola* (Grunow) Grunow in relation to the valve shape and conspicuous striae (Kociolek 2011a, 2011b). However, *Nitzschia* sp. 1 doesn't present central nodule, which is evident in the two other species (Trobajo *et al.* 2006). Furthermore, *N. fonticola* exhibit higher striae density (S: 28-30 in 10 µm) than *Nitzschia* sp. 1 (Trobajo *et al.* 2006). In this study it was found in surface sediment of three reservoirs ranging from meso- to eutrophic conditions (Itupararanga, Ipaneminha and

Hedberg, maximum abundance: 7.0%), and in phytoplankton of the same reservoirs (maximum abundance: 1.2%). Higher frequency occurred in mesotrophic samples (25.7%).

Examined material: BRASIL, SÃO PAULO: Iperó, Hedberg, 12-III-2014, *E. Bartozek & D.C. Bicudo* (phytoplankton: SP469508, SP469509, SP469510); Iperó, Hedberg, 26-VIII-2014, *E. Bartozek & D.C. Bicudo* (phytoplankton: SP469511, SP469512; surface sediment: SP469240, SP469241, SP469242); Sorocaba, Ipaneminha, 25-II-2014, *E. Bartozek & D.C. Bicudo* (phytoplankton: SP469502); Sorocaba, Ipaneminha, 21-VIII-2014, *E. Bartozek & D.C. Bicudo* (phytoplankton: SP469505; surface sediment: SP469237, SP469239); Sorocaba, Itupararanga, 21-II-2014, *E. Bartozek & D.C. Bicudo* (phytoplankton: SP469495); Sorocaba, Itupararanga, 25-VIII-2014, *E. Bartozek & D.C. Bicudo* (surface sediment: SP469236).

Nitzschia sp. 2
Figs. 110-112

Valves linear-lanceolate; ends expanded, subcapitate; striae parallel becoming slightly curved toward the ends, almost inconspicuous; fibulae equally spaced. L: 19.0-20.5 µm; W: 3.5-4.5 µm; S: 23-26 in 10 µm; F: 10-13 in 10 µm.

Nitzschia sp.2 resembles *N. bryophila* (Hustedt) Hustedt because of their similar valve shape. Nevertheless, *N. bryophila* is wider (W: 5.0 µm), presents higher striae density (S: 31-33 in 10 µm) and more prominent ends (Simonsen 1987). In the present study, it was found in surface sediment of mesotrophic reservoir Tatu (maximum abundance: 20.2%), and in the phytoplankton of the same reservoir (maximum abundance: 3.3%), with a frequency of 11.4% in the mesotrophic samples.

Examined material: BRASIL, SÃO PAULO: Limeira, Tatu, 18-VII-2013, *S. Zorzal-Almeida & D.C. Bicudo* (phytoplankton: SP469311, SP469312, SP469313; surface sediment: SP469267, SP469268, SP469269).

***Nitzschia* sp. 3**

Figs. 113-127

Valves linear to linear-lanceolate, frustules rectangular in girdle view; ends varying from rounded to slightly subrostrate; fibulae irregularly spaced. L: 38.3-62.7; W: 4.0-4.7; inconspicuous striae; F: 11-14 in 10 μm.

This species is similar to *Nitzschia linearis* (Agardh) Smith due to its linear-lanceolate valves (Kociolek 2011c), however, *Nitzschia* sp. 3 presents more attenuated ends. *Nitzschia* sp. 3 is also similar to *N. gracilis* Hantzsch. Nevertheless, *N. gracilis* exhibits larger valve variation, with individuals ranging from around 30.0 μm to more than 100.0 μm (Lange-Bertalot 1976). In this study, *Nitzschia* sp. 3 occurred in phytoplankton of hypereutrophic reservoir Barra Bonita (maximum abundance: 12.0%), with a frequency s of 18.4% (eu- and hypereutrophic samples).

Examined material: BRASIL, SãO PAULO: Barra Bonita, Barra Bonita, 20-III-2014, *E. Bartozek & D.C. Bicudo* (phytoplankton: SP469514, SP469515, SP469516, SP469517); Barra Bonita, Barra Bonita, 29-VII-2014, *E. Bartozek & D.C. Bicudo* (phytoplankton: SP469519, SP469520, SP469521).

Summarizing, from a total of 78 taxa recorded in surface sediments and phytoplankton samples, our study added seven new diatom species to the Brazilian flora and beyond those, five for São Paulo state. Furthermore, we registered other eleven possible new taxa for science. Eight taxa occurred exclusively in the surface sediment (*Achnanthidium lineare*, *Brachysira* sp., *Fragilaria parva*, *Gomphonema parvulum*, *Hantzschia amphioxys*, *Navicula symmetrica*, *Nitzschia perminuta* and *Sellaphora nigri* (see Table 4). Other eighteen taxa only occurred in the phytoplankton community (*Achnanthidium exiguum*, *A. macrocephalum*, *Achnanthidium* sp. 2, *Aulacoseira veraluciae*, *Brachysira brebissonii*, *Discostella pseudostelligera*, *Encyonopsis thienemannii*, *Eunotia desmogonioides*, *E. meridiana*, *Fragilaria crotonensis*, *F. spectra*, *Geissleria punctifera*, *Gomphonema hawaiense*, *Nitzschia amphibia*, *N. gracilis*, *N. palea* var.

debilis, *Nitzschia* sp. 3 and *Ulnaria acus*). Three species were exclusively recorded in oligotrophic conditions (*Navicula symmetrica*, *Nitzschia perminuta* and *Sellaphora nigri*), *Eunotia desmogonioides* was only found in mesotrophic conditions and four species occurred only in eutrophic waters (*Aulacoseira veraluciae*, *Brachysira brebissonii*, *Nitzschia* sp. 3 and *Placoneis exigua*).

Regarding the twelve species registered as new records for Brazil and São Paulo state, five of them presented wide distribution in relation to the trophic conditions, occurring from oligo- to eutrophic conditions (*Achnanthidium jackii*, *A. macrocephalum*, *Cymbella excisa* var. *procera*, *Fragilaria grunowii* and *Sellaphora rostrata*). Other four taxa occurred in oligo-mesotrophic conditions (*Encyonopsis thienemannii*, *Gomphonema naviculoides*, *Nitzschia perminuta* and *N. semirobusta*), while *Achnanthidium lineare* occurred in meso-eutrophic and *Placoneis exigua* was only recorded in eutrophic conditions. Two of the new records were exclusively found in the surface sediment (*Achnanthidium lineare* and *Nitzschia perminuta*) and other two only in the phytoplankton (*Achnanthidium macrocephalum* and *Encyonopsis thienenmannii*). Finally, this study increased the information on the ecology and distribution of these species, particularly in tropical reservoirs, and highlights the need of floristic surveys to improve the knowledge of biodiversity of freshwater tropical diatoms.

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Table 3. Frequency of occurrence (*f*), and minimum (min) and maximum (max) abundance of diatom in sampling sites according to the trophic state. - : taxon did not occur in sample; taxa in bold are the ones detailed in the present study; *: first record for Brazil; **: first record for São Paulo state.

Species	Oligotrophic			Mesotrophic			Eutrophic		
	f	*min*	*max*	*f*	*min*	*max*	*f*	*min*	*max*
Achnanthidium catenantum (Bily & Marvan) Lange-Bertalot	68.0	0.00	18.38	60.0	0.00	15.31	42.1	0.0	13.6
Achnanthidium exiguum (Grunow) Czarnecki	50.0	0.00	26.80	20.0	0.00	25.58	5.3	0.0	0.2
***Achnanthidium jackii* Rabenhorst**	76.0	0.00	6.57	37.1	0.00	6.84	34.2	0.0	24.7
***Achnanthidium lineare* Smith**	-	-	-	14.3	0.00	6.47	5.3	0.0	0.8
****Achnanthidium macrocephalum* (Hustedt) Round & Bukhtiyarova**	30.0	0.00	2.58	20.0	0.00	3.00	13.2	0.0	17.1
Achnanthidium minutissimum (Kützing) Czarnecki	72.0	0.00	17.33	71.4	0.00	22.93	31.6	0.0	3.4
***Achnanthidium* sp. 1**	2.0	0.00	0.97	17.1	0.00	6.28	5.3	0.0	0.9
***Achnanthidium* sp. 2**	-	-	-	11.4	0.00	44.04	10.5	0.0	2.9
Asterionella formosa Hassal	-	-	-	2.9	0.00	0.21	13.2	0.0	2.3
Aulacoseira ambigua (Grunow) Simonsen	96.0	0.00	20.90	97.1	0.00	44.05	86.8	0.0	63.6
Aulacoseira calypsi Tremarin *et al.*	2.0	0.00	0.44	14.3	0.00	4.05	5.3	0.0	1.1
Aulacoseira granulata var. *angustissima* (Müller) Simonsen	84.0	0.00	8.27	91.4	0.00	47.23	97.4	0.0	64.0
Aulacoseira granulata var. *granulata* (Ehrenberg) Simonsen	82.0	0.00	15.42	85.7	0.00	22.43	94.7	0.0	88.4
Aulacoseira herzogii (Lemmermann) Simonsen	4.0	0.00	0.94	14.3	0.00	1.22	18.4	0.0	2.5
Aulacoseira tenella (Nygaard) Simonsen	90.0	0.00	83.95	28.6	0.00	34.24	18.4	0.0	18.9
Aulacoseria veraluciae Tremarin *et al.*	-	-	-	-	-	-	2.6	0.0	2.1
Brachysira brebissonii Ross	-	-	-	-	-	-	2.6	0.0	3.1
Brachysira microcephala (Grunow) Compère	52.0	0.00	3.84	37.1	0.00	3.46	23.7	0.0	2.0
***Brashysira* sp.**	16.0	0.00	5.28	5.7	0.00	0.75	-	-	-
Cyclotella meneghiniana Kützing	26.0	0.00	1.23	57.1	0.00	3.62	89.5	0.0	68.5
****Cymbella excisa* var. *procera* Krammer**	2.0	0.00	0.40	22.9	0.00	6.91	10.5	0.0	0.9
Cymbopleura naviculiformis (Auerswald ex Heiberg) Krammer	2.0	0.00	0.40	22.9	0.00	3.08	5.3	0.0	1.1
Diadesmis confervacea Kützing	4.0	0.00	0.67	14.3	0.00	7.45	34.2	0.0	8.5
Discostella pseudostelligera (Hustedt) Houk & Klee	10.0	0.00	48.95	17.1	0.00	46.80	15.8	0.0	9.5
Discostella stelligera (Cleve & Grunow) Houk & Klee	100.0	0.60	65.92	97.1	0.00	91.99	73.7	0.0	33.4
Encyonema silesiacum (Bleisch) Mann	60.0	0.00	7.11	28.6	0.00	5.49	18.4	0.0	3.0
***Encyonema* sp.**	26.0	0.00	2.19	5.7	0.00	2.49	-	-	-
****Encyonopsis thienemannii* (Hustedt) Krammer**	4.0	0.00	3.63	5.7	0.00	0.98	-	-	-

Continues

Table 3 (*Continuation*)

Species	Oligotrophic			Mesotrophic			Eutrophic		
	f	*min*	*max*	*f*	*min*	*max*	*f*	*min*	*max*
Eunotia botulitropica Wetzel & Costa	48.0	0.00	5.74	28.6	0.00	17.65	15.8	0.0	2.6
Eunotia desmogonioides Metzeltin & Lange-Bertalot	-	-	-	2.9	0.00	4.41	-	-	-
Eunotia intricans Lange-Bertalot & Metzeltin	32.0	0.00	4.38	37.1	0.00	28.64	5.3	0.0	2.3
Eunotia longicamelus Costa *et al.*	14.0	0.00	18.78	17.1	0.00	3.67	-	-	-
Eunotia meridiana Metzeltin & Lange-Bertalot	12.0	0.00	2.29	5.7	0.00	2.00	-	-	-
Fragilaria aquaplus Lange-Bertalot & Ulrich	4.0	0.00	1.62	14.3	0.00	2.29	15.8	0.0	18.2
Fragilaria crotonensis Kitton	24.0	0.00	2.75	11.4	0.00	2.73	2.6	0.0	0.4
Fragilaria grunowii Lange-Bertalot & Ulrich	4.0	0.00	1.20	37.1	0.00	2.73	21.1	0.0	4.5
Fragilaria longifusiformis (Hains & Sebring) Siver *et al.*	16.0	0.00	9.00	31.4	0.00	12.27	13.2	0.0	14.1
Fragilaria parva (Grunow) Tuji & Williams	10.0	0.00	0.98	5.7	0.00	8.96	-	-	-
Fragilaria spectra Almeida *et al.*	4.0	0.00	19.45	22.9	0.00	38.18	10.5	0.0	46.4
Fragilaria tenera* var. *nanana (Lange-Bertalot) Lange-Bertalot & Ulrich	-	-	-	25.7	0.00	30.42	7.9	0.0	26.5
***Fragilaria* sp.**	22.0	0.00	7.52	20.0	0.00	18.36	-	-	-
Geissleria punctifera (Hustedt) Metzeltin *et al.*	12.0	0.00	2.99	2.9	0.00	0.21	-	-	-
Geissleria lateropunctata (Wallace) Potapova & Winter	42.0	0.00	7.65	20.0	0.00	1.49	-	-	-
Gomphonema hawaiense Reichardt	16.0	0.00	0.74	11.4	0.00	1.33	5.3	0.0	2.0
Gomphonema lagenula Kützing	40.0	0.00	1.50	34.3	0.00	11.03	21.1	0.0	3.2
***Gomphonema naviculoides* Smith**	10.0	0.00	2.94	14.3	0.00	2.49	-	-	-
Gomphonema parvulum (Kützing) Kützing	10.0	0.00	2.06	5.7	0.00	3.23	5.3	0.0	0.3
Hantzschia amphioxys (Ehrenberg) Grunow	4.0	0.00	1.96	5.7	0.00	3.46	-	-	-
Humidophila contenta (Grunow) Lowe	58.0	0.00	8.37	40.0	0.00	3.63	18.4	0.0	2.8
Navicula cryptocephala Kützing	6.0	0.00	1.72	34.3	0.00	14.38	10.5	0.0	18.1
Navicula cryptotenella Lange-Bertalot	4.0	0.00	1.36	20.0	0.00	5.65	10.5	0.0	1.7
Navicula kuseliana Lange-Bertalot & Rumrich	8.0	0.00	2.67	14.3	0.00	5.80	5.3	0.0	0.5
Navicula neomundana (Lange-Bertalot & Rumrich) Lange-Bertalot *et al.*	42.0	0.00	7.00	11.4	0.00	1.75	-	-	-
Navicula notha Wallace	94.0	0.00	19.73	54.3	0.00	18.20	31.6	0.0	7.1
Navicula rostellata Kützing	4.0	0.00	0.40	25.7	0.00	12.92	21.1	0.0	7.9
Navicula symmetrica Patrick	4.0	0.00	2.00	-	-	-	-	-	-
Nitzschia amphibia Grunow	-	-	-	2.9	0.00	0.25	18.4	0.0	2.7
Nitzschia gracilis Hantzch	4.0	0.00	2.59	20.0	0.00	2.07	5.3	0.0	0.4
Nitzschia palea (Kützing) Smith	38.0	0.00	3.19	37.1	0.00	2.99	42.1	0.0	83.1
Nitzschia palea var. *debilis* (Kützing) Grunow	28.0	0.00	2.25	8.6	0.00	1.50	-	-	-
***Nitzschia perminuta* (Grunow) Peragallo**	8.0	0.00	2.04	-	-	-	-	-	-
***Nitzschia semirobusta* Lange-Bertalot**	74.0	0.00	2.18	20.0	0.00	2.24	-	-	-

Continues

Table 3 (*Continuation*)

Species	Oligotrophic			Mesotrophic			Eutrophic		
	f	*min*	*max*	*f*	*min*	*max*	*f*	*min*	*max*
Nitzschia **sp. 1**	-	-	-	25.7	0.00	7.06	13.2	0.0	4.9
Nitzschia **sp. 2**	4.0	0.00	0.33	11.4	0.00	20.25	-	-	-
Nitzschia **sp. 3**	-	-	-	-	-	-	18.4	0.0	12.0
*Placoneis exigua **(Gregory) Mereschkovsky**	-	-	-	-	-	-	5.7	0.0	3.7
Planothidium rostratum (Østrup) Lange-Bertalot	6.0	0.00	0.44	42.9	0.00	11.46	5.3	0.0	1.9
Pseudostaurosira brevistriata (Grunow) Williams & Round	20.0	0.00	2.30	17.1	0.00	2.47	-	-	-
Pseudostaurosira **sp.**	2.0	0.00	2.43	37.1	0.00	2.42	21.1	0.0	3.8
Punctastriata lancettula (Schumann) Hamilton & Siver	8.0	0.00	73.97	25.7	0.00	81.84	5.3	0.0	0.9
Rimoneis **sp.**	6.0	0.00	2.63	20.0	0.00	6.94	5.3	0.0	2.1
Sellaphora nigri (De Notaris) Wetzel & Ector	4.0	0.00	2.46	-	-	-	-	-	-
*Sellaphora rostrata **(Hustedt) Johansen**	14.0	0.00	1.47	17.1	0.00	5.43	2.6	0.0	0.2
Sellaphora sassiana (Metzeltin & Lange-Bertalot) Wetzel	40.0	0.00	3.58	14.3	0.00	9.48	-	-	-
Spicaticribra kingstonii Johansen *et al.*	82.0	0.00	67.17	42.9	0.00	5.99	26.3	0.0	5.5
Staurosirella **sp.**	4.0	0.00	0.40	34.3	0.00	3.92	13.2	0.0	3.7
Ulnaria acus (Kützing) Aboal	8.0	0.00	0.65	17.1	0.00	2.67	18.4	0.0	3.9

Table 4. Minimum (min) and maximum (max) relative abundance of diatoms from surface sediment and phytoplankton in summer and winter. - : taxon did not occur in sample; taxa in bold are the ones detailed in the present study; *: first record for Brazil; **: first record for São Paulo state.

Species	Surface sediment		Summer phytoplankton		Winter phytoplankton	
	Min	Max	Min	Max	Min	Max
Achnanthidium catenantum (Bily & Marvan) Lange-Bertalot	0.00	18.38	0.00	8.73	0.00	13.57
Achnanthidium exiguum (Grunow) Czarnecki	-	-	0.00	26.80	0.00	25.58
***Achnanthidium jackii* Rabenhorst**	0.00	5.66	0.00	24.69	0.00	10.04
***Achnanthidium lineare* Smith**	0.00	6.47	-	-	-	-
****Achnanthidium macrocephalum* (Hustedt) Round & Bukhtiyarova**	-	-	0.00	2.58	0.00	17.10
Achnanthidium minutissimum (Kützing) Czarnecki	0.00	13.24	0.00	19.85	0.00	22.93
***Achnanthidium* sp.1**	0.00	6.28	-	-	0.00	0.86
***Achnanthidium* sp.2**	-	-	0.00	2.95	0.00	44.04
Asterionella formosa Hassal	0.00	2.01	-	-	0.00	2.33
Aulacoseira ambigua (Grunow) Simonsen	0.21	63.56	0.00	26.93	0.00	44.42
Aulacoseira calypsi Tremarin *et al.*	0.00	4.05	0.00	0.68	0.00	0.48
Aulacoseira granulata var. *angustissima* (Müller) Simonsen	0.21	63.74	0.00	33.92	0.00	63.99
Aulacoseira granulata var. *granulata* (Ehrenberg) Simonsen	0.00	51.64	0.00	19.90	0.00	88.36
Aulacoseira herzogii (Lemmermann) Simonsen	0.00	2.47	0.00	0.94	0.00	1.22
Aulacoseira tenella (Nygaard) Simonsen	0.00	54.72	0.00	38.40	0.00	83.95
Aulacoseria veraluciae Tremarin *et al.*	-	-	0.00	2.07	-	-
Brachysira brebissonii Ross	-	-	-	-	0.00	3.11
Brachysira microcephala (Grunow) Compère	0.00	3.46	0.00	3.84	0.00	2.67
***Brashysira* sp.**	0.00	5.28	-	-	-	-
Cyclotella meneghiniana Kützing	0.00	40.74	0.00	36.10	0.00	68.47
****Cymbella excisa* var. *procera* Krammer**	0.00	6.91	0.00	0.45	0.00	0.50
Cymbopleura naviculiformis (Auerswald ex Heiberg) Krammer	0.00	3.08	0.00	0.95	0.00	1.39
Diadesmis confervacea Kützing	0.00	7.45	0.00	3.23	0.00	8.46
Discostella pseudostelligera (Hustedt) Houk & Klee	-	-	0.00	48.95	0.00	6.51
Discostella stelligera (Cleve & Grunow) Houk & Klee	0.00	49.88	0.00	91.99	0.00	73.15
Encyonema silesiacum (Bleisch) Mann	0.00	7.11	0.00	2.29	0.00	3.67
***Encyonema* sp.**	0.00	2.19	0.00	2.49	0.00	1.11
****Encyonopsis thienemannii* (Hustedt) Krammer**	-	-	0.00	0.45	0.00	3.63
Eunotia botulitropica Wetzel & Costa	0.00	2.55	0.00	17.65	0.00	5.74
Eunotia desmogonioides Metzeltin & Lange-Bertalot	-	-	0.00	4.41	-	-
Eunotia intricans Lange-Bertalot & Metzeltin	0.00	28.64	0.00	1.50	0.00	3.33
Eunotia longicamelus Costa *et al.*	0.00	2.49	0.00	18.78	0.00	3.67

Continues

Table 4 (*Continuation*)

Species	Surface sediment		Summer phytoplankton		Winter phytoplankton	
	Min	Max	Min	Max	Min	Max
Eunotia meridiana Metzeltin & Lange-Bertalot	-	-	0.00	2.29	0.00	0.50
Fragilaria aquaplus Lange-Bertalot & Ulrich	0.00	18.23	0.00	5.80	0.00	11.63
Fragilaria crotonensis Kitton	-	-	0.00	2.75	0.00	0.37
Fragilaria grunowii Lange-Bertalot & Ulrich	0.00	2.70	0.00	2.73	0.00	4.46
Fragilaria longifusiformis (Hains & Sebring) Siver *et al.*	0.00	7.80	0.00	14.08	0.00	1.86
Fragilaria parva (Grunow) Tuji & Williams	0.00	8.96	-	-	-	-
Fragilaria spectra Almeida *et al.*	-	-	0.00	46.38	0.00	0.96
****Fragilaria tenera*** var. **nanana** (Lange-Bertalot) Lange-Bertalot & Ulrich	0.00	3.93	0.00	3.62	0.00	30.42
***Fragilaria* sp.**	0.00	4.98	0.00	18.36	0.00	17.33
Geissleria punctifera (Hustedt) Metzeltin *et al.*	-	-	0.00	1.17	0.00	2.99
Geissleria lateropunctata (Wallace) Potapova & Winter	0.00	3.27	0.00	1.88	0.00	7.65
Gomphonema hawaiense Reichardt	-	-	0.00	1.33	0.00	2.00
Gomphonema lagenula Kützing	0.00	1.96	0.00	11.03	0.00	1.48
****Gomphonema naviculoides*** Smith**	0.00	2.94	0.00	2.33	0.00	0.67
Gomphonema parvulum (Kützing) Kützing	0.00	3.23	-	-	-	-
Hantzschia amphioxys (Ehrenberg) Grunow	0.00	3.46	-	-	-	-
Humidophila contenta (Grunow) Lowe	0.00	2.78	0.00	8.37	0.00	3.32
Navicula cryptocephala Kützing	0.00	4.94	0.00	1.47	0.00	18.10
Navicula cryptotenella Lange-Bertalot	0.00	5.65	-	-	0.00	4.85
Navicula kuseliana Lange-Bertalot & Rumrich	0.00	5.80	0.00	1.20	0.00	2.67
Navicula neomundana (Lange-Bertalot & Rumrich) Lange-Bertalot *et al.*	0.00	7.00	0.00	1.79	0.00	2.99
Navicula notha Wallace	0.00	13.13	0.00	19.73	0.00	7.80
Navicula rostellata Kützing	0.00	2.55	0.00	3.30	0.00	12.92
Navicula symmetrica Patrick	0.00	2.00	-	-	-	-
Nitzschia amphibia Grunow	-	-	0.00	2.24	0.00	2.74
Nitzschia gracilis Hantzch	-	-	0.00	2.59	-	-
Nitzschia palea (Kützing) Smith	0.00	3.19	0.00	83.06	0.00	5.50
Nitzschia palea var. *debilis* (Kützing) Grunow	-	-	0.00	2.25	0.00	0.33
****Nitzschia perminuta*** (Grunow) Peragallo**	0.00	2.04	-	-	-	-
***Nitzschia semirobusta* Lange-Bertalot**	0.00	2.18	0.00	2.24	0.00	1.00
***Nitzschia* sp.1**	0.00	7.06	0.00	1.23	0.00	1.11
***Nitzschia* sp.2**	0.00	20.25	-	-	0.00	3.32
***Nitzschia* sp.3**	-	-	0.00	4.04	0.00	12.00
***Placoneis exigua* (Gregory) Mereschkovsky**	0.00	3.73	0.00	0.49	-	-
Planothidium rostratum (Østrup) Lange-Bertalot	0.00	11.46	0.00	1.77	0.00	2.29
Pseudostaurosira brevistriata (Grunow) Williams & Round	0.00	2.47	0.00	0.72	0.00	0.97
***Pseudostaurosira* sp.**	0.00	2.97	0.00	3.77	0.00	1.46

Table 4 (*Continuation*)

Species	Surface sediment		Summer phytoplankton		Winter phytoplankton	
	Min	Max	Min	Max	Min	Max
Punctastriata lancettula (Schumann) Hamilton & Siver	0.00	81.84	0.00	23.49	0.00	15.87
***Rimoneis* sp.**	0.00	6.94	0.00	0.45	0.00	1.39
Sellaphora nigri (De Notaris) Wetzel & Ector	0.00	2.46	-	-	-	-
***Sellaphora rostrata* (Hustedt) Johansen**	0.00	5.43	0.00	0.25	0.00	2.66
Sellaphora sassiana (Metzeltin & Lange-Bertalot) Wetzel	0.00	3.58	0.00	9.48	0.00	0.33
Spicaticribra kingstonii Johansen *et al.*	0.00	67.17	0.00	12.56	0.00	3.23
***Staurosirella* sp.**	0.00	3.92	0.00	2.36	0.00	1.49
Ulnaria acus (Kützing) Aboal	-	-	0.00	2.67	0.00	3.89

Legends and plates
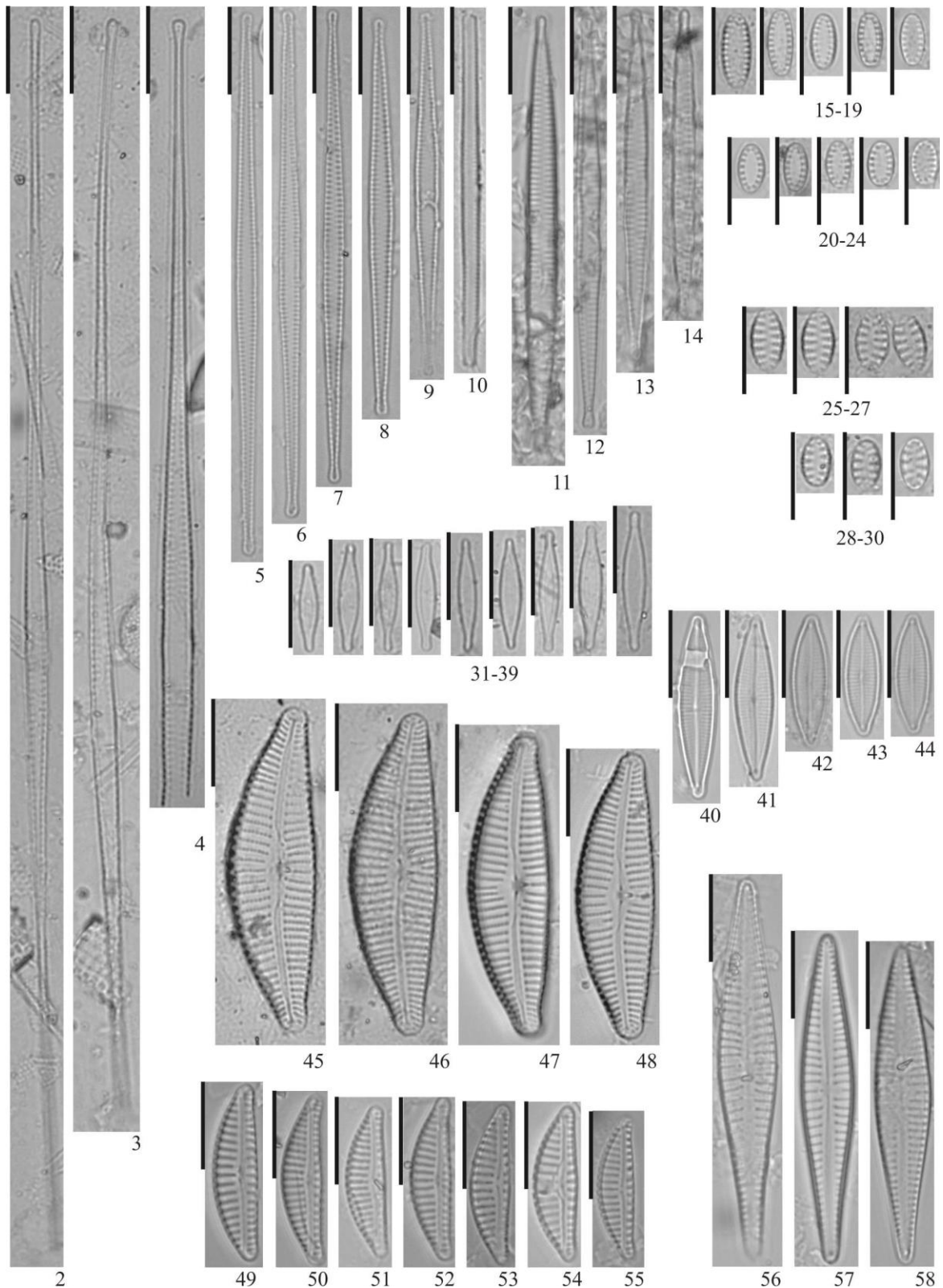
Figures 2-58. Surface sediment and planktonic diatoms. 2-4. *Fragilaria grunowii* Lange-Bertalot & Ulrich. 5-10. *Fragilaria tenera* var. *nanana* (Lange-Bertalot) Lange-Bertalot & Ulrich (Fig. 10. Lateral view). 11-14. *Fragilaria* sp. 15-24. *Pseudostaurosira* sp. 25-30. *Staurosirella* sp. 31-39. *Rimoneis* sp. 40-44. *Encyonopsis thienemannii* (Hustedt) Krammer. 45-48. *Cymbella excisa* Kützing var. *procera* Krammer. 49-55. *Encyonema* sp. 56-58. *Gomphonema naviculoides* Smith. Scale bar = 10 μm.
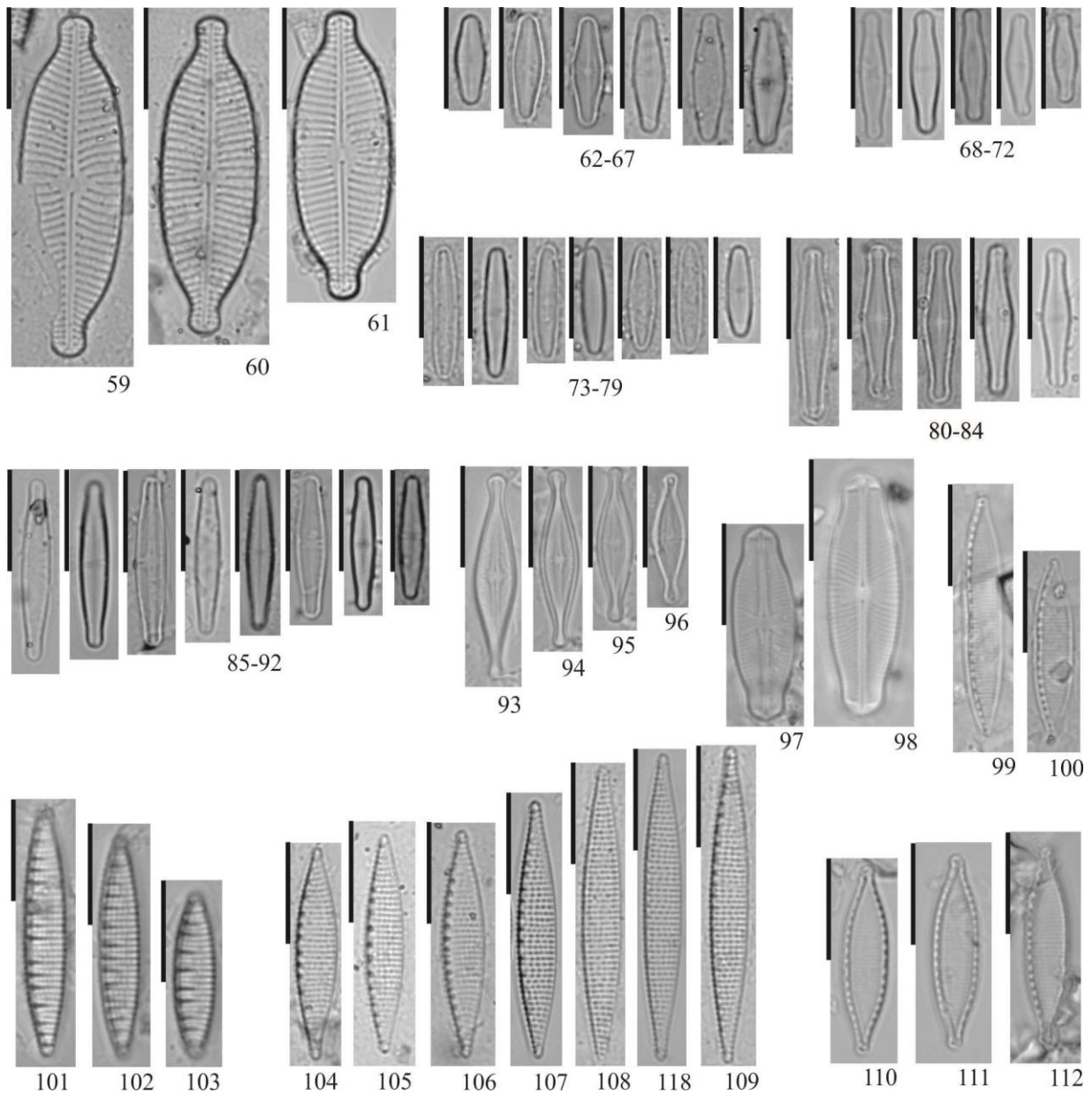
Figures 59-112. Surface sediment and planktonic diatoms. 59-61. *Placoneis exigua* (Gregory) Mereschkovsky. 62-67. *Achnanthidium jackii* Rabenhorst. 68-72. *Achnanthidium macrocephalum* (Hustedt) Round & Bukhtiyarova. 73-79. *Achnanthidium lineare* Smith. 80-84. *Achnanthidium* sp. 2. 85-92. *Achnanthidium* sp. 1. 93-96. *Brachysira* sp. 97-98. *Sellaphora rostrata* (Hustedt) Johansen. 99-100. *Nitzschia perminuta* (Grunow) Peragallo. 101-103. *Nitzschia semirobusta* Lange-Bertalot. 104-109. *Nitzschia* sp. 1. 110-112. *Nitzschia* sp. 2. Scale bar = 10 μm.
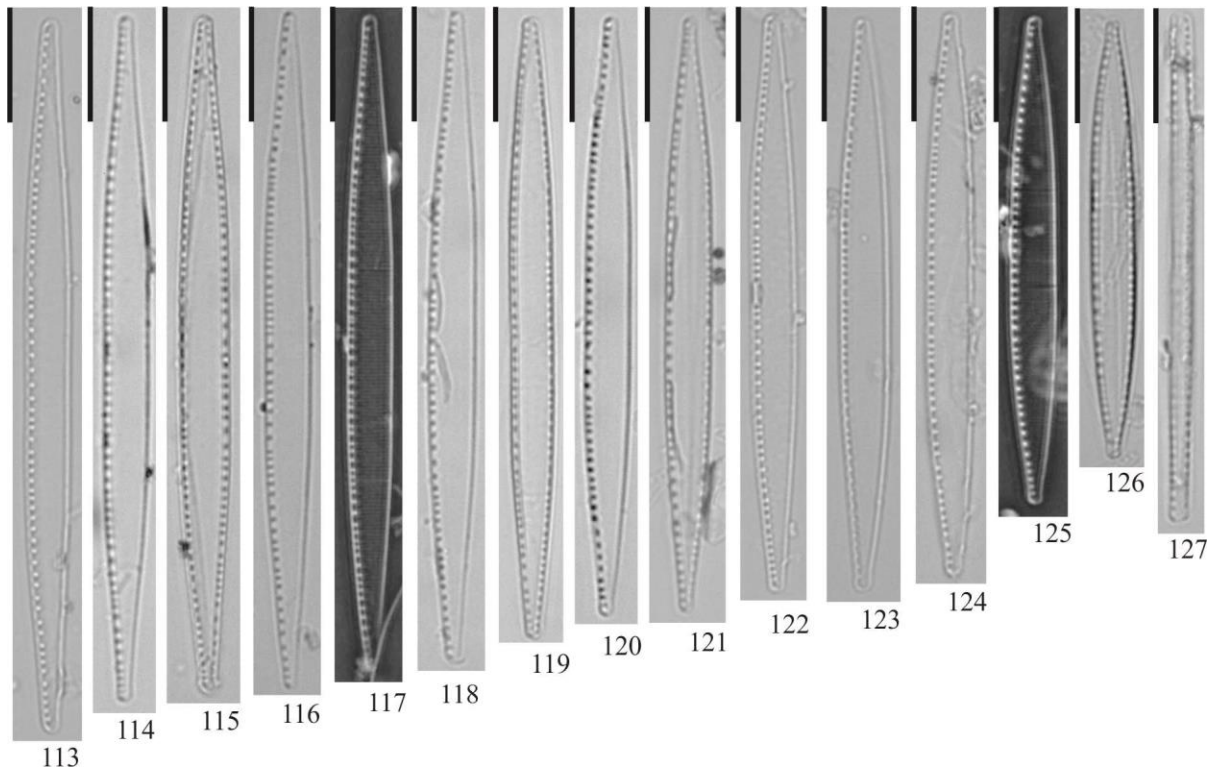
Figures 113-127. Surface sediment and planktonic diatoms. 113-127. *Nitzschia* sp. 3 (Fig. 127. Lateral view). Scale bar = 10 μm.

CONSIDERAÇÕES FINAIS

A presente tese foi organizada em três capítulos e, de modo geral, aborda a dinâmica de diatomáceas de sedimentos superficiais e planctônicas em represas tropicais, com ênfase nos efeitos da eutrofização antropogênica sobre a sua estrutura e biodiversidade.

O **Capítulo 1** avalia e compara os efeitos da eutrofização sobre a diversidade beta de diatomáceas do sedimento superficial e planctônicas em cinco represas localizadas na mesma bacia hidrográfica (bacia do Médio Tietê/Alto Sorocaba). Os resultados demonstram que a diversidade beta foi determinada principalmente pelo gradiente de eutrofização, de forma que foi maior na represa oligotrófica (Santa Helena) e, em geral, menor na hipereutrófica (Barra Bonita). O componente *substituição de espécies* (species replacement ou turnover) apresentou maior contribuição para a diversidade beta do que o componente *diferença de riqueza* (richness difference ou aninhamento). A contribuição dos locais para a diversidade beta do componente *substituição de espécies* ($Repl_{LCBD}$) apresentou relação negativa com o gradiente de eutrofização, sugerindo que o enriquecimento levou a uma redução da diversidade beta nas represas com maior concentração de nutrientes (Hedberg e Barra Bonita). Em geral, os maiores valores de $Repl_{LCBD}$ foram encontrados nos ambientes oligo- e mesotróficos (Santa Helena, Itupararanga e Ipaneminha), indicando que os ambientes não eutrofizados apresentam maior contribuição para a diversidade beta. De acordo com os valores da Contribuição das Espécies para a Diversidade Beta ($SCBD_{Total}$), as principais espécies que contribuíram para a diversidade beta, ou seja, que apresentaram maiores valores de $SCBD_{Total}$ foram diatomáceas planctônicas amplamente distribuídas nas amostras, entretanto com elevada variação na sua abundância e principalmente associadas a condições meso- a eutróficas como *Discostella stelligera* e espécies com maior abundância em condições eutróficas como *Aulacoseira ambigua*, *A. granulata* var. *granulata*, *A. granulata* var. *angustissima*, *Cyclotella meneghiniana*. Entretanto, a espécie *Punctastriata lancettula* também exibiu altos valores de $SCBD_{Total}$ possivelmente em resposta a sua elevada abundância em condições oligotróficas (Santa Helena). Finalmente, as diatomáceas do sedimento superficial apresentaram resposta mais sensível às variações na diversidade beta, confirmando o grande potencial desta comunidade em estudos sobre biodiversidade de ambientes aquáticos devido ao caráter acumulador deste compartimento ao longo do tempo e do espaço. Além disso, nossos resultados demonstram os efeitos negativos que a eutrofização cultural causa na biodiversidade aquática, levando a redução da diversidade beta nos ambientes mais enriquecidos.

O **Capítulo 2** aborda os preditores ambientais e espaciais como estruturadores das comunidades de diatomáceas de sedimentos superficiais e planctônicas no contexto de

metacomunidades em 31 represas de cinco bacias hidrográficas. Este estudo demonstra que ambas as comunidades foram estruturadas pela combinação de fatores ambientais e espaciais. Com relação às variáveis ambientais, tanto as comunidades dos sedimentos superficiais quanto as planctônicas foram estruturadas principalmente por variáveis relacionadas à produtividade dos ecossistemas como fósforo total, clorofila-*a* e transparência da água. Além disso, estas comunidades compartilharam algumas espécies de diatomáceas, principalmente planctônicas como *Aulacoseira granulata* var. *granulata*, *A. tenella*, *Discostella stelligera* e *Spicaticribra kingstonii*. Neste capítulo, também destacamos que as diatomáceas do sedimento superficial exibiram respostas mais sensíveis aos preditores ambientais e espaciais do que as planctônicas. Além disso, os resultados também demonstram a importância de se considerar a distribuição espacial das diatomáceas (além dos fatores ambientais), principalmente em estudos em grandes escalas espaciais, uma vez que as diatomáceas são amplamente utilizadas para compreender as alterações ambientais dos ecossistemas.

O **Capítulo 3** trata do levantamento florístico das diatomáceas de sedimentos superficiais e planctônicas de 10 represas de três bacias hidrográficas, com ênfase nas espécies com primeiro registro para o Brasil e para o Estado de São Paulo. Adicionalmente são fornecidas informações sobre a distribuição das espécies em relação ao estado trófico dos ambientes. Este estudo resultou no registro de 78 táxons, sendo sete deles novas citações para o Brasil, cinco para o Estado de São Paulo e outros 11 foram identificados apenas em nível de gênero, possivelmente representando novas espécies para a Ciência. Este trabalho apresenta novas citações de espécies para o Brasil e Estado de São Paulo, além de prováveis espécies novas e amplia as informações ecológicas sobre a distribuição das espécies. Demonstra, assim, a necessidade de trabalhos florísticos e taxonômicos principalmente em regiões tropicais que apresentam flora distinta e biodiversidade ainda pouco conhecida quando comparada àquelas de regiões temperadas. Tais estudos além de fornecerem informações sobre a biodiversidade fornecem a base para estudos ecológicos.

Em resumo, a distribuição das diatomáceas tanto do sedimento superficial quanto do plâncton foi determinada principalmente pelo gradiente trófico das represas, de forma que a diversidade beta apresentou redução em condições severas de enriquecimento, levando ao empobrecimento das comunidades de diatomáceas. Os resultados também demonstram que as diatomáceas do sedimento superficial foram mais sensíveis para caracterizar as alterações ambientais das represas, independentemente de se abordar uma escala espacial menor (Capítulo 1) ou maior (Capítulo 2). Destacamos, assim, tais comunidades, devido ao seu caráter integrador

no tempo e espaço, fornecem respostas mais refinadas e consistentes sobre as alterações ambientais nesses ecossistemas quando comparadas com as planctônicas. Neste sentido, as comunidades de sedimentos superficiais podem se tornar fortes aliadas em estudos de qualidade da água e dinâmica de comunidades. Ressaltamos, ainda, a importância de estudos florísticos, principalmente incluindo as diatomáceas acumuladas no sedimento, não apenas por serem escassos, mas principalmente por adicionarem novos registros e novas espécies para a flora tropical. Finalmente, nossos resultados trazem avanço sobre o uso da abordagem da contribuição dos locais (LCBD) e das espécies (SCBD) para a diversidade beta de diatomáceas e que pode potencialmente ser aplicada para identificar ambientes prioritários para conservação e recuperação. Como um todo, este estudo reforça que os fatores locais e regionais que controlam a dinâmica de suas comunidades devem ser considerados em futuros estudos, pois permitem a melhor compreensão dos processos que modelam a biodiversidade aquática, contribuindo para sua conservação e para os usos múltiplos das águas em represas.

APÊNDICE 1

Resultados das variáveis físicas e químicas da água registradas nas cinco represas localizadas na bacia do Médio Tietê/Alto Sorocaba no verão e inverno e nas diferentes profundidades (superfície, profundidade média e 1 m acima do sedimento).

Tabela 3. Variáveis físicas e químicas registradas nas represas Santa Helena (SH), Itupararanga (IT), Ipaneminha (IP), Hedberg (HB) e Barra Bonita (BB) no verão (v) e inverno (i) de 2014. Zmax: profundidade máxima; Sec: profundidade de desaparecimento do disco de Secchi (m); Temp: temperatura da água (ºC); Turb: turbidez (NTU); Cond: condutividade (μS cm^{-1}); Pot. Red: potencial redox; Alc: alcalinidade (meq L^{-1}); CO_2: gás carbônico (mg L^{-1}); HCO_3: íons bicarbonato (mg L^{-1}); OD: oxigênio dissolvido (mg L^{-1}); $N\text{-}NH_4^+$: amônio (μg L^{-1}); $N\text{-}NO_2^-$: nitrito (μg L^{-1}); $N\text{-}NO_3^-$: nitrato (μg L^{-1}); NT: nitrogênio total (μg L^{-1}); $P\text{-}PO_4$: ortofosfato (μg L^{-1}); P-PDT: fósforo total dissolvido (μg L^{-1}); PT: fósforo total (μg L^{-1}); SSR: sílica solúvel reativa (mg L^{-1}); Clo-*a*: clorofila-*a* (μg L^{-1}); S: superfície; M: profundidade média; F: um metro acima do fundo.

Locais	Turb	pH	Cond	Alc	CO_2	HCO_3	OD	$N\text{-}NH_4^+$	$N\text{-}NO_2^-$	$N\text{-}NO_3^-$	NT	$P\text{-}PO_4$	P-PDT	PT	SSR	Clo-*a*
SH1 Sv	5,13	7,14	94	0,5550	3,95	33,80	6,16	186,66	8,28	30,86	545,24	4,00	4,07	9,95	2,84	8,79
SH1 Fv	4,64	7,04	95	0,5705	5,12	34,76	6,01	183,14	7,86	25,58	493,40	4,00	4,22	8,26	2,84	0
SH2 Sv	8,95	7,04	105	0,6330	5,68	38,57	6,77	117,12	10,40	38,02	435,09	4,00	4,22	12,81	2,74	1,32
SH2 Mv	5,72	6,93	96	0,5885	6,80	35,86	6,01	180,50	7,29	24,36	456,10	4,00	4,22	9,78	2,81	4,83
SH2 Fv	9,90	6,78	98	0,5905	9,65	36,00	4,22	212,18	8,14	27,08	555,71	4,00	4,52	11,97	2,70	3,52
SH3 Sv	8,17	7,19	102	0,6075	3,86	36,99	7,11	158,05	9,69	31,59	483,02	4,00	4,37	11,46	2,72	10,11
SH3 Mv	10,10	7,03	111	0,6225	5,72	37,93	6,44	168,61	7,86	36,28	484,48	4,00	4,97	12,64	2,72	2,64
SH3 Fv	9,25	6,91	105	0,6610	8,00	40,29	5,18	217,02	8,99	33,01	550,40	4,00	5,27	13,65	2,78	2,20
SH1 Si	2,22	7,31	97	0,559	3,16	34,01	7,13	199,35	10,26	175,71	695,70	4,00	7,93	19,31	1,00	3,08
SH1 Fi	0,00	7,18	98	0,555	4,23	33,78	7,39	198,95	9,73	175,49	624,06	4,00	6,88	20,43	1,00	5,27
SH2 Si	1,79	6,63	101	0,575	15,58	35,03	5,50	195,33	9,79	164,25	592,43	4,00	7,48	16,73	1,00	0,88
SH2 Mi	0,93	7,15	101	0,572	4,68	34,82	6,63	192,92	9,12	167,90	661,80	4,00	5,08	15,12	1,00	4,83
SH2 Fi	2,55	7,11	106	0,600	5,38	36,53	6,57	202,97	7,52	181,43	672,55	4,00	6,43	23,01	1,00	2,64
SH3 Si	1,44	7,45	101	0,600	2,24	36,50	8,19	185,28	8,35	171,66	515,50	4,00	6,73	13,35	1,00	2,64
SH3 Mi	0,75	7,37	102	0,582	2,87	35,40	5,72	184,47	8,24	174,75	647,75	4,00	5,53	19,15	1,00	3,95
SH3 Fi	2,22	7,24	102	0,579	3,85	35,24	6,68	188,50	8,63	199,71	634,26	4,00	6,88	16,57	1,00	1,76
IT1 Sv	21,9	8,58	106	0,4970	0,12	29,05	8,56	10,00	5,00	8,00	614,94	4,00	12,98	53,41	3,47	36,25
IT1 Mv	33,4	7,30	95	0,4765	2,35	29,00	6,53	10,00	5,00	8,00	603,74	8,60	20,17	56,27	2,96	31,64
IT1 Fv	37,9	6,18	91	0,4435	42,69	27,05	4,29	27,34	5,00	9,09	523,50	13,37	26,30	49,20	2,18	14,94
IT2 Sv	14,5	7,00	93	0,5365	5,28	32,69	5,54	63,43	5,00	8,00	599,79	4,00	4,00	18,87	3,04	20,32
IT2 Mv	13,9	6,79	93	0,5545	8,85	33,80	4,83	77,07	5,00	8,00	606,41	4,00	4,00	16,85	2,75	14,44
IT2 Fv	17,7	6,43	143	0,6975	25,52	42,54	1,05	4130,96	5,00	10,05	5421,86	4,00	4,25	19,04	1,78	6,90
IT3 Sv	12,6	7,15	91	0,5675	3,95	34,56	5,35	59,47	5,00	8,00	705,50	4,00	4,00	14,33	2,71	7,14
IT3 Mv	8,9	6,63	92	0,5420	18,51	33,05	3,66	88,08	5,00	8,00	667,37	4,00	4,00	13,31	2,19	21,97
IT3 Fv	11,2	6,27	116	0,6970	54,53	42,51	0,87	3957,54	5,50	8,00	5436,41	4,00	4,00	14,16	1,19	1,76
IT4 Sv	11,2	7,26	90	0,5375	2,90	32,72	6,01	22,06	5,00	8,00	493,63	4,00	4,00	10,28	2,88	11,53
IT4 Mv	12,3	7,19	90	0,5280	3,35	32,15	5,66	16,78	5,00	8,00	433,32	4,00	4,00	12,30	2,40	10,04
IT4 Fv	10,3	6,97	90	0,5195	5,48	31,66	4,99	42,74	5,00	8,00	414,01	4,00	4,00	10,62	2,79	8,79

Tabela 3. Continuação.

Locais	Turb	pH	Cond	Alc	CO_2	HCO_3	OD	$N-NH_4^+$	$N-NO_2^-$	$N-NO_3^-$	NT	$P-PO_4$	P-PDT	PT	SSR	Clo-*a*
IT5 Sv	13,4	7,03	90	0,5230	4,80	31,86	5,86	18,98	5,00	8,00	411,32	4,00	4,00	11,97	2,76	2,20
IT5 Mv	11,10	7,30	90	0,5355	2,64	32,59	5,50	24,70	5,00	8,00	394,41	4,00	4,00	9,78	2,78	11,30
IT5 Fv	10,10	8,58	106	0,4970	0,12	29,05	2,23	10,00	5,00	8,00	614,94	4,00	12,98	53,41	3,47	36,25
IT1 Si	13,70	6,70	114	0,4415	9,29	26,91	7,56	11,13	6,60	175,04	1118,56	4,00	7,93	37,99	4,00	29,88
IT1 Mi	14,60	7,13	116	0,4545	3,89	27,69	7,93	15,96	7,10	186,50	1036,84	4,74	9,57	46,52	4,32	26,80
IT1 Fi	30,20	6,63	117	0,4535	12,29	27,65	6,63	46,12	7,68	203,17	1053,54	5,48	12,42	54,42	4,08	15,82
IT2 Si	10,90	6,69	105	0,4710	11,12	28,71	6,87	85,13	5,00	30,07	1072,80	4,00	6,43	40,40	2,49	49,65
IT2 Mi	2,61	7,02	104	0,4695	5,18	28,61	5,61	108,06	5,00	32,30	1026,60	4,00	7,33	32,84	2,51	33,83
IT2 Fi	1,39	6,38	106	0,4775	23,03	29,12	1,57	258,88	5,00	16,72	1101,12	4,00	6,73	24,30	2,47	6,59
IT3 Si	1,65	6,86	102	0,5085	8,11	30,99	6,57	147,07	5,00	44,81	947,12	4,00	7,18	28,81	2,32	14,06
IT3 Mi	0,00	6,78	102	0,5025	9,64	30,63	4,72	196,94	5,00	40,08	974,55	4,00	6,88	28,16	2,34	13,18
IT3 Fi	0,00	6,26	106	0,5110	32,49	31,16	1,46	295,48	5,00	29,24	1121,56	4,00	7,33	25,27	2,49	2,64
IT4 Si	4,28	7,33	97	0,4850	2,38	29,52	7,79	132,19	5,00	26,73	811,95	4,00	8,67	23,49	2,40	3,95
IT4 Mi	0,94	7,56	98	0,4920	1,42	29,90	7,59	148,68	5,00	21,45	814,98	4,00	7,78	23,17	2,38	4,83
IT4 Fi	1,83	7,31	97	0,5020	2,59	30,56	7,34	184,07	5,00	24,79	860,24	4,00	8,67	23,17	2,47	5,27
IT5 Si	0,33	6,92	95	0,5000	6,33	30,47	7,68	135,41	5,00	21,17	878,90	4,00	8,08	22,04	2,45	6,59
IT5 Mi	0,00	7,02	97	0,5115	5,64	31,17	6,63	211,42	5,00	25,06	919,91	4,00	6,58	19,47	2,51	2,64
IT5 Fi	1,65	6,30	99	0,5420	31,43	33,05	4,04	282,20	5,00	44,26	1082,26	4,00	7,63	23,33	2,62	0,88
IP1 Sv	40,70	6,62	163	1,1525	27,22	70,27	4,46	51,11	26,17	65,49	456,61	4,00	12,21	32,35	3,29	18,20
IP1 Fv	37,90	6,72	160	1,1700	21,95	71,33	3,80	60,79	24,33	50,98	500,25	4,00	14,81	25,27	3,53	2,20
IP2 Sv	50,30	6,80	161	1,2405	19,35	75,62	3,72	86,75	31,01	79,24	599,40	4,00	13,59	34,20	3,44	6,90
IP2 Fv	62,10	6,69	157	1,1360	22,84	69,26	2,43	130,76	21,35	43,06	594,39	6,36	16,34	39,09	2,60	2,64
IP3 Sv	42,50	6,84	158	1,1555	16,44	70,44	3,73	71,79	27,23	71,16	522,11	4,00	14,20	33,19	3,40	7,53
IP3 Fv	81,70	6,58	159	1,1170	28,93	68,11	2,62	114,48	23,93	61,63	587,56	6,36	16,19	37,07	2,62	2,64
IP1 Si	7,95	7,41	174	1,2580	5,15	76,56	9,10	324,43	33,78	33,78	1349,69	5,48	9,87	31,06	1,60	9,67
IP2 Si	8,54	7,64	166	1,2330	2,97	74,92	11,73	333,68	32,95	32,95	1288,08	6,21	11,52	35,25	1,00	13,18
IP2 Fi	9,43	7,41	179	1,2465	5,11	75,86	9,31	315,59	34,50	34,50	1274,01	6,07	10,77	32,03	1,56	12,30
IP3 Si	9,19	7,42	155	1,2010	4,81	73,09	10,26	291,05	31,92	31,92	1295,38	6,21	12,72	38,96	1,00	20,21
IP3 Fi	8,95	7,26	162	1,1845	6,86	72,14	7,71	308,35	30,26	30,26	1369,85	5,62	10,47	33,96	1,89	0,50

Tabela 3. Continuação.

Locais	Turb	pH	Cond	Alc	CO_2	HCO_3	OD	$N-NH_4^+$	$N-NO_2^-$	$N-NO_3^-$	NT	$P-PO_4$	P-PDT	PT	SSR	Clo-*a*
HB1 Sv	63,60	6,56	117	0,7800	21,15	47,56	4,16	87,19	29,44	300,64	773,89	34,23	45,28	79,35	6,02	5,02
HB1 Fv	64,00	6,58	117	0,8000	22,20	48,78	4,14	74,87	30,62	306,96	737,02	39,30	52,47	74,80	6,61	5,27
HB2 Sv	76,30	6,73	112	0,7680	14,08	46,82	6,32	22,06	27,74	186,82	610,55	26,03	41,76	90,30	5,97	41,30
HB2 Mv	92,90	6,45	110	0,7775	29,11	47,42	3,19	99,52	28,80	194,32	692,73	35,57	50,48	85,58	6,84	4,39
HB2 Fv	107,00	6,31	108	0,7510	33,03	45,80	1,82	137,81	27,49	239,13	714,02	41,09	59,51	59,98	6,05	4,39
HB3 Sv	97,30	7,06	110	0,7710	6,61	46,97	8,23	18,10	26,01	167,88	1293,28	23,50	40,23	183,45	6,61	62,05
HB3Mv	138,00	6,30	101	0,7100	37,55	43,30	3,25	55,95	27,88	177,77	600,99	37,06	54,92	71,94	6,67	14,06
HB3 Fv	135,00	6,22	102	0,7055	44,86	43,03	1,35	141,77	27,74	156,16	726,48	41,98	59,82	71,26	6,16	0,00
HB1 Si	14,40	8,56	156	0,8690	0,24	51,31	8,02	78,70	43,13	902,81	1797,64	26,07	40,01	85,66	1,95	3,95
HB1 Fi	18,70	8,86	156	0,8710	0,12	49,82	8,32	77,09	40,49	936,75	1435,07	30,18	44,51	85,02	3,19	4,39
HB2 Si	8,65	9,17	154	0,9295	0,06	49,93	8,77	82,32	74,70	729,60	1488,10	11,21	24,27	67,94	2,18	10,55
HB2 Mi	9,28	8,91	155	0,9390	0,11	53,33	6,48	102,03	96,04	673,98	1518,83	13,27	23,82	73,90	2,22	27,68
HB2 Fi	15,40	7,77	163	0,9630	1,72	58,43	3,29	208,60	107,39	655,16	1550,66	16,95	28,62	71,49	1,97	13,18
HB3 Si	14,10	9,38	157	0,9170	0,03	45,79	10,07	54,17	87,03	700,87	1828,82	9,60	21,12	95,32	3,43	153,78
HB3 Mi	11,60	8,48	156	0,9650	0,33	57,30	6,89	122,94	120,41	588,47	1684,35	11,36	22,32	84,21	2,66	54,37
HB3 Fi	13,90	7,20	160	0,9810	7,15	59,77	2,93	305,13	149,50	441,60	1462,13	6,95	16,32	49,26	2,19	15,38
BB1 Sv	106,00	8,84	337	1,3625	0,17	77,02	4,76	1978,53	584,60	2404,89	9859,15	56,29	92,73	537,72	2,57	83,48
BB1 Mv	1,14	7,03	421	1,7360	15,94	105,78	1,04	5418,19	243,77	1053,52	13735,95	227,82	258,83	297,50	3,08	13,73
BB1 Fv	0,10	6,98	391	1,5380	15,85	93,73	0,55	2983,06	240,98	1250,99	8361,10	206,81	277,20	308,62	3,88	5,49
BB2 Sv	31,50	9,49	287	1,1170	0,02	49,62	7,37	68,27	74,30	506,95	2014,82	5,62	18,95	85,25	5,27	114,24
BB2 Mv	0,98	7,16	410	1,5580	10,60	94,90	3,77	3376,12	221,99	1334,87	9639,36	171,19	200,20	222,71	3,26	10,98
BB2 Fv	0,00	7,02	354	1,4025	13,18	85,46	1,16	2267,89	249,07	1440,07	7378,19	154,80	194,08	212,60	3,78	2,75
BB3 Sv	33,90	9,15	306	1,1270	0,06	58,93	7,85	261,47	230,37	1069,70	3229,83	11,88	27,52	129,72	4,36	74,69
BB3 Mv	2,61	7,02	390	1,4150	13,30	86,22	2,58	2350,69	261,64	1634,66	7400,88	167,76	194,23	220,01	3,33	7,55
BB3 Fv	1,76	6,94	329	1,1800	13,33	71,92	1,30	505,29	247,68	2192,72	3380,75	131,10	151,06	167,79	3,78	1,37
BB4 Sv	50,60	8,08	361	1,2350	1,00	74,42	7,16	1003,70	587,41	2724,03	6633,10	89,97	121,21	277,62	3,13	90,62
BB4 Mv	0,88	7,01	351	1,2175	11,71	74,19	1,59	1259,24	381,96	2285,55	5506,20	140,19	162,85	194,75	3,23	4,12
BB4 Fv	0,00	6,96	326	0,9930	10,71	60,52	1,57	321,77	226,46	2381,16	3350,22	133,04	143,56	160,38	3,41	2,06
BB5 Sv	183,00	9,11	324	1,1555	0,08	62,20	7,43	20,74	144,66	1740,68	9076,15	44,66	77,12	567,70	3,58	197,72
BB5 Mv	2,67	7,22	320	1,0990	6,51	66,92	1,79	34,82	99,99	2215,61	3549,59	98,61	117,23	146,23	3,61	2,75
BB5 Fv	0,00	6,92	321	1,1345	13,42	69,15	1,82	699,82	173,69	2466,37	3553,42	113,96	128,71	153,98	3,80	0,69

Tabela 3. Continuação.

Locais	Turb	pH	Cond	Alc	CO$_2$	HCO$_3$	OD	N-NH$_4^+$	N-NO$_2^-$	N-NO$_3^-$	NT	P-PO$_4$	P-PDT	PT	SSR	Clo-*a*
BB1 Si	10,50	7,10	481	1,8340	15,35	111,75	2,42	5597,20	157,68	1793,32	8136,65	428,05	459,64	478,52	1,79	74,14
BB1 Mi	9,18	7,05	487	1,8470	17,35	112,55	2,08	6069,77	153,17	1667,38	11786,11	444,82	474,93	508,01	1,75	64,53
BB1 Fi	7,73	7,00	495	1,9005	20,04	115,82	2,83	5929,00	153,87	1662,79	9378,30	465,11	496,97	522,17	1,83	61,16
BB2 Si	7,03	7,43	361	1,2940	5,06	78,74	5,46	907,64	145,53	1361,56	3121,28	118,27	146,59	190,94	2,43	38,45
BB2 Mi	5,30	7,17	364	1,2905	9,19	78,61	5,07	1120,80	147,19	1605,21	7112,15	127,83	158,89	188,11	2,36	47,43
BB2 Fi	5,79	7,00	400	1,4585	15,38	88,89	3,19	2548,56	135,00	1553,15	6723,36	228,27	263,54	276,81	2,23	0,50
BB3 Si	5,71	7,43	388	1,4080	5,50	85,68	6,55	1494,83	164,09	1806,37	4197,85	177,83	208,07	233,40	2,00	26,09
BB3 Mi	3,79	7,23	379	1,3985	8,67	85,18	4,95	1744,19	154,95	1788,26	6414,56	193,42	226,66	229,63	1,97	47,43
BB3 Fi	5,61	7,15	383	1,3785	10,28	83,98	5,15	1068,52	175,45	1798,91	4259,53	166,36	200,57	210,28	1,92	21,97
BB4 Si	7,31	7,72	362	1,2725	2,54	77,26	7,06	513,50	202,87	1728,65	4375,45	122,83	148,99	191,88	1,79	56,30
BB4 Mi	6,34	7,33	366	1,2560	6,18	76,47	6,48	666,33	200,38	1900,53	4667,41	128,71	154,69	171,59	1,78	66,16
BB4 Fi	2,83	7,22	369	1,2865	8,17	78,36	5,55	718,61	184,87	1871,26	3465,84	133,27	157,09	181,50	1,86	26,36
BB5 Si	7,98	7,93	335	1,2095	1,48	73,22	8,53	110,07	142,21	1746,48	2700,36	70,77	92,32	141,87	1,72	72,77
BB5 Mi	2,58	7,58	338	1,2020	3,32	73,07	6,65	84,33	153,84	1830,25	2304,64	59,15	79,12	113,56	1,73	98,61
BB5 Fi	1,63	7,44	339	1,2120	4,63	73,75	6,87	53,36	137,22	1585,98	3251,94	61,07	76,12	99,87	1,74	26,36

APÊNDICE 2

Tabela 4. Táxons com abundância relativa ≥ 2% nas amostras de sedimento superficial nas represas da Bacia do Médio Tietê/Alto Sorocaba. SH: represa Santa Helena, IT: represa Itupararanga, IP: represa Ipaneminha, HB: represa Hedberg, BB: represa Barra Bonita.

Espécies	SH1	SH2	SH3	IT1	IT2	IT3	IT4	IT5	IP1	IP2	IP3	HB1	HB2	HB3	BB1	BB2	BB3	BB4	BB5
Aulacoseira ambigua	7,49	6,33	4,84	29,06	63,56	44,05	31,79	30,73	0,25	10,02	2,70	1,18	4,41	55,20	13,58	16,51	14,08	19,32	22,07
Achnanthidium cf. *catenatum*	1,93	0,97	0,48	4,41	1,58	5,24	3,08	1,83	0,99	0,00	0,00	0,39	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Achnanthidium jackii	0,00	0,00	0,00	0,40	0,00	0,00	1,16	1,38	0,00	0,00	0,00	4,71	0,93	0,50	0,00	0,00	0,00	0,00	0,00
Achnanthidium minutissimum	3,38	1,95	0,00	3,21	0,53	0,95	1,54	3,21	3,95	0,95	0,98	7,45	1,39	0,00	0,00	0,00	0,00	0,00	0,00
Achnanthidium lineare	0,48	0,00	0,00	0,80	0,18	1,43	0,00	0,00	5,93	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Achnanthidium sp. 1	6,28	0,97	0,00	0,00	0,00	0,48	0,00	0,46	2,47	0,00	0,00	1,18	0,46	0,00	0,00	0,00	0,00	0,00	0,00
Asterionella formosa	0,00	0,00	0,00	0,00	0,61	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Aulacoseira calipsi	0,00	0,00	0,00	0,00	1,05	4,05	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Aulacoseira granulata var. *angustissima*	0,72	0,73	0,24	3,41	2,11	4,52	5,78	5,96	1,73	16,71	17,44	4,90	24,83	23,51	31,11	45,41	28,82	30,49	19,48
Aulacoseira granulata var. *granulata*	3,86	2,43	1,21	8,62	8,25	13,57	8,29	14,91	2,22	22,43	8,35	2,75	19,95	8,42	11,60	19,50	36,73	37,88	51,64
Aulacoseira herzogii	0,00	0,00	0,00	0,00	0,18	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	2,47	0,00	1,07	0,76	1,17
Brachysira microcephala	0,48	0,00	0,00	0,00	0,35	0,00	0,39	0,00	3,46	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Cyclotella meneghiniana	0,00	0,00	0,00	2,40	0,18	0,00	0,00	0,46	0,00	0,24	0,25	0,78	3,48	0,00	40,74	14,68	16,09	10,61	5,16
Cymbella excisa var. *procera*	0,00	0,00	0,48	0,00	0,00	0,00	0,00	0,00	6,91	0,48	0,00	0,78	0,93	0,00	0,00	0,00	0,00	0,00	0,00
Cymbopleura naviculiformis	0,48	0,00	0,00	0,00	1,05	0,48	3,08	1,38	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Diadesmis confervacea	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	7,45	0,93	0,00	0,00	0,92	0,27	0,38	0,47
Discostella stelligera	2,42	1,22	1,93	7,42	5,62	7,86	15,03	14,67	10,87	18,86	42,26	1,37	2,79	0,75	0,49	0,00	0,27	0,00	0,00
Encyonema silesiacum	0,00	0,00	0,00	0,80	0,18	0,00	0,00	0,92	0,00	0,00	0,49	5,49	3,02	0,00	0,00	0,00	0,00	0,00	0,00
Eunotia intricans	0,97	0,00	0,48	0,00	0,00	0,00	0,00	0,00	28,64	0,48	0,00	1,57	2,32	0,50	0,00	0,00	0,00	0,00	0,00
Eunotia sp.	0,00	0,00	0,00	0,40	0,00	0,00	0,00	0,00	0,49	0,00	0,49	1,57	2,55	0,00	0,00	0,00	0,00	0,00	0,00
Fragilaria aquaplus	0,00	0,00	0,00	18,23	1,32	0,00	0,77	2,29	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Fragilaria grunowii	0,00	0,00	0,00	0,00	0,53	0,48	2,70	1,38	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Fragilaria longifusiformis	0,00	4,87	0,00	2,81	2,37	1,90	6,36	7,80	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Fragilaria tenera var. *nanana*	0,00	0,00	0,00	0,40	0,00	0,00	0,00	0,00	0,99	2,39	3,93	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Gomphonema lagenula	0,48	0,00	0,00	0,00	0,00	0,00	0,39	0,00	0,00	0,00	0,00	1,96	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Humidophila contenta	0,00	0,00	0,00	0,40	0,44	0,48	0,77	0,00	0,99	0,00	0,49	1,57	2,78	0,00	0,00	0,00	0,00	0,00	0,00
Navicula cryptocephala	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	4,94	2,86	0,98	0,39	0,00	0,00	0,00	0,00	0,00	0,00	0,00

Tabela 4. Continuação.

Espécies	SH1	SH2	SH3	IT1	IT2	IT3	IT4	IT5	IP1	IP2	IP3	HB1	HB2	HB3	BB1	BB2	BB3	BB4	BB5
Navicula cryptotenella	0,00	0,49	1,45	0,80	0,00	0,48	0,00	2,06	4,94	0,00	5,65	0,00	0,93	0,50	0,00	0,00	0,00	0,00	0,00
Navicula kuseliana	5,80	0,49	0,00	0,00	0,00	0,00	0,39	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Navicula notha	0,97	0,00	0,00	0,00	0,00	0,00	0,40	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Navicula rostellata	0,00	0,00	0,00	1,20	0,00	0,00	0,00	0,00	0,00	0,48	0,25	2,55	0,46	0,00	0,00	0,00	0,00	0,00	0,00
Nitzschia palea	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,92	0,67	0,00	0,00
Nitzschia sp. 2	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,92	2,47	0,00	1,47	7,06	4,87	0,99	0,00	0,00	0,00	0,00	0,00
Placoneis exigua	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	3,73	0,00	0,00	0,00	0,00	0,27	0,00	0,00
Planothidium rostratum	4,59	0,24	0,48	0,60	0,00	0,48	0,39	0,00	0,74	11,46	3,93	0,98	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Pseudostaurosira brevistriata	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	2,47	1,43	1,47	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Pseudostaurosira sp.	0,00	2,43	2,42	0,00	0,53	1,90	1,93	0,92	0,00	1,67	0,98	0,78	2,78	2,97	0,00	0,00	0,00	0,00	0,00
Punctastriata lancettula	48,31	73,97	81,84	0,00	0,00	0,00	0,00	0,00	0,49	2,39	2,46	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Rimoneis sp.	0,00	0,00	0,48	0,00	2,11	6,67	6,94	3,67	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Sellaphora rostrata	0,00	0,00	0,00	0,40	0,00	0,00	0,00	0,00	3,95	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Spicaticribra kingstonii	0,00	0,00	0,00	0,00	5,53	1,90	3,28	0,46	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Staurosirella sp.	0,48	0,00	1,94	0,00	0,00	0,95	0,77	0,46	0,49	2,86	0,00	3,92	3,71	2,48	0,00	0,00	0,00	0,00	0,00

Tabela 5. Táxons com abundância relativa ≥ 2% nas amostras de fitoplâncton no verão nas represas da Bacia do Médio Tietê/Alto Sorocaba. SH: represa Santa Helena, IT: represa Itupararanga, IP: represa Ipaneminha, HB: represa Hedberg, BB: represa Barra Bonita.

Espécies	SH1	SH2	SH3	IT1	IT2	IT3	IT4	IT5	IP1	IP2	IP3	HB1	HB2	HB3	BB1	BB2	BB3	BB4	BB5
Aulacoseira ambigua	20,14	18,27	23,71	2,90	4,55	2,12	3,45	6,48	0,17	0,20	0,00	5,51	17,69	13,27	0,00	0,00	0,23	0,00	0,00
Achnanthidium cf. *catenatum*	5,69	2,81	3,13	8,70	2,73	5,77	6,56	5,35	1,05	0,39	0,36	2,21	0,94	0,49	0,00	0,00	0,00	0,95	0,00
Achnanthidium jackii	0,00	0,00	0,89	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Achnanthidium minutissimum	0,00	0,80	0,00	0,83	0,00	0,00	0,69	0,32	0,35	0,39	0,00	19,85	0,94	2,46	0,00	0,00	0,00	0,00	0,00
Achnanthidium sp. 2	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	1,84	2,83	2,95	0,00	0,00	0,00	0,00	0,00
Aulacoseira calipsi	0,00	0,00	0,00	0,00	0,68	0,19	0,35	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Aulacoseira granulata var. *angustissima*	0,95	2,61	1,79	0,83	0,91	0,77	0,86	1,30	0,00	0,20	0,00	2,94	25,00	31,94	3,80	3,06	5,84	5,46	0,00
Aulacoseira granulata var. *granulata*	3,55	7,83	2,91	1,45	1,14	0,38	0,69	1,78	0,17	0,00	0,00	2,57	16,75	19,90	0,00	0,00	1,64	1,66	0,23
Aulacoseira herzogii	0,00	0,00	0,00	0,00	0,23	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Brachysira microcephala	0,00	0,40	0,45	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	1,47	0,00	0,49	0,00	0,00	0,47	0,00	0,00
Cyclotella meneghiniana	0,24	0,00	0,22	0,83	0,00	0,00	0,00	0,49	1,57	1,77	3,62	1,47	1,65	0,49	18,05	16,71	27,34	36,10	0,00
Cymbella excisa var. *procera*	0,00	0,40	0,45	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,37	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Cymbopleura naviculiformis	0,95	0,40	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,37	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Discostella pseudostelligera	8,77	4,02	14,09	9,52	30,23	43,65	46,80	48,95	0,00	0,00	0,00	0,00	0,00	0,49	0,00	0,00	0,00	0,00	0,00
Discostella stelligera	11,85	0,60	0,00	0,21	0,23	0,19	0,52	0,81	91,99	90,37	88,22	1,65	3,77	3,19	0,00	0,00	0,00	0,00	0,00
Encyonema silesiacum	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,74	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Encyonpsis thienemannii	0,00	0,00	0,00	0,00	0,45	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Eunotia desmogonioides	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	4,41	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Eunotia intricans	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,74	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Eunotia sp.	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	17,65	0,47	0,00	0,00	0,00	0,00	0,00	0,47
Fragilaria aquaplus	0,00	0,00	0,00	5,80	1,36	0,00	0,00	1,62	0,00	0,39	0,00	0,00	0,47	0,00	0,00	0,00	0,00	0,00	0,00
Fragilaria grunowii	1,42	1,20	2,24	2,48	1,36	0,38	1,38	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Fragilaria longifusiformis	0,00	0,40	0,89	14,08	12,27	6,92	2,07	3,24	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Fragilaria spectra	13,27	15,66	25,06	46,38	38,18	34,23	27,12	19,45	0,00	0,00	0,00	0,00	0,00	0,98	0,00	0,00	0,00	0,00	0,00
Fragilaria tenera var. *nanana*	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	1,39	1,18	3,62	0,00	0,00	0,00	0,00	0,00	0,00	0,48	0,00

Tabela 5. Continuação.

Espécies	SH1	SH2	SH3	IT1	IT2	IT3	IT4	IT5	IP1	IP2	IP3	HB1	HB2	HB3	BB1	BB2	BB3	BB4	BB5
Gomphonema lagenula	0,00	0,20	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	11,03	0,94	0,00	0,00	0,00	0,00	0,00	0,00
Humidophila contenta	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,32	0,00	0,00	0,00	1,10	2,83	1,47	0,00	0,00	0,00	0,00	0,00
Navicula cryptocephala	0,00	0,00	0,00	0,00	0,91	0,00	0,35	0,32	0,35	0,00	0,00	1,47	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Navicula kuseliana	0,47	1,20	0,45	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Navicula notha	1,90	4,02	4,47	0,00	0,00	0,00	0,69	0,32	0,00	0,00	0,00	0,00	0,00	0,98	0,00	0,00	0,00	0,00	0,00
Navicula rostellata	0,00	0,40	0,00	0,00	0,00	0,00	0,00	0,32	0,35	0,39	0,00	1,47	3,30	2,46	0,00	0,00	0,00	0,00	0,00
Nitzschia gracilis	0,71	1,00	0,22	0,41	0,23	1,15	2,07	2,59	0,00	0,20	0,00	0,37	0,24	0,00	0,00	0,00	0,00	0,00	0,00
Nitzschia palea	0,47	0,00	0,00	0,00	0,00	0,19	0,00	0,00	0,17	0,00	0,00	0,74	0,47	0,98	74,11	80,00	63,55	53,68	83,06
Nitzschia sp. 1	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	4,04	0,24	0,47	1,19	0,00
Nitzschia sp. 2	0,00	0,00	0,00	0,00	0,00	0,00	0,35	0,00	0,17	0,00	0,00	0,37	0,47	1,23	0,00	0,00	0,00	0,00	0,00
Placoneis exigua	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,37	0,00	0,49	0,00	0,00	0,00	0,00	0,00
Planothidium rostratum	0,00	0,00	0,00	0,00	0,00	0,00	0,17	0,00	0,52	1,77	0,72	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Pseudostaurosira brevistriata	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,72	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Pseudostaurosira sp.	0,95	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	2,21	3,77	1,47	0,00	0,00	0,00	0,00	0,00
Punctastriata lancettula	20,14	23,49	8,50	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Rimoneis sp.	0,00	0,00	0,00	0,00	0,45	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Spicaticribra kingstonii	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	1,89	0,00	0,00	0,00	0,00	0,00	0,00
Staurosirella sp.	0,00	0,40	0,45	0,00	0,00	0,00	0,00	0,32	0,00	0,00	0,00	0,37	2,36	0,98	0,00	0,00	0,00	0,00	0,00

Tabela 6. Táxons com abundância relativa ≥ 2% nas amostras de fitoplâncton no inverno nas represas da Bacia do Médio Tietê/Alto Sorocaba. SH: represa Santa Helena, IT: represa Itupararanga, IP: represa Ipaneminha, HB: represa Hedberg, BB: represa Barra Bonita.

Espécies	SH1	SH2	SH3	IT1	IT2	IT3	IT4	IT5	IP1	IP2	IP3	HB1	HB2	HB3	BB1	BB2	BB3	BB4	BB5
Achnanthidium cf. *catenatum*	0,49	2,00	0,45	0,00	0,00	0,00	0,00	0,00	0,00	1,25	1,72	0,00	0,00	0,97	0,00	0,98	0,48	3,37	0,00
Achnanthidium jackii	0,49	0,44	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,50	0,49	0,00	0,00	0,00	0,00	0,00
Achnanthidium minutissimum	22,93	10,22	8,16	0,93	0,95	0,00	0,00	0,00	4,37	2,50	3,45	5,17	2,48	2,43	0,00	0,00	0,00	0,00	0,00
Achnanthidium sp. 1	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,42	0,86	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Achnanthidium sp.2	0,00	0,00	0,00	2,33	1,90	0,48	0,46	44,04	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Asterionella formosa	0,00	0,00	0,00	2,33	0,48	0,00	0,00	0,00	0,00	0,21	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Aulacoseira ambigua	9,02	10,44	9,98	39,77	44,42	20,67	8,56	4,82	0,24	0,83	0,43	1,66	3,96	4,87	0,00	6,88	2,87	5,06	1,42
Aulacoseira calipsi	0,00	0,44	0,00	0,00	0,48	0,48	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Aulacoseira granulata var. *angustissima*	0,73	0,89	0,91	15,35	4,51	1,68	0,46	0,23	0,97	1,04	1,51	47,23	63,61	63,99	14,12	8,11	6,46	7,47	3,09
Aulacoseira granulata var. *granulata*	7,32	9,78	7,26	6,74	11,16	15,14	6,71	5,96	0,73	0,21	0,43	0,18	0,74	2,43	5,17	47,17	56,94	70,60	88,36
Aulacoseira herzogii	1,22	0,00	0,00	0,00	0,24	0,24	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,24
Brachysira brebisonii	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	3,11	0,00	0,00
Brachysira microcephala	0,00	0,44	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Cyclotella meneghiniana	0,00	0,22	0,23	3,02	0,00	0,72	0,23	0,00	0,97	0,00	0,00	1,85	0,50	4,14	68,47	28,01	17,94	6,50	1,19
Cymbella excisa var. *procera*	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,49	0,42	0,43	0,00	0,50	0,49	0,00	0,00	0,00	0,00	0,00
Cymbopleura naviculiformis	0,00	0,00	0,00	0,00	0,48	0,96	1,39	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Diadesmis confervacea	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	2,21	0,00	0,00	0,00	0,98	0,00	0,96	0,00
Discostella pseudostelligera	0,00	0,00	0,00	6,51	0,24	0,48	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Discostella stelligera	34,88	35,78	43,08	2,56	25,65	53,37	73,15	36,24	37,38	32,50	33,41	0,37	0,50	2,43	0,00	0,74	1,19	0,00	1,19
Encyonema silesiacum	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	1,11	0,50	0,00	0,00	0,00	0,00	0,00	0,00
Encyonpsis thienemannii	0,98	0,44	3,63	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Eunotia intricans	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,49	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Eunotia sp.	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,92	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	1,91	0,00	0,00
Fragilaria aquaplus	0,00	0,00	0,91	11,63	3,33	0,96	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Fragilaria grunowii	0,00	0,00	0,00	0,00	0,00	0,48	0,46	1,83	0,00	0,00	0,00	0,00	0,00	2,92	0,00	0,00	0,00	0,00	0,00
Fragilaria longifusiformis	0,00	0,00	0,45	1,86	1,43	0,00	0,46	0,46	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Fragilaria spectra	0,00	0,00	0,00	0,00	0,48	0,96	0,00	0,92	0,00	0,83	0,43	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Fragilaria tenera var. *nanana*	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,46	26,46	30,42	26,51	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Gomphonema lagenula	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,49	0,00	0,00	1,48	0,99	0,49	0,00	0,00	0,00	0,00	0,00
Humidophila contenta	0,00	0,00	0,00	0,93	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,74	0,00	0,00	0,00	0,00	0,00	0,00	0,00

Tabela 6. Continuação.

Espécies	SH1	SH2	SH3	IT1	IT2	IT3	IT4	IT5	IP1	IP2	IP3	HB1	HB2	HB3	BB1	BB2	BB3	BB4	BB5
Navicula cryptocephala	0,00	0,00	0,00	0,93	0,00	0,00	0,46	0,00	10,68	14,38	18,10	0,37	0,00	0,00	0,00	0,49	0,00	0,00	0,00
Navicula cryptotenella	0,00	0,00	1,36	0,00	0,00	0,00	0,00	0,00	4,85	3,33	1,72	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Navicula kuseliana	0,98	2,67	2,27	0,00	0,48	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,48	0,00
Navicula notha	7,80	2,67	3,17	0,47	0,48	0,00	0,00	0,46	0,49	0,00	0,00	0,74	0,00	0,00	0,00	0,49	0,00	0,48	0,00
Navicula rostellata	0,00	0,00	0,00	0,93	0,00	0,00	0,00	0,00	0,49	0,42	0,86	12,92	7,92	1,95	0,00	0,00	0,00	0,00	0,00
Nitzschia palea	0,49	0,00	0,23	0,23	0,00	0,96	0,00	0,00	0,73	0,42	3,66	0,00	0,00	0,00	0,00	1,72	5,50	3,13	4,51
Nitzschia sp. 1	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	12,00	0,74	0,72	0,00	0,00
Nitzschia sp.2	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,24	0,00	0,00	1,11	0,99	0,00	0,00	0,00	0,00	0,00	0,00
Planothidium rostratum	0,00	0,44	0,23	0,00	0,00	0,00	0,00	0,00	1,70	2,29	1,94	0,74	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Pseudostaurosira brevistriata	0,00	0,00	0,45	0,00	0,00	0,00	0,00	0,00	0,97	0,42	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Pseudostaurosira sp.	0,00	0,00	0,00	0,00	0,00	0,48	1,39	0,00	0,49	0,00	0,43	0,37	0,50	1,46	0,00	0,00	0,00	0,00	0,00
Punctastriata lancettula	6,83	13,33	15,87	0,00	0,00	0,00	0,00	0,00	0,00	0,42	0,86	0,00	0,00	0,00	0,00	0,00	0,48	0,00	0,00
Rimoneis sp.	0,00	0,00	0,00	0,00	0,48	0,00	1,39	0,46	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Spicaticribra kingstonii	0,24	0,44	0,00	0,00	0,24	0,96	0,69	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,72	0,00
Staurosirella sp.	0,00	0,00	0,00	0,00	0,00	0,00	0,46	0,00	0,00	0,00	0,00	0,37	1,49	0,00	0,00	0,00	0,00	0,00	0,00
Ulnaria acus	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,43	0,74	1,98	3,89	0,00	0,00	0,00	0,00	0,00

APÊNDICE 3

Pranchas dos táxons com ocorrência igual ou superior a 2% no sedimento superficial e fitoplâncton nas represas da Bacia do Médio Tietê/Alto Sorocaba.

PRANCHA 1

Figuras 1-6. *Aulacoseira ambigua* (Grunow) Simonsen

Figuras 7-14. *Aulacoseira granulata* var. *angustissima* (Müller) Simonsen

Figuras 15-18. *Aulacoseira granulata* var. *granulata* (Ehrenberg) Simonsen

Figuras 19-23. *Aulacoseira herzogii* (Lemmermann) Simonsen

Figuras 24-27. *Aulacoseira calipsi* Tremarin et al.

Figuras 29-32. *Cyclotella meneghiniana* Kützing

Figuras 33-37. *Discostella stelligera* (Cleve & Grunow) Houk & Klee

Figuras 38-41. *Discostella pseudostelligera* (Hustedt) Houk & Klee

Figuras 42-45. *Spicaticribra kingstonii* Johansen et al.

Escala = 10 μm.

1-6

7-14

15-18

19-23

24-27

28-29

33-37

30-32

38-41

42-45
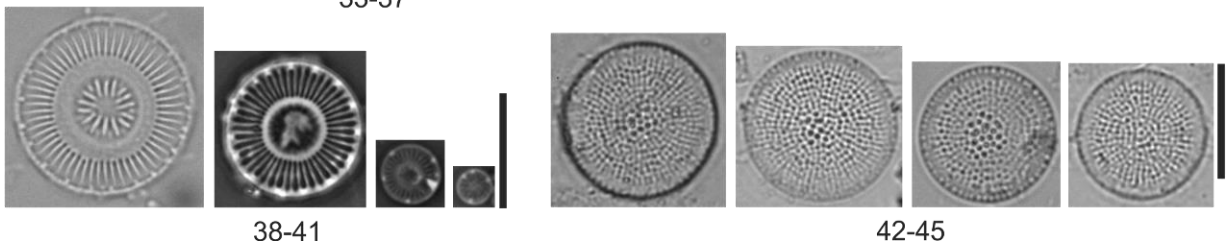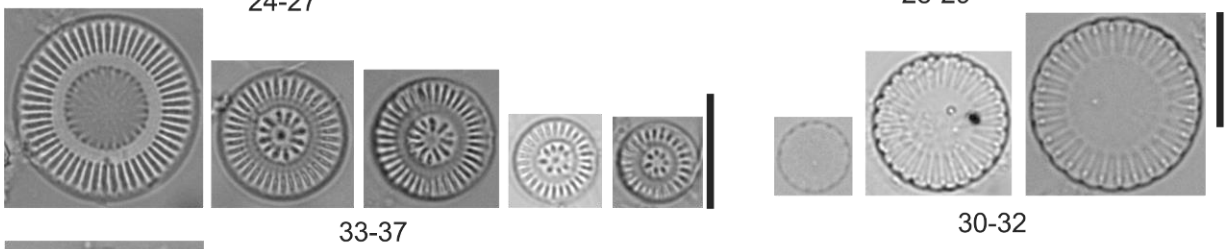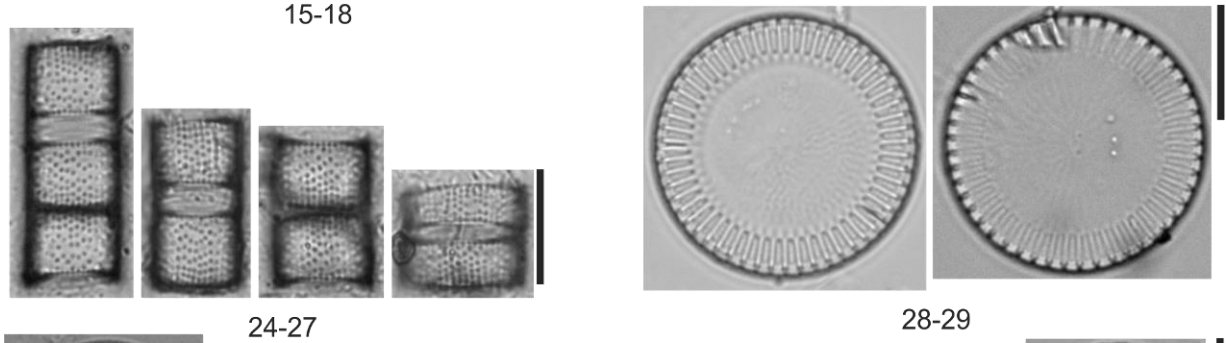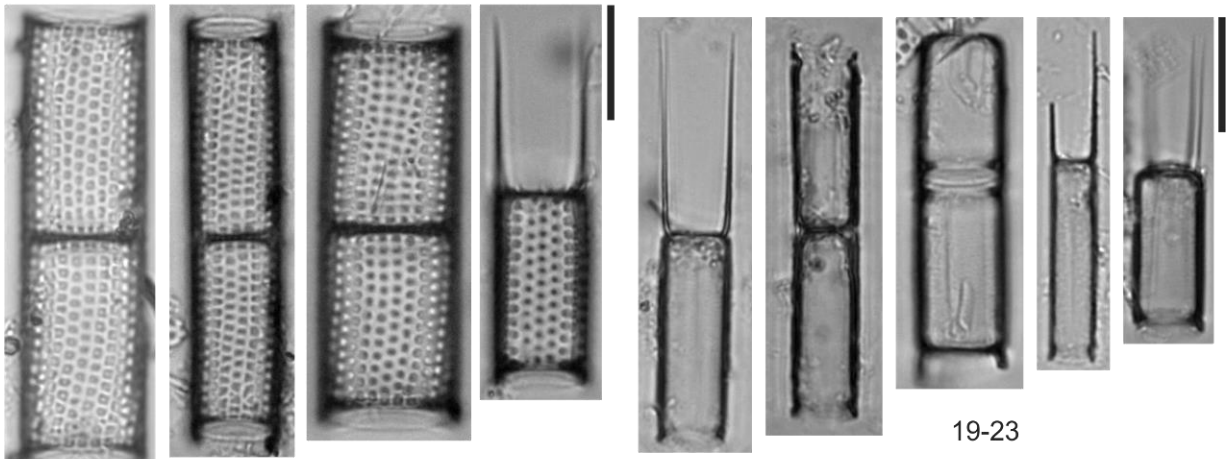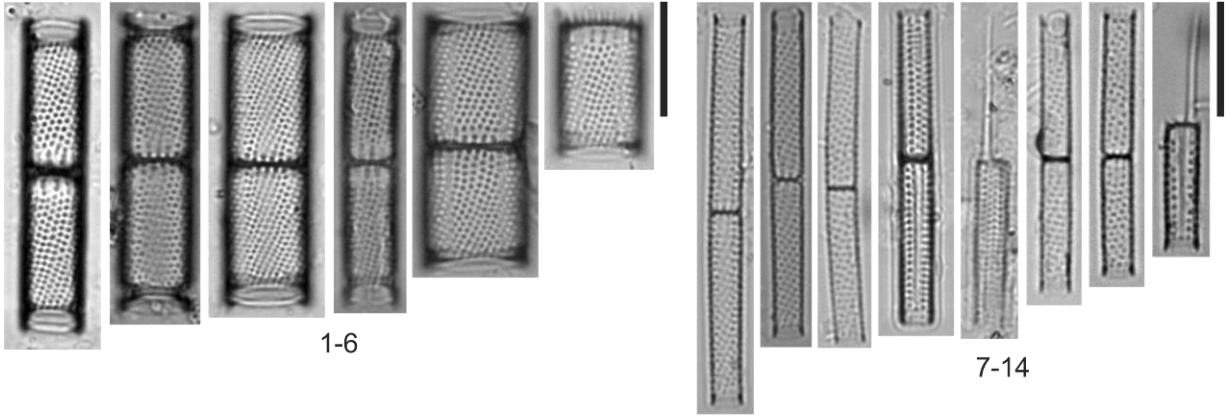
PRANCHA 2

Figuras 1-10. *Asterionella formosa* Hassal

Figuras 11-19. *Fragilaria aquaplus* Lange-Bertalot & Ulrich

Figuras 20-32. *Fragilaria tenera* var. *nanana* (Lange-Bertalot) Lange-Bertalot & Ulrich

Escala = 10 μm.

1-10

11-19

20-32
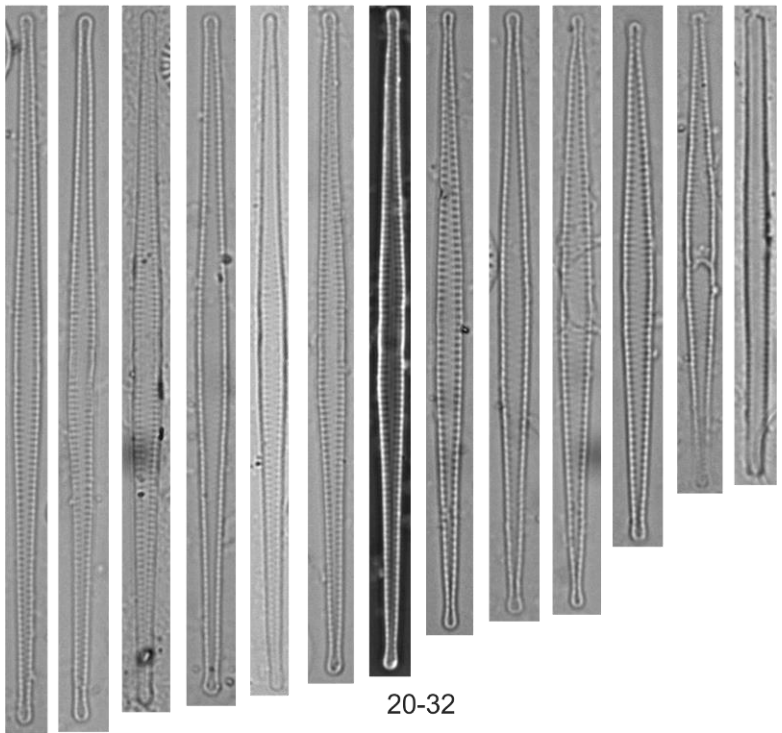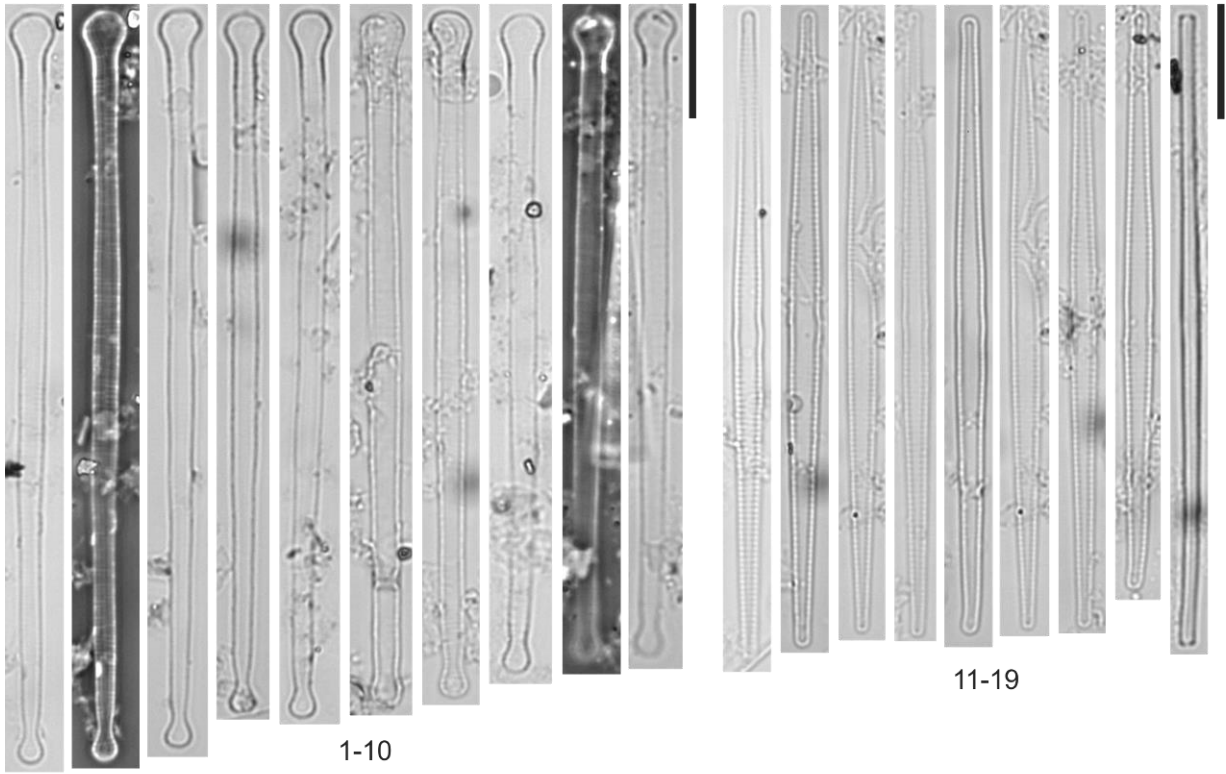
PRANCHA 3

Figuras 1-6. *Fragilaria grunowii* Lange-Bertalot & Ulrich

Figuras 7-13. *Fragilaria longifusiformis* (Hains & Sebring) Siver et al.

Figuras 14 e 15. *Ulnaria acus* (Kützing) Aboal

Escala = 10 μm.

1-6

7-13

14

15
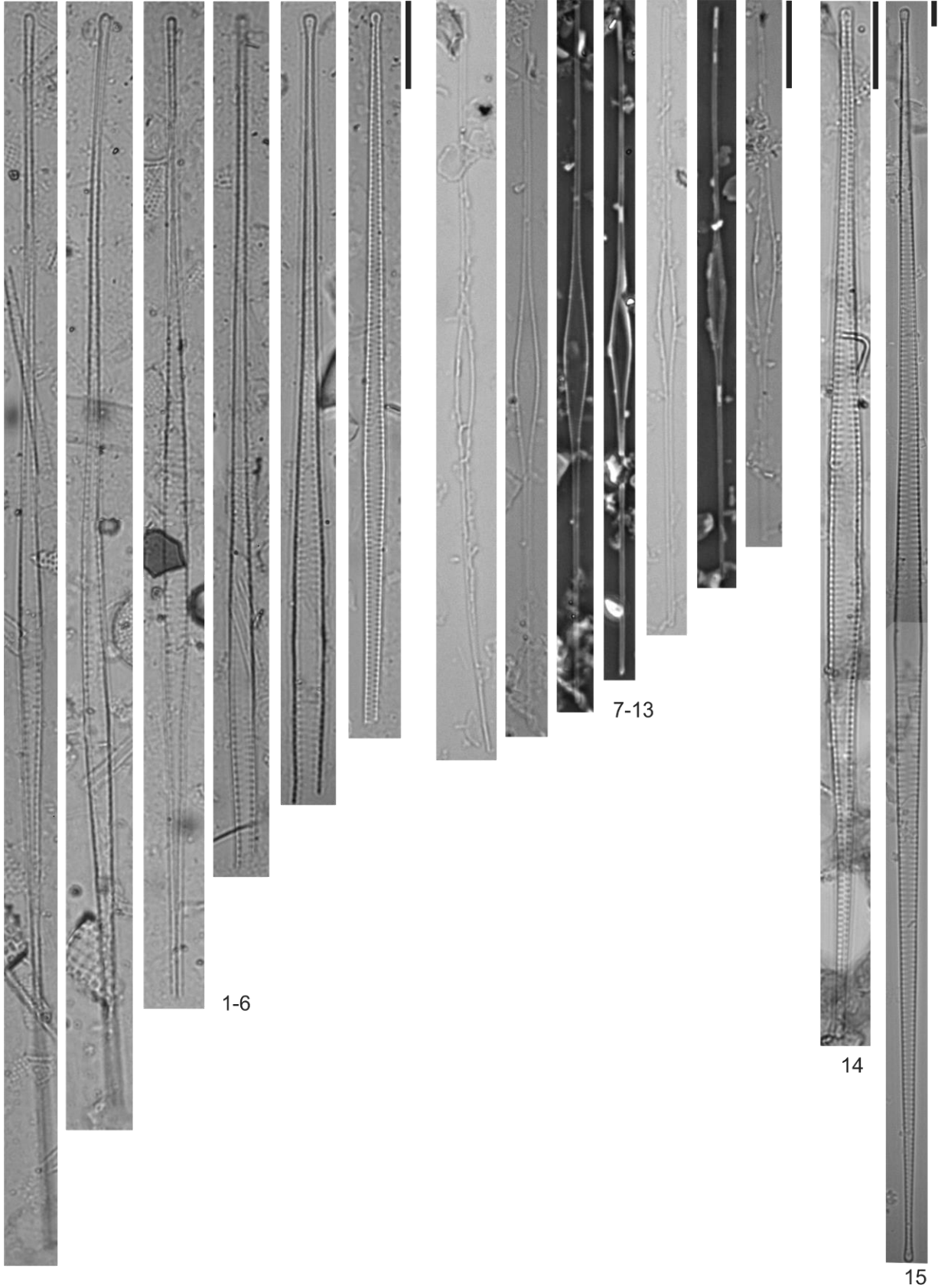
PRANCHA 4

Figuras 1-12. *Fragilaria spectra* Almeida et al.

Figuras 13-28. *Pseudostaurosira brevistriata* (Grunow) Williams & Round

Figuras 29-38. *Pseudostaurosira* sp. (Capítulo 3)

Figuras 39-53. *Punctastriata lancettula* (Schumann) Hamilton & Siver

Figuras 54-67. *Staurosirella* sp. (Capítulo 3)

Figuras 68-81. *Rimoneis* sp. (Capítulo 3)

Escala = 10 µm.

1-12
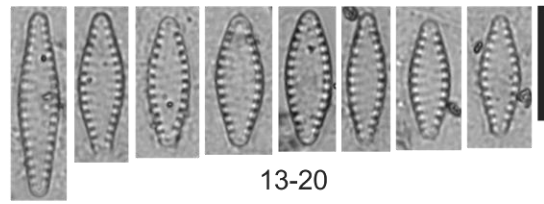
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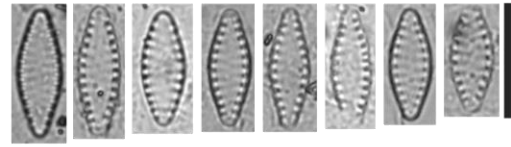
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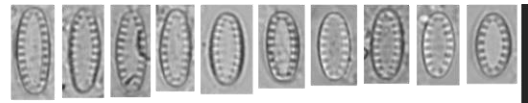
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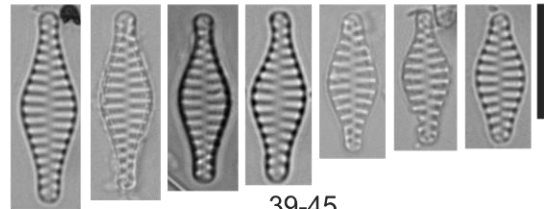
39-45
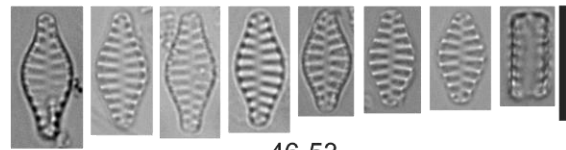
46-53
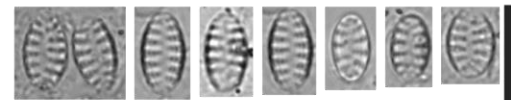
54-60
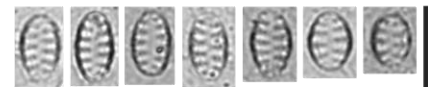
61-67
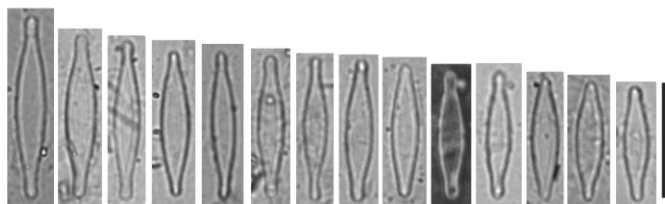
68-81

PRANCHA 5

Figuras 1 e 2. *Eunotia desmogonioides* Metzeltin & Lange-Bertalot

Figuras 3-11. *Eunotia intricans* Lange-Bertalot & Metzeltin

Figuras 12-26. *Eunotia* sp. (Capítulo 3)

Figuras 27-33. *Cymbella excisa* var. *procera* Krammer

Escala = 10 µm.

1

2

3-11

12-26

27-33
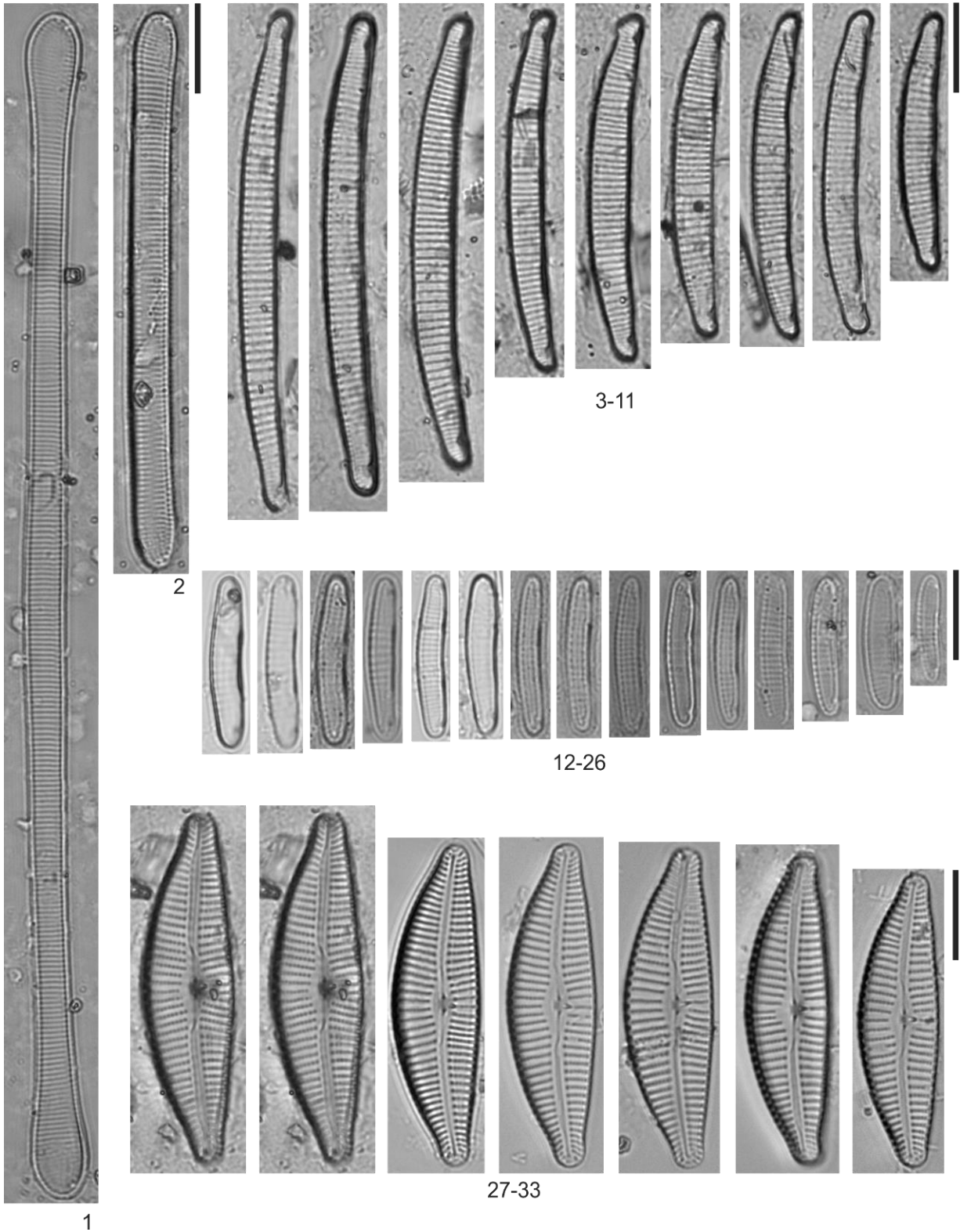
PRANCHA 6

Figuras 1-5. *Cymbopleura naviculiformis* (Auerswald ex Heiberg) Krammer

Figuras 6-9. *Encyonema silesiacum* (Bleisch) Mann

Figuras 10-16. *Encyonopsis thienemanii* (Hustedt) Krammer

Figuras 17-24. *Planothidium rostratum* (Østrup) Lange-Bertalot

Figuras 25-31. *Gomphonema lagenula* Kützing

Figuras 32-35. *Placoneis exigua* (Gregory) Mereschkovsky

Figuras 36-54. *Achnanthidium* cf. *catenatum* (Bily & Marvan) Lange-Bertalot

Figuras 55-73. *Achnanthidium minutissimum* (Kützing) Czarnecki

Escala = 10 μm.
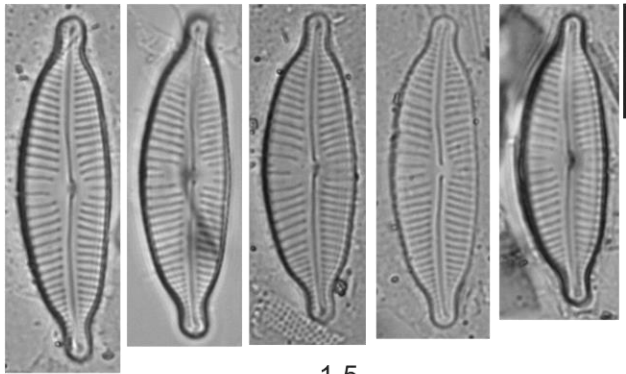
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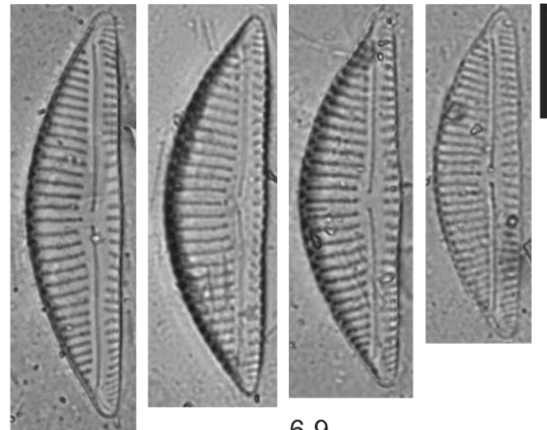
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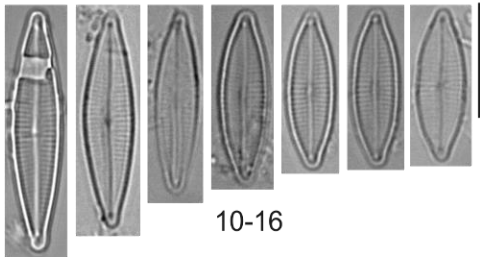
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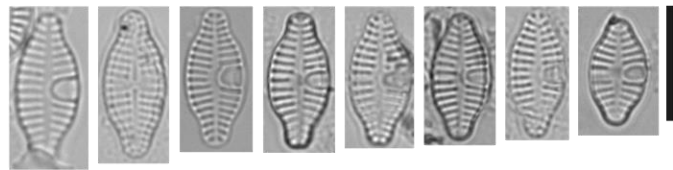
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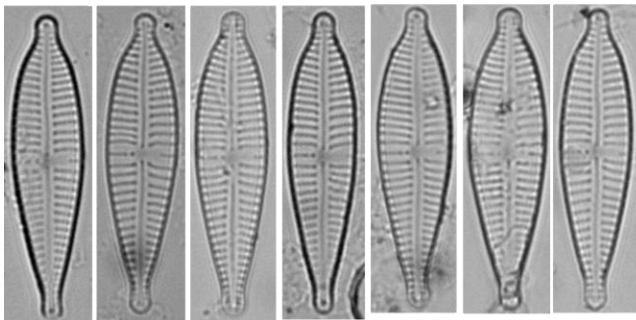
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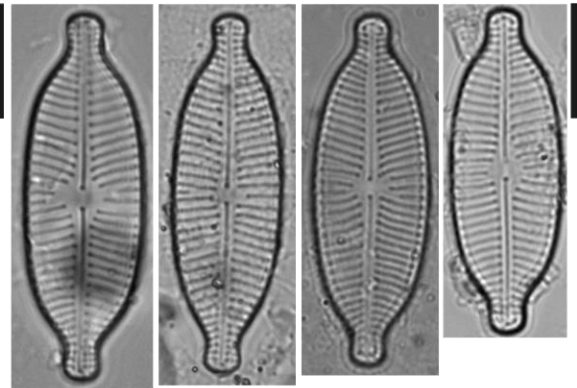
32-35
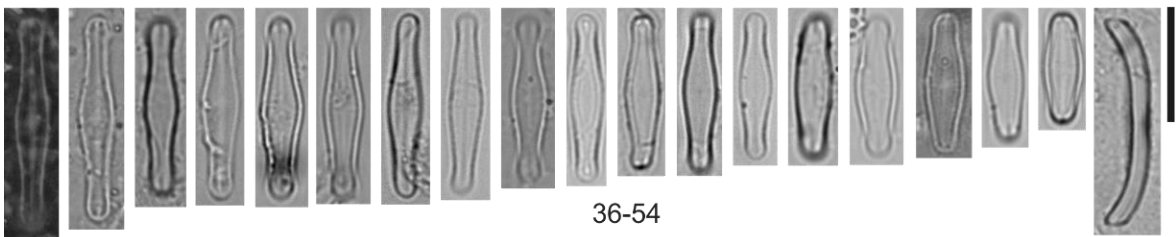
36-54
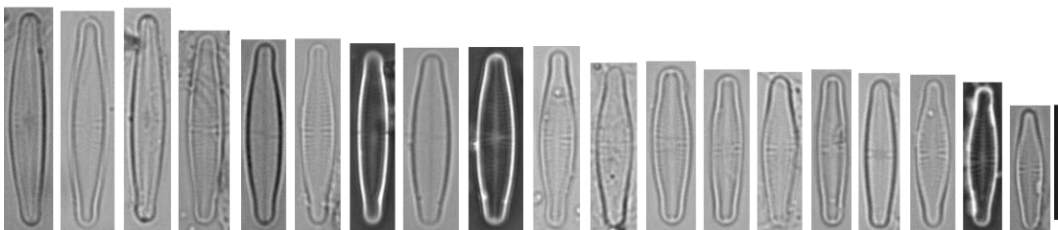
55-73

PRANCHA 7

Figuras 1-12. *Achnanthidium jackii* Rabenhorst

Figuras 13-19. *Achnanthidium lineare* W.Smith

Figuras 20-32. *Achnanthidium* sp. 1 (Capítulo 3)

Figuras 33-49. *Achnanthidium* sp. 2 (Capítulo 3)

Figuras 50-63. *Navicula cryptocephala* Kützing

Figuras 64-77. *Navicula cryptotenella* Lange-Bertalot

Escala = 10 µm.
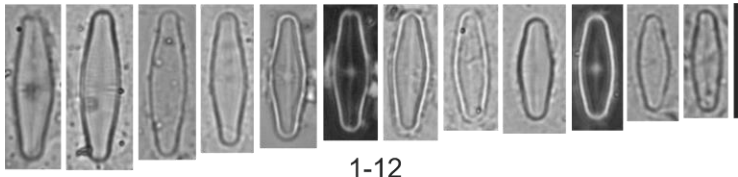
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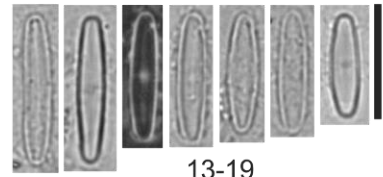
13-19
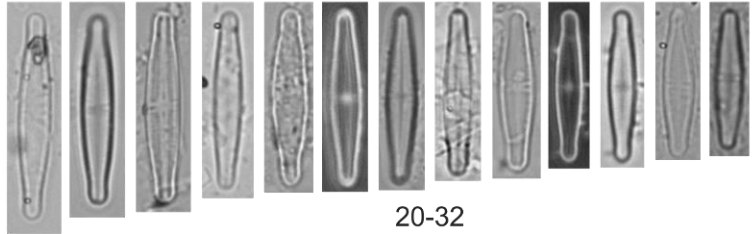
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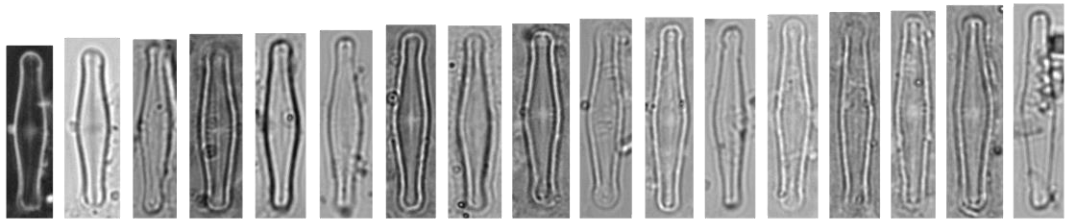
33-49
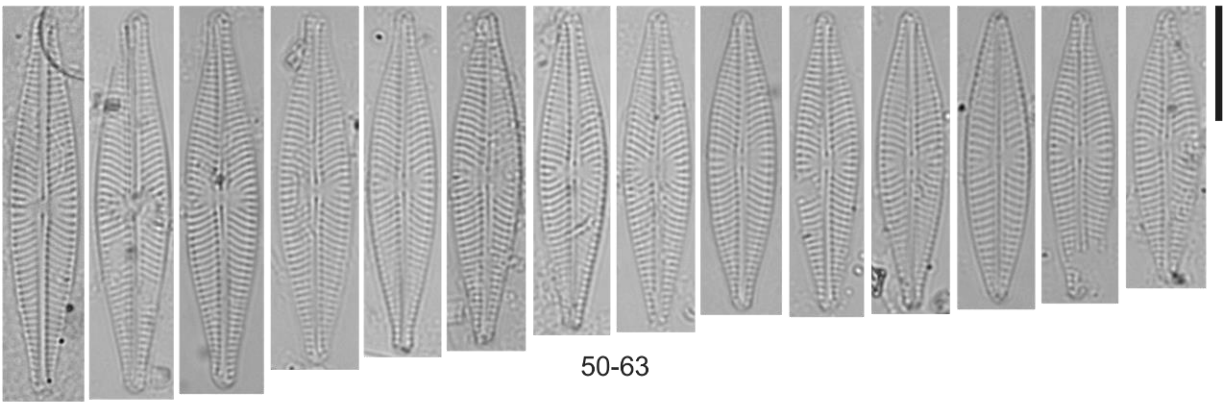
50-63
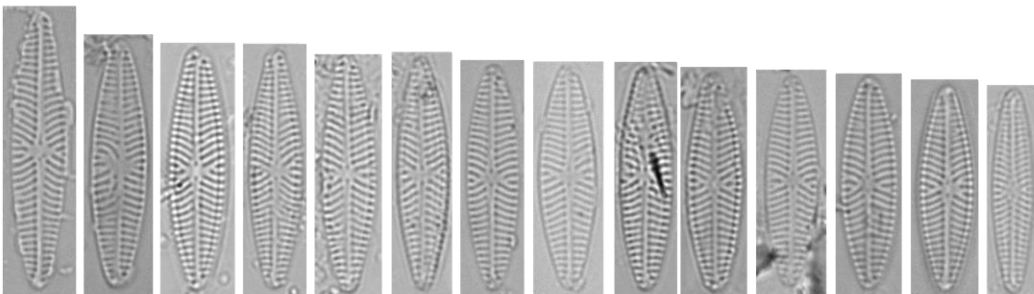
64-77

PRANCHA 8

Figuras 1-9. *Navicula kuseliana* Lange-Bertalot & Rumrich

Figuras 10-24. *Navicula notha* Wallace

Figuras 25-32. *Navicula rostellata* Kützing

Escala = 10 μm.
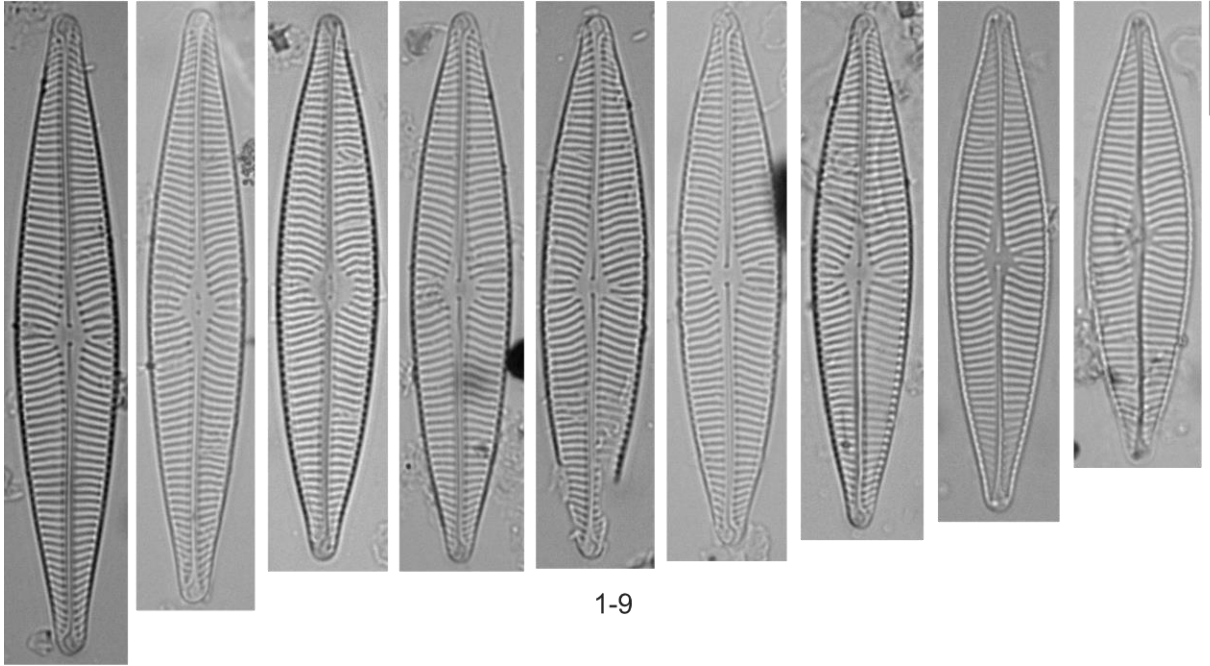
1-9
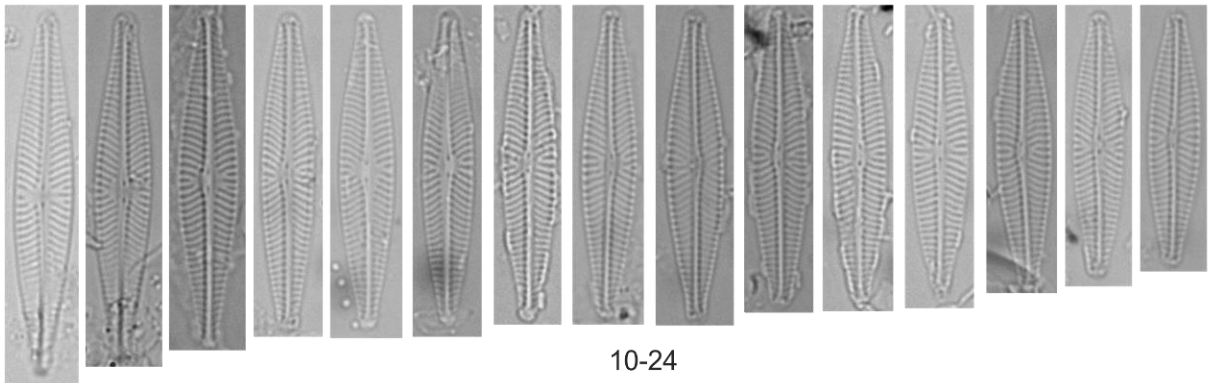
10-24
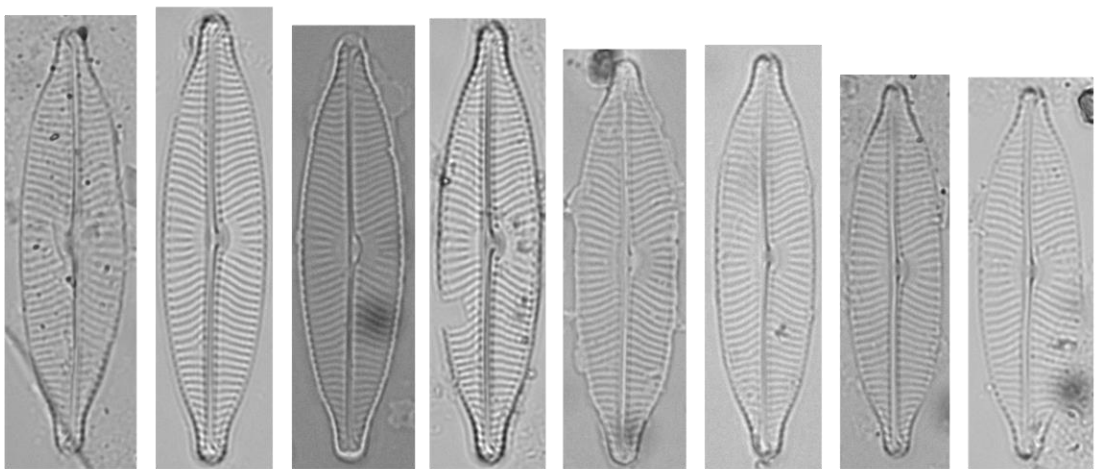
25-32

PRANCHA 9

Figuras 1-3. *Brachysira brebisonii* R.Ross

Figuras 4-9. *Brachysira microcephala* (Grunow) Compère

Figuras 10-16. *Humidophila contenta* (Grunow) Lowe et al.

Figuras 17-21. *Diadesmis confervacea* Kützing

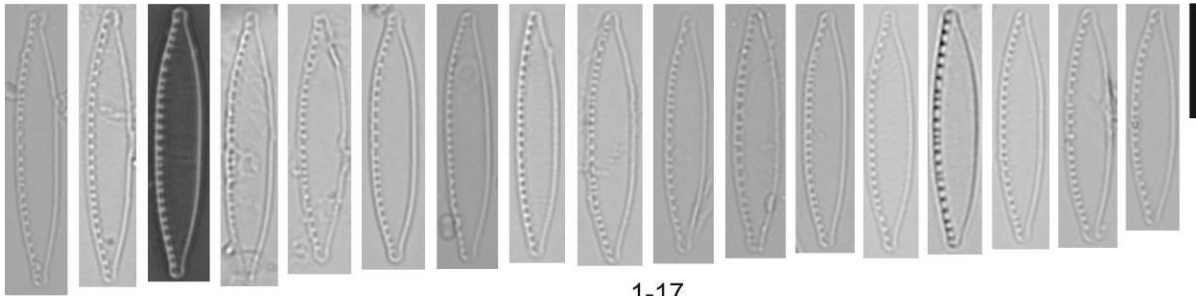**Figuras 22-37.** *Nitzschia gracilis* Hantzsch

Escala = 10 µm.

1-3

4-9

10-16

17-21
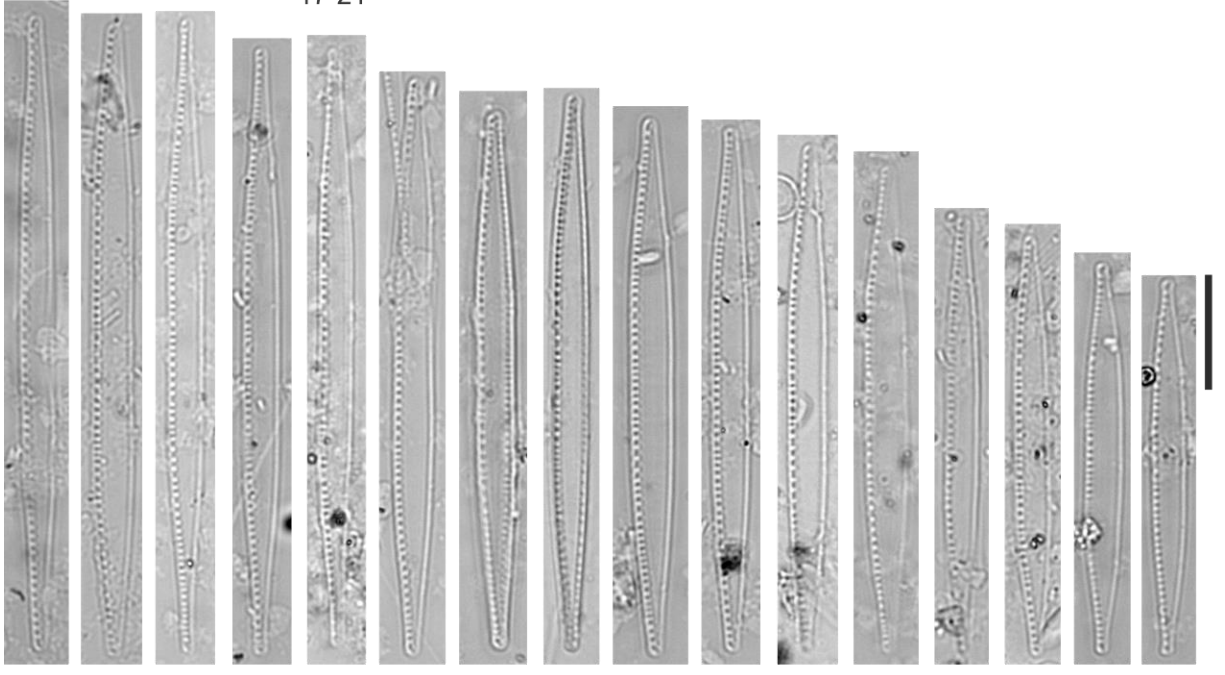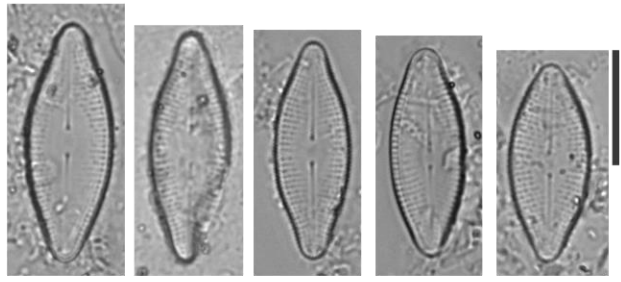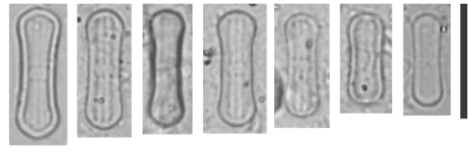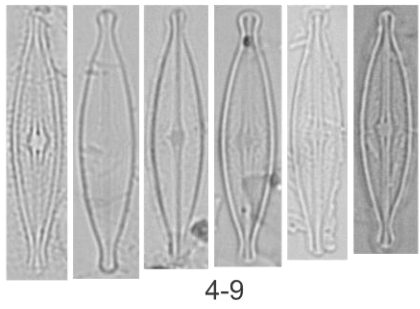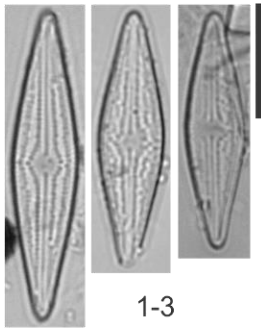
22-37

PRANCHA 10

Figuras 1-17. *Nitzschia palea* (Kützing) Smith
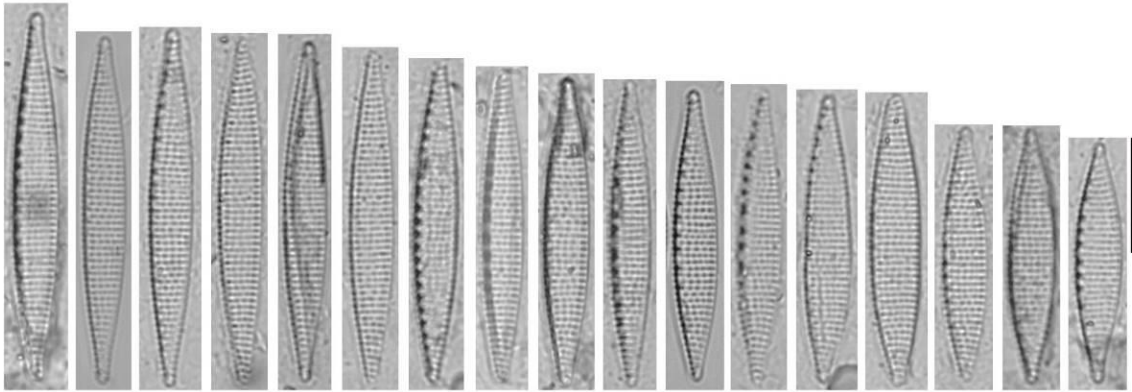
Figuras 18-34. *Nitzschia* sp. 1 (Capítulo 3)
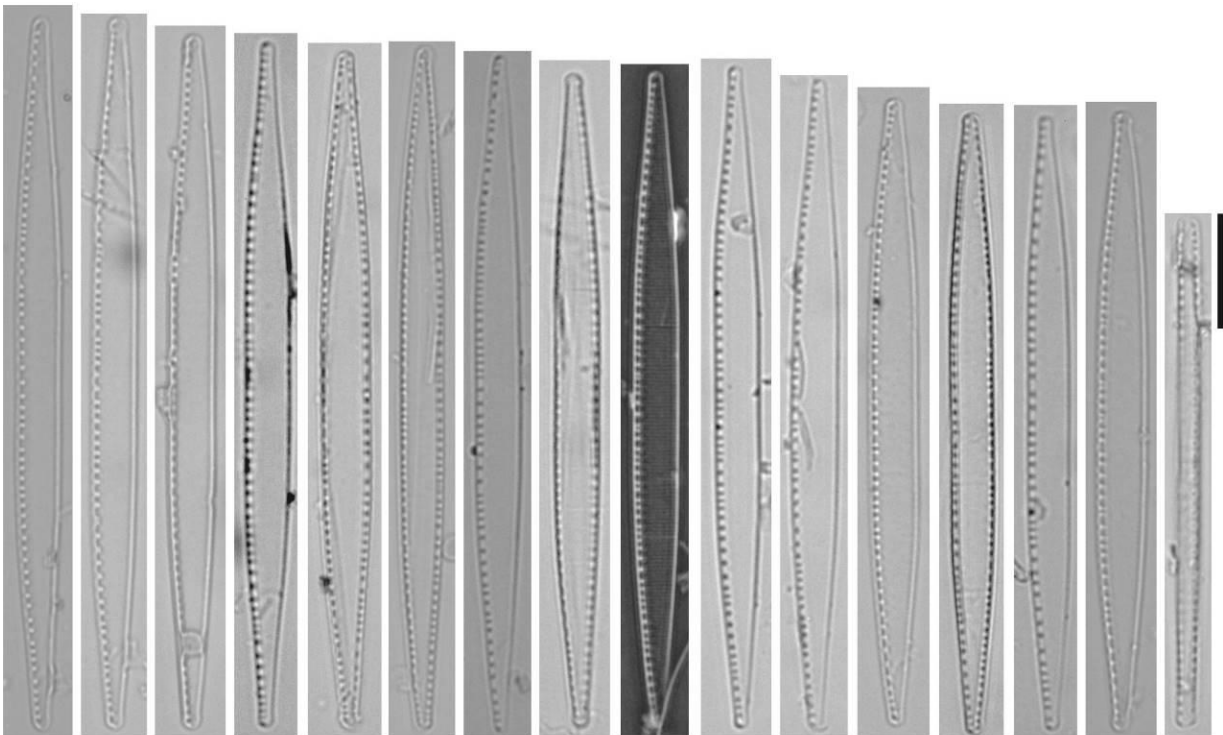
Figuras 35-50. *Nitzschia* sp. 3 (Capítulo 3)

Escala = 10 μm.

1-17

18-34

35-50