

UNIVERSIDADE ESTADUAL DE GOIÁS
Pró Reitoria de pesquisa e Pós-Graduação
Câmpus Anápolis de Ciências Exatas e Tecnológicas – Henrique Santillo
Programa de Pós-Graduação *Stricto Sensu* em Recursos Naturais do
Cerrado

João Paulo Francisco de Souza

**O PAPEL DO USO DO SOLO NA DIVERSIDADE DE COMUNIDADES
FITOPLANCTÔNICAS DE VEREDAS E RIACHOS**

Anápolis

2018

Elaborada pelo Sistema de Geração Automática de Ficha Catalográfica da UEG com os dados fornecidos pelo(a) autor(a).

dso729p de Souza, João Paulo Francisco
O PAPEL DO USO DO SOLO NA DIVERSIDADE DE
COMUNIDADES FITOPLANCTÔNICAS DE VEREDAS E RIACHOS /
João Paulo Francisco de Souza; orientador Fernanda Melo Carneiro. --
Anápolis, 2018.
37 p.

Mestrado - PPGSS Recursos Naturais do Cerrado -- Câmpus -
Anápolis CET. Universidade Estadual de Goiás, 2018.

1. Conservação. 2. Diversidade. 3. Veredas. 4. Riachos. 5. Structural
Equation Model - SEM. I. Melo Carneiro, Fernanda, orient. II. Título.

UNIVERSIDADE ESTADUAL DE GOIÁS
Pró Reitoria de pesquisa e Pós-Graduação
Câmpus Anápolis de Ciências Exatas e Tecnológicas – Henrique Santillo
Programa de Pós-Graduação *Stricto Sensu* em Recursos Naturais do
Cerrado

João Paulo Francisco de Souza

DIVERSIDADE FITOPLANCTÔNICA: O PAPEL DE MUDANÇAS NA
DINÂMICA DE USO EM VEREDAS E RIACHOS

Dissertação apresentada ao Programa de Pós-Graduação *stricto sensu* em Recursos Naturais do Cerrado da Universidade Estadual de Goiás como parte dos requisitos para a obtenção do título de Mestre em Recursos Naturais do Cerrado.

Dr^a Fernanda Melo Carneiro

Anápolis

2018

Aos que não sabem, nem querem.

Aos que me leem e me ajudam a nascer.

Aos que não ensinam, ordenam, comandam.

Àquel@s que me deixam encaixar e @s que não encaixam, se fazem encaixar.

Àquel@s que sangram, criam, lutam, choram, corrigem, simpatizam, entendem, nadam, se descobrem, se transformam, brilham, vivem.

A tod@s

Agradecimentos

À minha mãe, Elenice, que nunca mediu esforços para que eu chegasse onde estou (e nunca duvidou que eu conseguiria).

To my friend, Jane Lima, a friend from other lives, soul sister, my inspiration, the one that helped me in so many ways that without her it would be impossible to even start this journey. "You step too much gurl, please step less, I beg you". For you, I am eternally grateful.

À minha família por todo o suporte fornecido e por entenderem minhas ausências durante as confraternizações da família.

À minha parceira de graduação e pós-graduação, Ana Paula, pela amizade, parceria, troca de ideias e incentivo.

À minhas amigas, Mayara Stefany e Gabriela Caetano, que foram mais importantes nessa fase da minha formação que podem sequer imaginar.

Ao Fagner Junior Machado de Oliveira, Luciano Benedito Lima, Fernando Vieira Borges e Dilermando Pereira Lima Junior pela realização das coletas usadas nesse estudo.

Aos meus colegas do PPGSS-RENAC pelas parcerias e ótimos momentos juntos, só tenho a agradecer cada um(a) de vocês.

À Nina e aos Docentes do PPGSS-RENAC, sem os quais seria possível a existência desse programa.

Aos professores Anamaria Achtschin Ferreira e Patrick Thomaz de Aquino Martins pelo auxílio durante a extração das variáveis de uso de solo.

To my friends, Luke Maybury and Robert Crowe, for helping me with comments this work and reviewing the English when needed.

Ao pessoal, maravilhos@s, do PreparaTrans com quem tive a oportunidade de conviver e aprender.

À UEG por estar presente na maior parte da minha formação acadêmica e pela bolsa de Mestrado fornecida durante esses dois anos de estudos da pós-graduação.

Por último, mas longe de ser menos importante, agradeço a minha orientadora, Dr^a Fernanda Melo Carneiro, por quase uma década de orientação, ensinamentos, puxões de orelha e pela amizade construída durante esse período. A vocêserei eternamente grato.

“Let's dig! Otherwise she has to lie under that bullshit forever”.

Nai Cash

SUMÁRIO

Resumo	8
Abstract.....	9
Lista de figuras	10
Lista de tabelas	11
Lista de siglas e abreviações.....	12
Lista de símbolos	13
Introdução	14
Referências	15
Objetivos.....	19
Hipóteses	19
Phytoplankton diversity: direct and indirect role of shifts in land use across headwater streams and palm swamps	20
Abstract	20
Introduction	20
Materials and methods.....	22
<i>Study site</i>	<i>22</i>
<i>Sampling and identification of phytoplankton</i>	<i>23</i>
<i>Sampling of environmental and spatial data.....</i>	<i>24</i>
<i>Data analysis.....</i>	<i>25</i>
Results.....	28
Discussion	33
Conclusion	36
References.....	36
Considerações finais	40

Resumo

Compreender como as comunidades são distribuídas no espaço e tempo é um dos temas mais estudados em ecologia. Além disso, diante das intensas ações antropogênicas na natureza, é de interesse do ecólogo entender como as diferentes espécies respondem a esses distúrbios. Um dos principais impactos que está mudando a paisagem natural é o uso da terra para agricultura, pecuária e habitação. Os diferentes usos da terra afetam ecossistemas terrestres e aquáticos moldando esses habitats e a distribuição dos organismos nesses sistemas. Nosso objetivo principal foi testar se há relação entre o uso da terra, condições físico-químicas da água e variáveis espaciais e analisar como elas atuam sobre a diversidade taxonômica e funcional do fitoplâncton em riachos de cabeceira e de veredas. Nós hipotetizamos que (i) o uso da terra tem efeito direto e significativo sobre as características limnológicas; (ii) o uso da terra e as variáveis limnológicas são estruturadas espacialmente e (iii) somente as variáveis ambientais (uso da terra e limnológicas) atuam sobre os índices de biodiversidade sendo essas não estruturadas espacialmente. As amostragens foram realizadas em 41 habitats (rios de cabeceira e veredas) do bioma Cerrado durante a estação de seca de 2016 e 2017. Para estimar a diversidade taxonômica usamos riqueza de espécies, densidade, índice de Shannon-Wiener e biovolume. A riqueza funcional (FRic), dispersão funcional (FDis), uniformidade funcional (FEve) e a média ponderada dos traços da comunidade (CWM) foram utilizados para medir a diversidade funcional. Construímos um modelo de equação estrutural (SEM) para avaliar os efeitos diretos e indiretos nas variáveis abióticas (limnológicas, uso do solo e espaciais) e o efeito delas nas variáveis bióticas (índices de diversidade taxonômica e funcional). Entre as variáveis de uso da terra, apenas a mudança anual do uso da terra, foi selecionada no modelo, enquanto a condutividade foi a única selecionada entre as variáveis limnológicas. Em geral, o uso da terra foi estruturado espacialmente enquanto que o limnológico e o biológico não foram afetados diretamente pelo espaço, porém a diversidade foi indiretamente afetada pelo espaço por meio da mudança de uso do solo. Da mesma forma, o uso do solo também não teve impacto detectado nas variáveis limnológicas. O modelo de estruturado explicou a maior parte da variável taxonômica ($r^2_{\text{adj}} = 0,8$) e funcional ($r^2_{\text{adj}} = 0,78$). No entanto, a mudança de uso da terra representou a maior parte dessa variação deixando de lado as variáveis espaciais e limnológicas. Nossos resultados destacam a importância das variáveis de uso da terra, especialmente as mudanças no uso de um ano para outro, tenham repercussão na diversidade, afetando a diversidade taxonômica e funcional do fitoplâncton.

Palavras-chaves Conservação. Diversidade. Veredas. Riachos. Traços. SEM.

Abstract

Understanding how communities are distributed across space and time is one of the most studied subjects in ecology. Due to the intense anthropogenic actions on nature, it is crucial to understand how the different species respond to those anthropogenic doing. Land use is one of the main anthropogenic impact that is changing nature, which effects on both terrestrial and aquatic ecosystems. Our main goal was to test whether and how the land use, and physical and chemical conditions of the water respond to the spatial variables and verify how those acts upon phytoplankton taxonomic and functional diversity in headwater streams and palm swamps habitats. We hypothesize that (i) land use would have a direct and significant effect on the limnological features; (ii) that both land use and limnological variables would be spatially structured and also (iii) that only environmental variables (land use and limnological) would act upon the biodiversity indexes and that space would not demonstrate such effect. To test our hypothesis we sampled 41 habitats (headwater streams and palm swamps) from the Cerrado biome during the dry season in 2016 and 2017. To estimate the taxonomic diversity we used species richness, density, Shannon-Wiener index and biovolume. Functional richness (FRic), functional dispersion (FDis), functional evenness (FEve) and the community-weighted mean trait (CWM) were the components used to measure the functional diversity. We constructed a structural equation model (SEM) to evaluate the direct and indirect effects within abiotic variables (limnological, land use, and spatial) and the effect of them on the biotic variables (taxonomic and functional indexes). Among the land use variables, only land use change, through a timespan of one year, was selected in the model while conductivity was the only one selected among the limnological variables. In general, the land use was spatially structured while neither the limnological nor the biologic were affected directly by space, even though the biodiversity was indirectly affected by space through use change. Similarly, the land use also had no impact detected on the limnological variables. The structure model explained most of the taxonomic ($r^2_{adj} = 0.8$) and functional diversity ($r^2_{adj} = 0.78$). However, land use change accounted for most of that variation leaving aside the spatial and limnological variables. Our results highlight the importance that land use variables, especially the shifts in use from one year to another, have on the stream biota, affecting both taxonomic and functional diversity of phytoplankton.

Keywords Conservation. Diversity. Palm swamps. Headwaters. Traits. SEM.

Lista de figuras

Figure 1 - The sampled environments used in this study, headwaters (red) and palm swamps (blue), were collected in an upper section of the Rio das Mortes basin. This river is one of the most important tributaries of the Araguaia-Tocantins basin (green shape), which is one of the largest in the country.-----23

Figure 2 - Initial analytical basic model showing the tested relationships. Variables in circles represent latent variables. Observed variables corresponding to each latent variable are listed in Table 2. Arrows indicate hypothesized direction of causality. Dashed lines indicate paths expected to be non-significant.-----28

Figure 3 - Simple regression analysis of the main components of the taxonomic diversity measured. Response of the phytoplankton species richness (**A**); species density (**B**); Shannon (**C**) and biovolume (**D**) to the latest change in the drainage area above the sampling points. Biologic variables are log transformed.-----30

Figure 4 - Simple regression analysis of the main components of the functional diversity measured. Response of the phytoplankton Functional evenness - FEve (**A**); Functional richness - FRic (**B**); Functional Dispersion - FDis (**C**) and Community-weighted mean trait - CWM (**D**) to the latest change in the drainage area above the sampling points.-----31

Figure 5 - Structure equation modeling analysis indicating all tested paths. Variables in circles represent latent variables, observed variables are represented in squares. Numbers above the lines indicate standardized path coefficients (slope). Bold number next to the variables indicate the coefficients of determination (r_{adj}); for the biologic observed variables bold numbers mean its contribution for the latent variables. Observed variables not showing were not selected in the model. Dashed arrows are not significant at $p=0.05$; thin arrows $0.05 > p > 0.001$; thick arrows $p < 0.001$.-----32

Lista de tabelas

- Table 1 -Functional traits, sampled during the biological identification process or through the literature, that were used in the calculation of functional diversity.-----24
- Table 2 -Latent variables and observed variables that were sampled *insitu* (limnological and biological) or obtained through either geoprocessing or statistical methods (Space and Land use variables).-----26
- Table 3 -Characterization of headwater streams and palm swamps environments according to biologic variables (diversity indexes), environmental and land use parameters. Values in parentheses represent the standard deviation (sd). FRic (functional richness); FEve (functional uniformity); FDis (Functional Dispersion).-----29
- Table 4 -Total standardized effect (slope) of the land use and conductivity in the biological variables. For the total effect only significant relationships were considered. And overall determination coefficient (r^2_{adj}) for the different diversity measures. i = only indirect effects observed; d = only direct effect observed.-----33

Lista de siglas e abreviações

MT	= Mato Grosso
MDA	= Máxima dimensão axial
m	= Metro
km	= Quilômetro
cm	= Centímetro
S	= Riqueza
Dens	= Densidade
Biov	= Biovolume
H'	= Índice de diversidade de Shannon
PCoA	= Análise de Coordenadas principais
PCA	= Análise de Componentes principais
SEM	= Modelo de equação estruturada (<i>structuralequationmodelling</i>)
PCNM	= <i>Principal Coordinates of Neighborhood Matrix</i>
X ²	= qui quadrado
df	= Graus de liberdade
r ² _{adj}	= Coeficiente de determinação ajustado
CFI	= Índice de explicação comparada (<i>Comparativefit index</i>)
RMSEA	= <i>Root mean square error of approximation</i>
FRic	= Riqueza funcional
Feve	= Uniformidade funcional
FDis	= Dispersão funcional
CWM	= Média do traço ponderado pela densidade da comunidade
Cond	= Condutividade
Temp	= Temperatura
LRF	= Largura da mata ciliar
sd	= Desvio padrão
mm	= milímetros
mL	= mililitros
µL	= microlitros

Lista de símbolos

%
°C

Introdução

O bioma Cerrado apresenta uma malha hídrica que abriga nascentes de rios que dão origem ou alimentam as principais bacias hidrográficas do país (Moreira, Pott, Pott, & Damasceno-Junior, 2011). Os rios de cabeceiras (riachos) têm importante papel nesse contexto, pois constituem a maioria dos sistemas aquáticos e alimentam sistemas aquáticos de maior ordem (Thorp, Thoms, & DeLong, 2006; Wantzen, Siqueira, Cunha, & Pereira de Sá, 2006). As veredas, também atuam alimentando os rios do Cerrado (Ramos et al., 2006). Nesse sentido, rios de cabeceiras e veredas constituem o habitat permanente e temporário de inúmeros grupos de organismos (Brasil, Vieira, de Oliveira-Junior, Dias-Silva, & Juen, 2017; Costa-Milanez, Lourenço-Silva, Castro, Majer, & Ribeiro, 2014; Dunck, Nogueira, & Felisberto, 2013; Guimarães, Araújo, & Corrêa, 2002; Pacheco & Vasconcelos, 2012; Tubelis, 2009; Valente-Neto, Saito, Siqueira, & Fonseca-Gessner, 2016) constituindo ambientes muito importantes para a manutenção da biodiversidade das comunidades do Cerrado.

No entanto, a ação antropogênica tem provocado alterações significativas na dinâmica da biota e funcionamento dos ecossistemas (Matthews, Cottee-Jones, & Whittaker, 2014). Esses ecossistemas sofrem profundas alterações como resultado de perturbações resultantes da ação humana (Souza & Fernandes, 2009). Avaliar a diversidade de comunidades biológicas em ecossistemas sujeitos a distúrbios antrópicos é fundamental para elaborar estratégias de conservação e proteção de habitats (Magrini et al., 2011), pois a perda de biodiversidade tem sérias implicações, como a diminuição da resiliência, resistência a distúrbios, além da perda de integridade ecológica e serviços ecossistêmicos (Tschardt et al., 2005; Cardinale et al., 2012).

Uma das comunidades biológicas com papel fundamental no funcionamento dos ecossistemas é o fitoplâncton (Hébert et al., 2017). Esse grupo de organismos está presente em diferentes ambientes aquáticos, desde o marinho aos dulciaquícolas (Graham, 2009). O fitoplâncton abrange organismos microscópicos que vivem suspensos na coluna d'água de grande importância no funcionamento e produtividade dos ambientes aquáticos, devido sua posição chave nas cadeias tróficas aquáticas, como produtores primários, e na dinâmica de nutrientes (Keister et al., 2012; Jose et al., 2015). Além disso, são comumente usados como bioindicadores da qualidade ambiental (Abdul et al., 2016).

Geralmente o conhecimento sobre a biodiversidade para elaboração de estratégias de conservação é baseado na composição e riqueza de espécies (Batista et al., 2016). Entretanto,

pesquisas recentes em ecologia têm utilizado além de medidas tradicionais de diversidade, como riqueza e abundância, medidas de diversidade funcional (Katsiapi et al., 2012). Abordagens baseadas em traços funcionais são utilizadas para quantificar e prever os efeitos de mudanças ambientais sobre as comunidades biológicas (Mc Gill et al., 2006). Quantificar a diversidade funcional com base nos traços funcionais das espécies pode levar a melhores ligações entre dirigentes ambientais e composição das comunidades (Litchman & Klausmeier 2008). Essa premissa é suportada por meio do corpo crescente de estudos mostrando que traços mudam através de diferentes gradientes ambientais (Edwards, 2013).

Traços funcionais são características morfológicas, fisiológicas ou fenológicas mensuráveis, em nível de indivíduo, que afetam o desempenho das espécies no ecossistema, devido aos efeitos no seu crescimento, reprodução ou sobrevivência (Violle et al., 2007). Muitos traços funcionais de espécies aquáticas são utilizados para prever a resposta das comunidades biológicas e resiliência dos ecossistemas a diferentes variáveis ambientais ou perturbações antrópicas (Capoane et al., 2015). Diante da importância do fitoplâncton para as comunidades aquáticas e de traços funcionais. O objetivo do projeto é estudar se e como a comunidade fitoplanctônica se comporta, taxonomicamente e funcionalmente, em ambientes aquáticos sujeitos a diferentes níveis de impactos antrópicos (intensidade de uso do solo). Além de verificar a influência de variáveis ambientais nas métricas de diversidade da comunidade.

Referências

Abdul *et al.*, 2016. The effects of environmental parameters on zooplankton assemblages in tropical coastal estuary, South-west, Nigeria. *Egyptian Journal of Aquatic Research*, xxx, xxx–xxx.

Brasil, L. S., Vieira, T. B., de Oliveira-Junior, J. M. B., Dias-Silva, K., & Juen, L. (2017). Elements of metacommunity structure in Amazonian Zygoptera among streams under different spatial scales and environmental conditions. *Ecology and Evolution*, (February), 1–11. <http://doi.org/10.1002/ece3.2849>

Cardinale *et al.*, 2012. Biodiversity loss and its impact on humanity. *Nature*, 486: 59-67.

Capoane, Viviane & Tiecher, Tales & Schaefer, Gilmar & Ciotti, Lucas & dos Santos, Danilo. (2015). Transferência de nitrogênio e fósforo para águas superficiais em uma bacia hidrográfica

com agricultura e produção pecuária intensiva no Sul do Brasil. *Ciência Rural*. 45. 647-650. 10.1590/0103-8478cr20140738.

Costa-Milanez, C., Lourenço-Silva, G., Castro, P., Majer, J., & Ribeiro, S. (2014). Are ant assemblages of Brazilian veredas characterised by location or habitat type? *Brazilian Journal of Biology*, 74(1), 89–99. <http://doi.org/10.1590/1519-6984.17612>

Dunck, B., Nogueira, I. de S., & Felisberto, S. A. (2013). Distribution of periphytic algae in wetlands (Palm swamps, Cerrado), Brazil. *Brazilian Journal of Biology*, 73(2), 331–346. <http://doi.org/10.1590/S1519-69842013000200013>

Guimarães, A. J. M., Araújo, G. M. De, & Corrêa, G. F. (2002). Estrutura fitossociológica em área natural e antropizada de uma vereda em Uberlândia, MG. *Acta Botanica Brasilica*, 16(3), 317–329. <http://doi.org/10.1590/S0102-33062002000300007>

Hébert MP, Beisner, BE & Maranger, R, 2017. Linking zooplankton communities to ecosystem functioning: toward an effect-trait framework. *Journal of Plankton Research*, 39: 3–12.

Edwards KF, Litchman E, Klausmeier, CA, 2013. Functional traits explain phytoplankton community structure and seasonal dynamics in a marine ecosystem. *Ecology Letters*, 16: 56–63.

Graham L, Graham J & Wilcox L, 2009. *Algae*. San Francisco: Benjamin Cummings.

Gualdoni & Oberto, 2012. Estructura de la comunidad de macroinvertebrados del arroyo Achiras (Córdoba, Argentina): análisis previo a la construcción de una presa. *Iheringia*, 102:177-186.

Katsiapi *et al.*, 2012. Watershed land use types as drivers of freshwater phytoplankton structure. *Hydrobiologia*, 698:121–131.

Kobayashi *et al.*, 1998. Freshwater zooplankton in the Hawkesbury-Nepean River: comparison of community structure with other rivers. *Hydrobiologia*, 377: 133–145.

Litchman, E., de Tezanos Pinto, P., Klausmeier, C. A., Thomas, M. K., & Yoshiyama, K. (2010). Linking traits to species diversity and community structure in phytoplankton. *Hydrobiologia*, 653(1), 15–28. <http://doi.org/10.1007/s10750-010-0341-5>

Laliberté E & Legendre P, 2010. A distance-based framework for measuring functional diversity from multiple traits. *Ecology*, 91: 299-305.

Magrini, MJ, Freitas, AVL & Uehara-Prado, M. The effects of four types of anthropogenic disturbances on composition and abundance of terrestrial isopods (Isopoda: Oniscidea). *Zoologia*, 28: 63–71.

Magurran AE, 2004. *Measuring Biological Diversity*. EUA: Blackwell Science.

Moreira, S., Pott, A., Pott, V., & Damasceno-Junior, G. (2011). Structure of pond vegetation of a vereda in Brazilian Cerrado. *Rodriguésia*, 62(4), 721–729.

Matthews, T. J., Cottee-Jones, H. E., & Whittaker, R. J. (2014). Habitat fragmentation and the species-area relationship: A focus on total species richness obscures the impact of habitat loss on habitat specialists. *Diversity and Distributions*, 20(10), 1136–1146. <http://doi.org/10.1111/ddi.12227>

Nogueira et al., 2008. Diversidade (alfa, beta e gama) da comunidade fitoplanctônica de quatro lagos artificiais urbanos do município de Goiânia, GO. *Hoehnea*, 35: 219-233.

Pacheco, R., & Vasconcelos, H. L. (2012). Habitat diversity enhances ant diversity in a naturally heterogeneous Brazilian landscape. *Biodiversity and Conservation*, 21(3), 797–809. <http://doi.org/10.1007/s10531-011-0221-y>

Ramos, M., Curi, N., Motta, P., Vitorino, A., Ferreira, M., & Silva, Ma. (2006). Veredas do Triângulo mineiro: Solos, Água e Uso. *Ciênc. agrotec*, 30(2), 283–293.

Souza BDA & Fernandes, VO. 2009. Estrutura e dinâmica da comunidade fitoplanctônica e sua relação com as variáveis ambientais na lagoa Mãe-Bá, Estado do Espírito Santo, Brasil. *Acta Scientiarum. Biological Sciences*, 31: 245-253.

Thorp, J. H., Thoms, M. C., & Delong, M. D. (2006). The riverine ecosystem synthesis: Biocomplexity in river networks across space and time. *River Research and Applications*, 22(2), 123–147. <http://doi.org/10.1002/rra.901>

Tubelis, D. P. (2009). Veredas and their use by birds in the Cerrado, South America: a review. *Biota Neotropica*, 9(3), 363–374. <http://doi.org/10.1590/S1676-06032009000300031>

Tscharntke *et al.*, 2005. Landscape perspectives on agricultural intensification and biodiversity – ecosystem service management. *Ecology Letters*, 8: 857–874.

Valente-Neto, F., Saito, V. S., Siqueira, T., & Fonseca-Gessner, A. A. (2016). Evidence of species sorting driving aquatic beetles associated with woody debris in a transitional region between Cerrado and Atlantic Forest biomes. *Aquatic Ecology*, 50(2), 209–220. <http://doi.org/10.1007/s10452-016-9569-0>

Violle, C., M. L. Navas, D. Vile, E. Kasakou, C. Fortunel, I. Hummel & E. Garnier, 2007. Let the concept of trait be functional! *Oikos* 116: 882–892.

Wantzen, K. M., Siqueira, A., Cunha, C. N. da, & Pereira de Sá, M. de F. (2006). Stream-valley systems of the Brazilian Cerrado: impact assessment and conservation scheme. *Aquatic Conservation: Marine and Freshwater Ecosystems*, 16(7), 713–732. <http://doi.org/10.1002/aqc.807>

Objetivos

O artigo intitulado **“Phytoplankton diversity: direct and indirect role of shifts in land use across head water streams and palms wamps.”** possuem citações e referências formatadas de acordo com as normas da revista científica *“Hydrobiologia”*.

- Caracterizar os ambientes de veredas e riachos de cabeceiras de acordo com suas variáveis ambientais (limnológicas, morfométricas e de uso do solo) e biológicas (índices de diversidade taxonômica e funcional);
- Determinar através de modelos de equação estruturada as principais variáveis preditoras das diversidades taxonômica e funcional das comunidades fitoplanctônicas.

Hipóteses

H1: Atividades de uso de solo afeta as variáveis limnológicas e morfométricas, aumentando condutividade e fluxo, diminuindo oxigênio dissolvido e profundidade dos ambientes.

H2: Informações ambientais (uso de solo, limnológicas e morfométricas) são espacialmente estruturadas, com ambientes mais próximos apresentando caracteres similares quando comparados àqueles habitats mais distantes.

H3: As informações de uso da bacia a montante do local amostrado juntamente com as variáveis ambientais locais (limnológicas e morfométricas), atuam determinando a distribuição dos índices de diversidade taxonômica e funcional nos ambientes amostrados. Os índices de diversidade aumentam com o aumento da intensidade de uso do solo e a condutividade.

Phytoplankton diversity: direct and indirect role of shifts in land use across headwater streams and palm swamps

João Paulo Francisco de Souza* & Fernanda Melo Carneiro

*Programa de Pós-graduação em Recursos Naturais do Cerrado, Universidade Estadual de Goiás, Câmpus Henrique Santillo, Anápolis, Brasil. E-mail: souzajpf@gmail.com. Phone: +55 649 8405 5216.

Formatted according to the scientific journal *Hydrobiologia*

Abstract

Our main goal was to test whether and how the land use, and physical and chemical conditions of the water respond to the spatial variables and verify how those acts upon phytoplankton taxonomic and functional diversity in headwater streams and palm swamps habitats. To estimate the taxonomic diversity we used species richness, density, Shannon-Wiener index and biovolume. Functional richness (FRic), functional dispersion (FDis), functional evenness (FEve) and the community-weighted mean trait (CWM) were the components used to measure the functional diversity. We constructed structural equation models (SEM) to evaluate the direct and indirect effects within abiotic variables (limnological, land use, and spatial) and the effect of them on the biotic variables (taxonomic and functional indexes). In general, land use was spatially structured while neither the limnological nor the biological variables were affected spatially. Similarly, land use also had no impact detected on the limnological variables. The structure model explained most of the taxonomic ($r^2_{adj}= 0.8$) and functional diversity ($r^2_{adj}= 0.78$). However, land use change accounted for most of that variation leaving aside the spatial and limnological variables. Our results highlight the importance that land use variables, especially the shifts in use from one year to another, have on the stream biota, affecting both taxonomic and functional diversity of phytoplankton.

Keywords Conservation. Diversity. Palm swamps. Headwaters. Traits. SEM.

Introduction

Species distribution across different spatial and temporal scales is governed by numerous factors that affect and interact directly and indirectly throughout many possible pathways. Understanding how these factors work together shaping biodiversity distribution has been of interest of ecologists through time (Leibold et al., 2004). Among the investigated factors that act on biodiversity, anthropogenic activities, such as land use, have received much attention due to their direct influence in the carbon cycle and climate change (Matson et al., 1997). In addition, intense and unplanned land use leads to a loss of biological biodiversity and

important ecosystem services in both terrestrial and aquatic systems (Pimm & Raven, 2000). In the context of aquatic systems, land use leads to direct consequences for changing hydrological flow (e.g., use for irrigation, damming) and indirectly for the loss of water quality (e.g., nutrient and pollutant inflow) (Bennett et al., 2001; Houghton & Hackler, 2001; Schiesari & Grillitsch, 2011).

The land use has been impacted one of the most diverse biome in the World, the Cerrado, which has lost its natural area, mainly due to agriculture and livestock activities (Nepstad et al., 1997; Batlle-Bayer et al., 2010). These activities fragment, modify and destroy the terrestrial environment, besides affect indirectly limnological and biological composition in aquatic ecosystems (Leboulanger et al., 2011). Indeed, agricultural activities are associated with loss in riparian vegetation, increase in turbidity, conductivity, cyanobacteria density (Schiesari&Corrêa, 2016), nitrogen levels and changes in macroinvertebrate and fish communities (Maloney, 2011).

Ecosystem recovery from land use activities can take centuries, and these recovering ecosystems are compositionally and functionally different from undisturbed areas (Maloney et al., 2008). In streams, for example, woody debris and sediment can be centuries-old remnants of past catchment conditions (May & Gresswell, 2003; Walter & Merritts, 2008). Water chemistry recovers relatively faster than physical characteristics, but depending on how intense the disturbance is the effects on water quality may persist for decades (Swank et al., 2001). The effects of land use can also be observed in stream biological communities, because stream biota is strongly controlled by chemical and physical characteristics. Phytoplankton tends to respond rapidly to a degree of intensity of land use, especially indicating an increase in the productivity of environments under intense exploration, mainly due to the high input of nutrients through the intense use of land for agricultural purposes (Correll, 1998).

However, studies that evaluate land use effects in streams have examined only individual components of a stream and have only tested direct relationships (Burcher et al., 2007), leaving aside, for example, indirect effects in both biotic and within-stream variables. In addition, only certain aspects of biodiversity, related to richness and density, are analyzed (Borics et al., 2014). These more traditional ecological diversity indexes in ecology fails to account for functional information of the species (Tilman, 2001; Violle et al., 2007). To overcome these issues and look at the complex webs of relationships, both direct and indirect, incorporating functional information (e.g., traits), in this paper, we analyze how the stream environments respond, within the scope of their environmental variables, to the use of the soil.

In addition, we intend to verify if and how the functional and taxonomic diversity of phytoplankton respond to loss of natural areas in palm swamps and headwaters streams.

We expect that land use around the aquatic environment have an immediate impact on the limnological variables, as result of either increasing the input of dejects from human activities (e.g., Agrochemicals, sewage) or increasing inorganic matter (soil) that comes from land disturbances (Wantzen et. al., 2012). In addition, we expect that both land use and limnological variables respond to a spatial gradient (distance), which means that near sites would be under similar conditions of land use and would have similar limnological characteristics. As for the biological diversity indexes, we expect that they would not respond to the spatial gradient but would respond, in fact, to land use and limnological variables. Yet, we expect that the functional diversity indexes would be more suitable to monitoring the studied environments due to their better response to land use activities.

Materials and methods

Study site

The study area consists of 41 habitats (25 headwaters and 16 palm swamps) located in an upper section of the Rio das Mortes Basin in the state of Mato Grosso, Brazil. The sampling occurred during the dry season (June to August) from 2016 and 2017. The sampling area is in a drainage area that covers approximate 936.28 km² in the Cerrado biome. Agricultural and livestock activities are the predominant anthropic uses in this region (Fig.1).

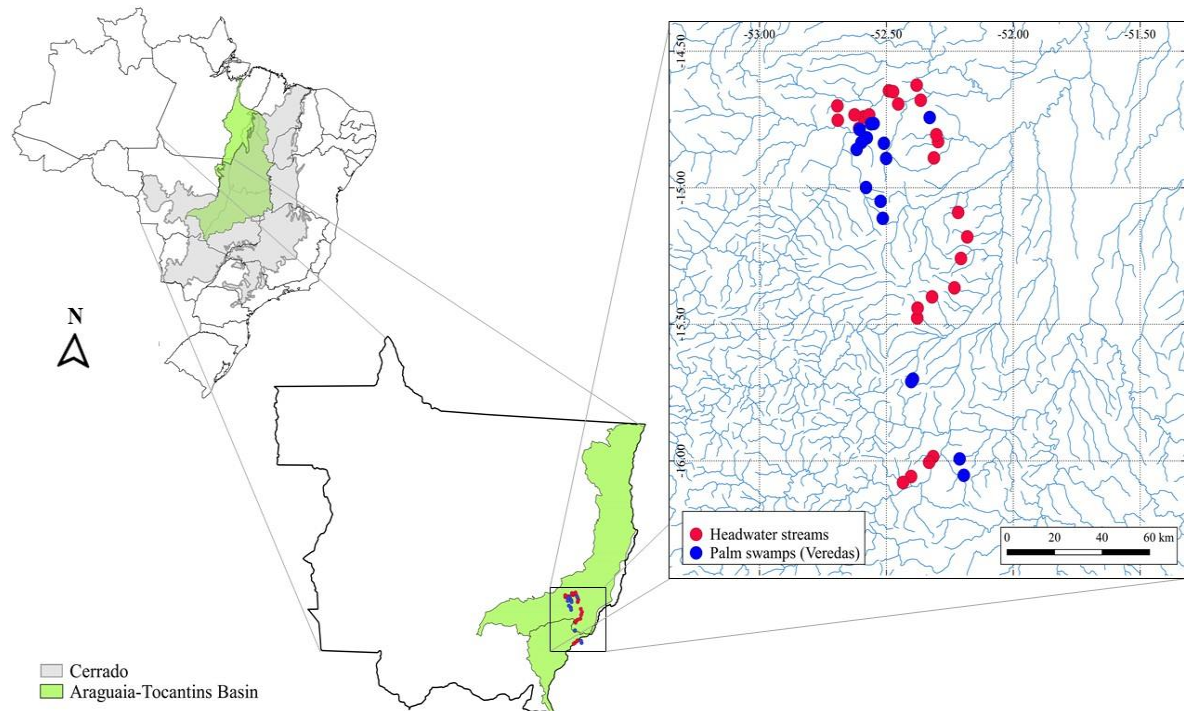


Figure 1 - The sampled environments used in this study, headwaters (red) and palm swamps (blue), were collected in an upper section of the Rio das Mortes basin. This river is one of the most important tributaries of the Araguaia-Tocantins basin (green shape), which is one of the largest in the country.

Sampling and identification of phytoplankton

The data of the phytoplankton community were obtained by collecting samples in the sub-surface in 100 ml amber flasks and fixed with acetic Lugol solution (Bicudo & Menezes, 2006). The species were then identified according to Utermöhl (1958) using sedimentation chambers ranging in volume from 2ml to 10ml. The species density was calculated using APHA (2005) and was expressed as individuals.mL⁻¹, and biovolume was calculated based on Hillebrand et al. (1999) and expressed as μm³.mL⁻¹. The algae from as many random fields were counted as necessary to stabilize the number of species. In other words, there was not more species added per field (e.g., species accumulation curve, species *versus* number of fields counted).

Phytoplankton identification was performed at the species level or at the lowest possible taxonomic level. During the process of identification of the community, functional traits were collected through bibliographic search. Specifically, for each species identified, the following functional traits were collected: the maximum axial length (MDA), body shape (unicellular, coenobium, colonial and filamentous), and the presence of morphological and physiological

specializations (toxins, aerotopes, heterocysts, flagella, mucilage, presence of silica, body extensions and nutrition) (Table 1).

Table 1 - Functional traits sampled during the biological identification process or through the literature used to calculate the functional diversity.

Traits	Scale	Ecological role		
		Reproduction	Resource acquisition	Avoidance
Biovolume	Continuous	x	x	x
Maximum axial length	Continuous	x	x	x
Body shape	Categorical (4 categories ¹)	x	x	x
Flagella	Binary (presence/absence)		x	x
Body extensions	Binary (presence/absence)		x	x
Mucilage	Binary (presence/absence)		x	x
Silica	Binary (presence/absence)		x	x
Heterocysts	Binary (presence/absence)		x	x
Aerotopes	Binary (presence/absence)		x	x
Toxin ²	Binary (presence/absence)		x	x
Nutrition	Binary ³	x	x	

¹Filamentous, unicellular, colonial, coenobium.

² As toxin we considered both metabolic products that avoid predation (e.g. cyanotoxins) and those that inhibits other species proliferation (e.g. allelopathy).

³Autotrophic (0), Mixotrophic (1).

Sampling of environmental and spatial data

The environmental variables were sampled *in situ* using a U-50 Horiba multiparameter probe. As for the source of land use/land cover data, we used the data from the years 2015, 2016 and 2017 that were generated from downloaded Sentinel 2 imagery from United States of America Geological Service (USGS). The images used were already with level 2 of processing (orthorectified and atmospheric correction). The drainage was obtained through the digital processing of Shuttle Radar Topography Mission (SRTM) images, obtained from the Ministério da Agricultura, Pecuária e Abastecimento.

To classify the images, we used Mahalanobis distance algorithm, a supervised method. This method has the property of minimizing the distance between the pixel and the class average, which is calculated based on the region of interest for each class (Meneses & Almeida, 2012). Mahalanobis is faster than other algorithms since it assumes that the variance in the classes are the same. To evaluate the state of the classification of the images we used the accuracy index (threshold of 95%), which measure how many pixels (%) have been corrected classified. Also we looked at the Kappa value (0,9572) that represents the quality of the classification (Landis & Koch, 1997). The imagery was processed using QGIS 2.18.13, and layer stacking, image subsetting, and land use/land cover classification were undertaken in

ENVI 5.0 software. Five land use classes were identified: agriculture, livestock, exposed soil, water, Cerrado vegetation.

Using the classified images, we were able to calculate four land use variables used in our analysis. (i) River basin area; (ii) remaining natural area, which represents the undisturbed area in the watershed upstream the sampled point; (iii) percentage of remaining natural area, which indicates how great the human impact is when compared to the complete drainage area, and (iv) the land use change, which represents the percentage of vegetation lost (or earned) throughout one year in the drainage area. We selected a one-year-period for detecting the vegetation change due to limitations in data (image), because the availability for sentinel-2 to make imagery classification is impossible for longer period. With geographic coordinate, we measured the distance among the sampled points, both directional distance (connection through watercourse) and non-directional (based on Euclidean distance – see below) (Dray et al., 2006).

Data analysis

For each sample, we calculated species richness (S), density (Dens), biovolume (Biov) and Shannon diversity index (1-D) using taxonomic classification. To calculate the functional diversity indexes we use all the 11 functional traits sampled (Table 1). First, with the traits matrix, we calculated a distance matrix between the points using the Gower distance, which is recommended for mixed data (e.g., quantitative, binary and qualitative) (Gower, 1971; Podani, 1999). Then, the distance matrix calculated was used to perform a Principal Coordination Analysis (PCoA), of which axes were used to calculate the functional richness (FRic), Functional Uniformity (Feve) and functional dispersion (FDis) indexes (Villéger et al., 2008; Laliberté & Legendre, 2010). All indexes were calculated using the software R (R Development Core Team, 2017) using the FD package (Laliberté & Legendre, 2010) and Picante (Webb et al., 2008).

Using the sampled traits, we also calculated the mean value of the Community-Weighted Mean trait (CWM), in which the density of the species weighted the presence of each trait where it is present (Garnier et al., 2004). CWM represents the functional composition of the community ("functional identity") (Laliberté & Legendre, 2010). Resulting in a matrix with 14 CWMs one for each trait, except for body organization that was decomposed into 4 (one for each type of organization). Then, these 14 CWMs were summarized in axis through a Principal Component Analysis (PCA), which were used as response variables. In all, 08 diversity indices

of which 06 are density based (Dens, Biov, 1-D, FEve, Fdis, CWM), and 02 are based on richness (S, Fric).

The spatial matrix consists of a Principal Coordinates of Neighborhood Matrix (PCNM) generated from the coordinates of the environments sampled, according to the methodology described in Dray et al. (2006). Spatial matrices of PCNM are suitable for investigating spatial structures in lotic environments (Blanchet et al., 2008). For this study were selected the vectors of PCNM through a forward selection analysis. The analyses were performed using software R (R Development Core Team, 2017).

We used structural equation models (SEM) to investigate links among independent factors (spatial variables, land use variables and limnological variables) and the dependent variable (biodiversity). Thus, we created latent variables based on the observed variables (Table 02). Structural equation models (SEMs) are multivariate regression models. However, unlike the more traditional multivariate linear models, the response variable in SEM regression may appear as a predictor in another equation (Menéndez et al., 2007). In addition, variables in a SEM may influence one another reciprocally, either directly or through other variables as intermediaries (Arhonditsis et al., 2006).

Table 2 - Latent variables and observed variables that were sampled *in situ* (limnological and biological) or obtained through either geoprocessing or statistical methods (Space and Land use variables).

Latent variable	Observed variable	Spatial scale	Details
Space	Directional distance	Basin	Distance among sampled points through watercourse.
	Non-directional distance	Basin	Euclidian distance among sampled points.
Land Use	Basin area (km ²)	Basin	Drained area above sampled point.
	Remaining natural area (km ²)	Basin	Remaining natural area in the drained area above the sampled point.
	Undisturbed area (%)	Basin	Undisturbed area in the drained area above the samples point. Calculated as: (Remaining natural area /Basin area).
	Landscape change (%)	Basin	Shift that occurred in the vegetation over one-year-period.
	Riparian forest (m ²)	Local	Amount of riparian forest that surrounds the sampled point.
Limnological	Depth (cm)	Local	Limnological variables from the sampled points.
	Dissolved oxygen (mg/L)	Local	

	Latent variable	Observed variable	Spatial scale	Details
		Conductivity (mS/cm)	Local	
		Flow (m/s)	Local	
		Temperature (°C)	Local	
		pH	Local	
		Width (m)	Local	
Biological	Taxonomic Diversity	Richness (S)	Local	Biologic variables measured for the sampled points. See text for more details.
		Density (ind/ml)	Local	
		Biovolume (µL)	Local	
	Functional Diversity	Shannon	Local	
		Functional Richness	Local	
		Functional Evenness	Local	
		Functional Dispersion	Local	
CWM	Local			

For analysis, we first built an initial analytical basic model based on our hypothesis (**Fig. 2**), where land use variables and limnological variables were used as intermediate latent variables, and the previously mentioned spatial variables (directional and non-directional) as independent latent variable. This initial model includes all potential links between the latent variables. We then considered a number of alternatives, testing nested models sharing the same causal structure as the basic model but eliminating some of the paths and variables that were not significant. To reject or accept a model we used the goodness of fit (chi-square: X^2) and two information criterion indexes: Comparative Fit Index (CFI; Garver & Mentzer, 1999) and Root Mean Square Error of Approximation (RMSEA; Steiger, 1990). The RMSEA is a population-based index that relies on the noncentral X^2 distribution, which is the distribution of the fitting function when the fit of the model is not perfect.

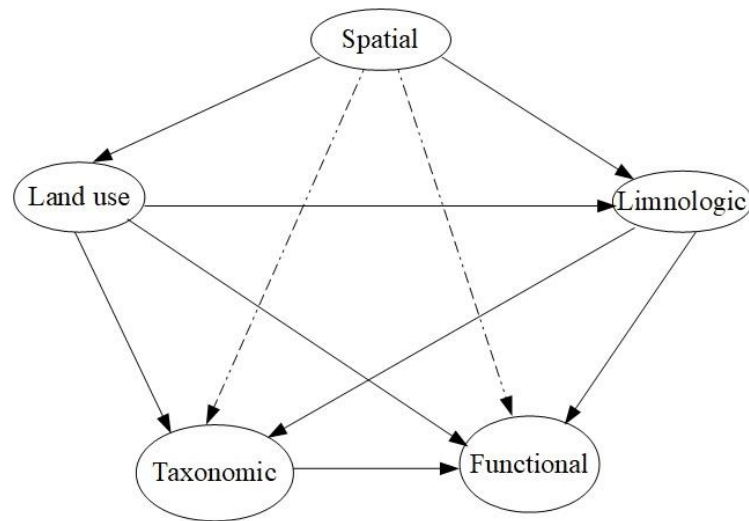


Figure 2- Initial analytical basic model showing the tested relationships. Variables in circles represent latent variables. Observed variables corresponding to each latent variable are listed in Table 2. Arrows indicate hypothesized direction of causality. Dashed lines indicate paths expected to be non-significant.

Results

The sampled sites are localized in a region which mainly land use activity consists in livestock (52.74%) followed by Cerrado vegetation (34.97%), exposed soil (10.76%), agriculture (1.40%) and water (0.12%). The sampled habitats are, in general, shallow and narrow with wide riparian vegetation (see Table 3). The limnological parameters are consistent with good water quality environments. We also found higher conductivity values in stream environments that presented slower flow, when compared to palm swamps environments. Palm swamps environments suffer less from anthropic actions when compared to headwater streams, which present less riparian forest and less remaining natural area (Table 3).

Regarding the biological variables, we identified 148 species, distributed in 13 classes. Among them, Bacillariophyceae, Chlorophyceae and Cyanophyceae were the most representative (45, 23 and 21 species respectively). On average, the environments presented low richness (~ 5 species.point⁻¹). The density and biovolume, although showed a low average in general, were higher in the streams when compared to the palm swamps (Table 03). In general, functional diversity indexes presented low values (<0.5), and only functional uniformity index (FEve) was higher.

Table 3 - Characterization of headwater streams and palm swamps environments according to biological variables (diversity indexes), environmental and land use parameters. Values in parentheses represent the standard deviation (sd). FRic (functional richness); FEve (functional uniformity); FDis (Functional Dispersion).

Variables	Headwaters (n=25)			Palm swamps (n=16)		
	Mean (sd)	Confidence interval (95%)		Mean (sd)	Confidence interval (95%)	
		Lower limit	Upper limit		Lower limit	Upper limit
Richness	6.16 (2.8)	2	12	4.88 (2.4)	1	10
Density (ind.mL ⁻¹)	97.9 (130.7)	8.2	529.3	44.5 (66.3)	2.4	274.1
Biovolume (μl)	49.3 (16.2)	4	75	49.3 (21)	0	70
Shannon (H)	1.42 (0.47)	0.6	2.1	0.98 (0.67)	0	2.2
FRic	0.09 (0.08)	0	0.24	0.11 (0.08)	0	0.22
FEve	0.65 (0.18)	0	0.91	0.77 (0.15)	0	0.99
FDis	0.31 (0.09)	0.07	0.41	0.26 (0.15)	0	0.43
Conductivity (mS/cm)	0.07 (0.2)	0.002	0.78	0.01 (0.01)	0.002	0.04
pH	5.8 (1)	3.4	8.6	4.83 (0.8)	3.3	6.3
Temperature (°C)	22.7 (2.1)	18	25.7	24.8 (2)	21.29	28.38
Depth (cm)	29.5 (17.5)	10.4	74.3	29 (15.7)	2.8	61.8
Flow (m/s)	11.3 (13.5)	2.4	70.18	12 (12.7)	0	56
Canal width (m)	4.3 (3.2)	1.5	18	9 (19.6)	0.75	80
Linear riparian forest (m)	31.4 (23.2)	2	100	50 (27.8)	10	100
Basin area (km ²)	32.14 (26.62)	5.56	106.59	8.30 (15.41)	0.08	61.62
Remaining natural area (km ²)	12.81 (11.73)	0.75	48.76	1.56 (3)	0.01	12.61
Proportion of undisturbed area	0.39 (0.13)	0.09	0.7	0.25 (0.18)	0.07	0.71
Latest use change (%)	0.97 (0.49)	-0.58	1.4	0.71 (0.64)	-0.68	1.26
Soil type	43% Latosols; 57% Neosols			17% Latosols; 83% Neosols		

The land use variables had a significant effect on both taxonomic and functional diversity. Regarding land use change, the land use accounts, significantly, for most of the variability of species richness ($r^2_{adj} = 0.68$; $p < 0,001$; **Fig. 3A**). The land use change also significantly explained the variability in Shannon diversity ($r^2_{adj} = 0.65$; $p < 0.001$; **Fig. 3C**) and Density ($r^2_{adj} = 0.50$; $p < 0.001$; **Fig. 3B**). The biovolume was the only variable not directly related to any land use tested ($r^2_{adj} = 0.084$; $p = 0.06$; **Fig. 3D**).

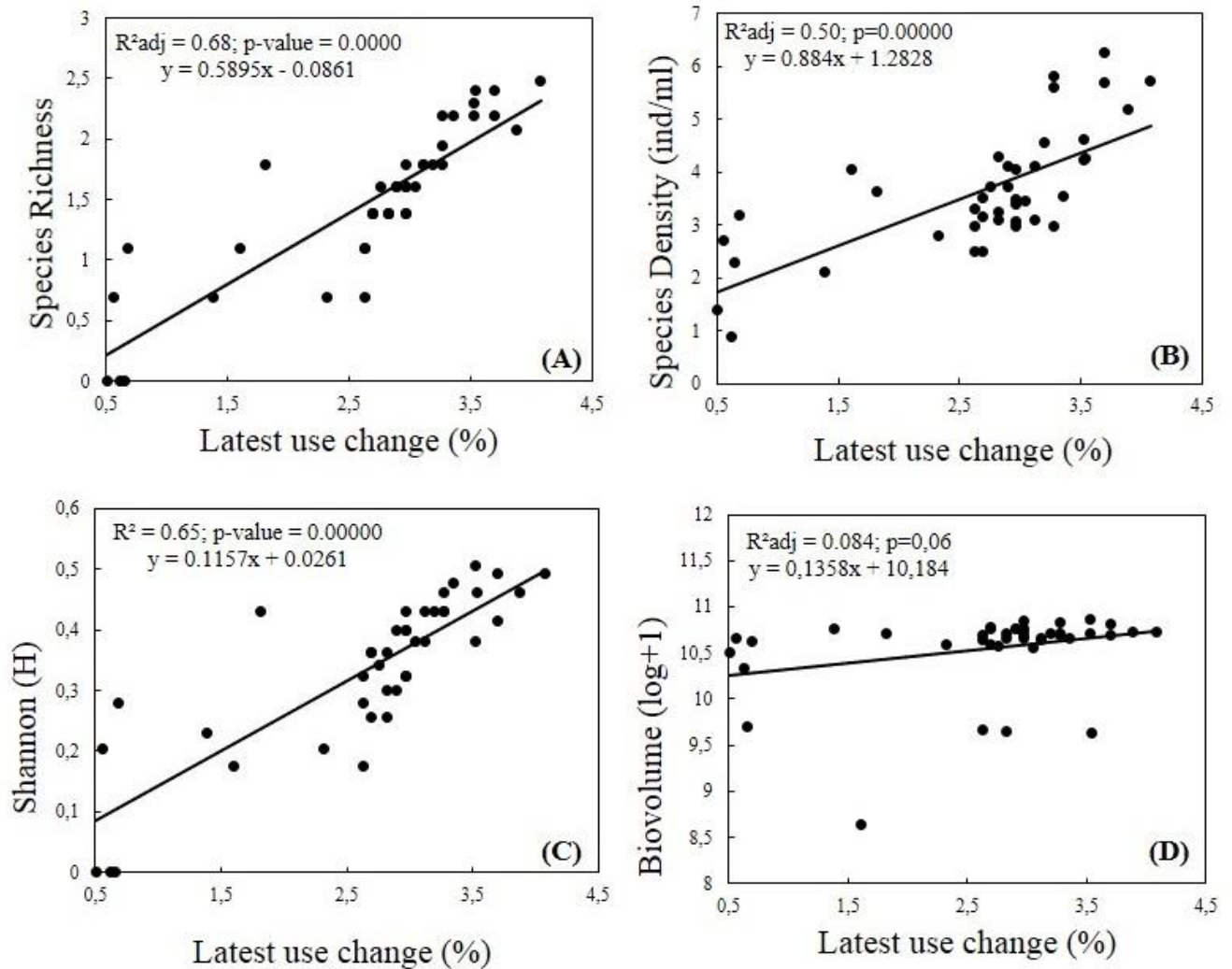


Figure 3 - Simple regression analysis of the main components of the taxonomic diversity measured. Response of the phytoplankton species richness (A); species density (B); Shannon (C) and biovolume (D) to the latest change in the drainage area above the sampling points. Biologic variables are log transformed.

The functional diversity indexes respond similarly to that relationship between taxonomic and land use change, however, the functional diversity showed slighter variation explained by that land use change. Functional dispersion (FDis) showed most of its variability explained by the use change ($r^2_{adj}=0.42$; $p\text{-value}=0.000$; **Fig.4C**), followed by Functional richness – Fric ($r^2_{adj}=0.39$; $p\text{-value}=0.000$; **Fig.4B**), Functional evenness - FEve ($r^2_{adj}=0.35$; $p\text{-value}=0.000$; **Fig.4A**).

The first two PCA axis with the CWM parameters together explained 43.07% of the variation of the community's traits. Some of the variables were positively related to the first axis (28.29%), such as unicellular body form, presence of silica and autotrophic nutrition. The first axis also was negatively related to colonial body form, presence of mucilage, aerotopes,

toxin and more body volume. This first axis was negatively related to the latest land use ($r^2_{\text{adj}}=0.14$; $p\text{-value}=0.01$; **Fig.4D**). Therefore, showing a reduction of traces such as unicellular body shape, silica use, small size and autotrophy along the intensity of soil use. In addition, along the gradient of use, there was a favoring of traits such as colonial body shape, mucilage, aerotopes, presence of toxin and a bigger body size.

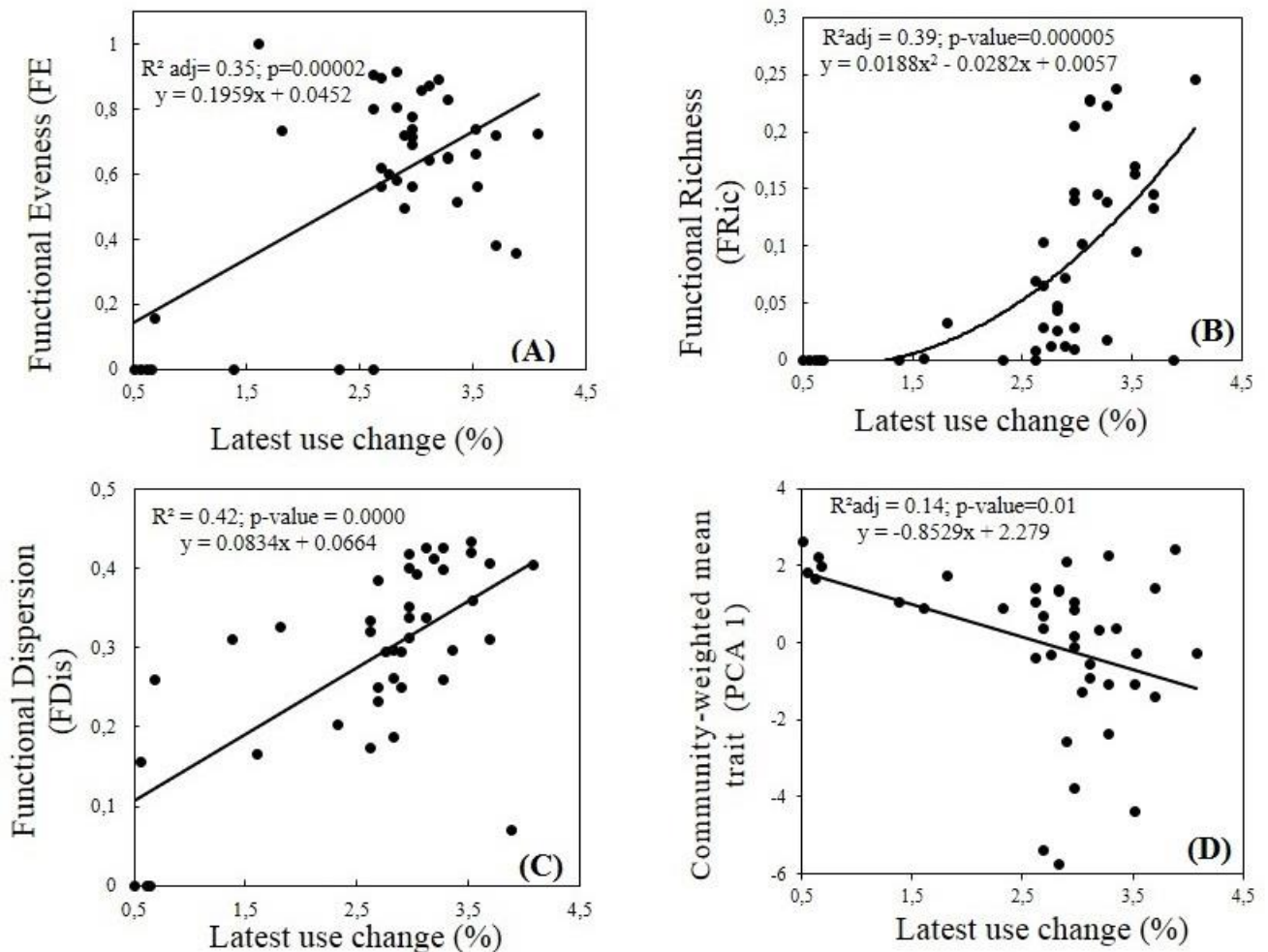


Figure 4 -Simple regression analysis of the main components of the functional diversity measured. Response of the phytoplankton Functional evenness - FEve (A); Functional richness – Fric (B); Functional Dispersion – Fdis (C) and Community-weighted mean trait - CWM (D) to the latest change in the drainage area above the sampling points.

Between the land use and limnological variables, only the use change, conductivity and non-directional distance were selected in the structured model; other variables did not show direct and indirect significant effect on the biological indexes. Among the functional indexes tested, CWM had a low not significant representation of the latent variable and, therefore, removed. Anthropogenic land use activities (use change) are directly associated with spatial

variable, closer watershed have similar use ($R_{adj}=0.44$; p -value= 0.001). However, limnological and biodiversity variables do not respond the same way (p values varying between 0.56 and 0.7) (Fig. 5). On the other hand, the landscape change has a significant direct effect on taxonomic diversity (p -value=0.0001) and indirect on functional diversity (Fig. 4). Among the limnological variables, only conductivity presented a direct effect on biodiversity (p -value=0.05).

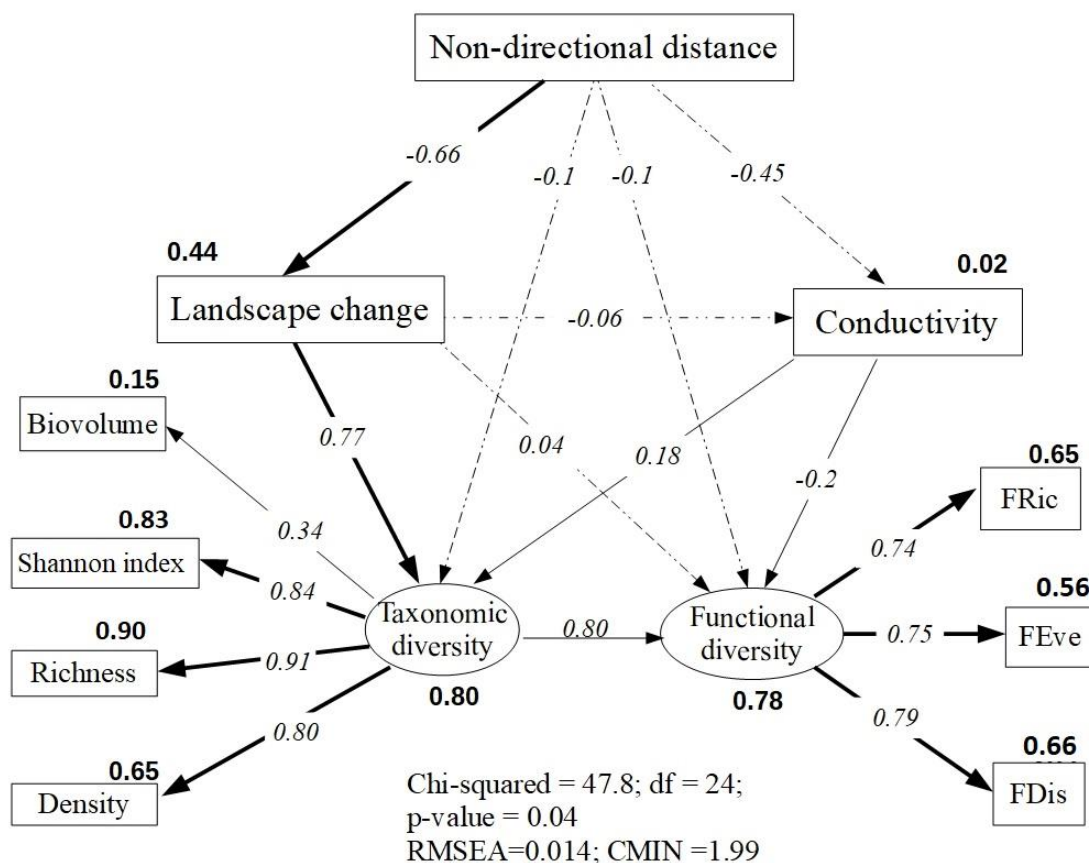


Figure 5 -Structure equation modeling analysis indicating all tested paths. Variables in circles represent latent variables, observed variables are represented by squares. Numbers above the lines indicate standardized path coefficients (slope). Bold number next to the variables indicate the coefficients of determination (r_{adj}^2); for the biologic observed variables bold numbers mean its contribution for the latent variables. Observed variables not showing were not selected in the model. Dashed arrows are not significant at $p=0.05$; thin arrows $0.05 > p > 0.001$; thick arrows $p < 0.001$.

The structural equation model (SEM) explained most of the taxonomic diversity ($r_{adj}^2=0.8$; p -value=0.04) and functional diversity ($r_{adj}^2=0.78$). Therefore, variables other than use change, explained a small fraction. Regard to the direct and indirect effects, we noticed that distance show a negative effect, in module, for taxonomic and functional diversity. On the other hand, conductivity showed low effect on the biodiversity, as is the case of functional

indexes. As for the land use we observed that an overall high effect over the biotic indexes (Table 4).

Table 4 - Total standardized effect (slope) of the land use and conductivity on the biological variables. For the total effect, only significant relationships were considered. And overall determination coefficient (r^2_{adj}) for the different diversity measures. i = only indirect effects observed; d = only direct effect observed.

	Space	Conductivity	Land use	Overall determination coefficient
Biovolume	-0.17 ⁱ	0.06 ^d	0.26 ^d	0.12
Shannon	-0.42 ⁱ	0.15 ^d	0.64 ^d	0.66
Richness	-0.46 ⁱ	0.16 ^d	0.7 ^d	0.72
Density	-0.4 ⁱ	0.14 ^d	0.61 ^d	0.52
Fric	-0.3 ⁱ	-0.04 ^{d i}	0.45 ⁱ	0.50
Feve	-0.3 ⁱ	-0.05 ^{d i}	0.46 ⁱ	0.51
Fdis	-0.32 ⁱ	-0.05 ^{d i}	0.48 ⁱ	0.43

I = indirect effect; d = direct effect

Discussion

Among the variables sampled only conductivity was selected as important for the biodiversity indexes. The same variable has been demonstrated as an important feature for aquatic organisms elsewhere (Borges et al., 2015; Maria et al., 2016). However, unlike what we expected, that land use would influence the limnological variables sampled, we have found no evidences of that in our analysis. Conductivity is thought to be greatly affected by the land use, especially in agricultural areas (Schiesari & Corrêa, 2016) and urban areas (Souto, Facure, Pavanin, & Jacobucci, 2011) being used then as an indirect measure of the concentration of pollutants in water surrounded by those uses. In our study area, however, the main anthropic use consists in livestock others limnological variables would demonstrate a better correlation with that use activity. Besides, limnological variables are the ones in aquatic habitats that first respond to land use but also they are the first ones to recover when the disturbance is ceased (Swank et al., 2001).

We expected that the conversion of natural vegetation to the different anthropogenic land use and patterns in limnological features would follow a spatial pattern. In other words that grouped sites would be under similar patterns of shifts in land use. For land use change we observed that a spatial gradient explains a good fraction of the use. Since land use disturbance is widespread not having natural boundaries such as watershed (Nepstad et al., 1997) barely respecting legal boundaries (Castelo, 2015), the use have been observed as a spatially structured

while the fragments (undisturbed vegetation) are not (Silva, Farinas, Felfili, & Klink, 2006). On the other hand, we could not find a spatial relationship for the limnological (conductivity) across the sampled sites.

Phytoplankton communities, considering both taxonomic and their functional diversity, were more similar among closer sites, because niche conditions play the main role in shaping phytoplankton, not because dispersal is favored among nearby communities (Huszar, Nabout, Appel, & Santos, 2015). Phytoplankton are microscopic organisms with a wide roll of dispersal strategies (see Santos, Silva, Branco, & Huszar, 2015). Although it is known that conductivity is mainly led by the entrance of ions coming from the adjacent terrestrial environment (Haase, Tonkin, Stoll, & Ja, 2016), we find no evidence that use change might influence that loading of ions, suggesting that riparian forest might play a role maintaining water characteristics (Vieira, Dias-Silva, & Pacífico, 2015).

Among the biotic variables tested (taxonomic diversity, functional diversity and CWM), we can observe that both the taxonomic and functional diversity metrics are associated with recent changes in the structure of the drainage basin upstream the collected points. In other words, recent changes (<1 year) alter the composition of the phytoplankton community by changing the composition of the community from both a taxonomic and functional point of view. This synchronized dynamic suggests that these metrics respond similarly to the impact that occurs when the environment favours multiple traits in different species (Weithoff et al., 2015).

The overall low observed taxonomic and functional indexes are normally related to oligotrophic habitats, such as the headwater streams and palm swamps, in these habitats the population of phytoplankton and its metrics are limited due to resource and niche limitation (Rose, Posa, Wijedasa, & Corlett, 2011). Thus, changes in the in the trophic state (enrichment) are estimated as the main factors to affect patterns in plankton community (Anneville, Dur, Rimet, & Souissi, 2017). However, even though, plankton might benefit taxonomically and functionally from enrichment in oligotrophic habitats, they are also the first ones to fade when that environment become eutrophic; mainly due to rises in competition rate among species performing similar ecologic role (Ang, Wezel, Vallod, & Oertli, 2014; Arthaud, Vallod, Robin, & Bornette, 2012).

The CWM (functional identity) showed how the traits varied along the gradient of land use. We can observe that the most undisturbed environments, naturally more protected against

the entry of allochthonous nutrients, presenting a smaller amount of available resources (Junk et al., 1989; Towsand, 1996); the presence of unicellular organisms of small volume, mixotrophic nutrition and using silica were the dominant species. These features are known to offer advantages for survival and establishment of species under such conditions. For example, single cell organisms have a higher surface-to-volume ratio when compared to other forms of body organization of the same size (e.g., filament, colony, and cenobium). This relationship has been observed as one of the main traits that are important for algae to get nutrients under resource limitation (Leonilde et al., 2017).

Under low environmental stress, autotrophic organisms are more successful, since with the low input of allochthonous organic matter (common in headwater streams), autotrophy gives advantage in providing independence from the adjacent terrestrial environment (Striebel, Behl, &Stibor, 2009). On the other hand, anthropogenic environments with greater input of nutrients mixotrophic nutrition becomes a trait that brings advantages to the survival and establishment of these organisms in the community (Litchman, de Tezanos Pinto, Klausmeier, Thomas, &Yoshiyama, 2010). Other traits that have also become present in environments with a greater recent impact (colonies, mucilage, aerotopes, toxins and higher volume) are traits that already provide advantages for environments that have a greater input of allochthonous nutrients and consequently more productive ones (Maria et al., 2017). In addition, these traits are characteristic of groups known to be good competitors/colonizers in high trophic conditions because they exhibit rapid growth, high lipoprotein, inhibition of herbivory (toxins) and competitors (allelopathy) (Weithoff&Gaedke, 2016). Organisms with these traits, mainly Cyanophyceae and Chlorophyceae, are known for high causing blooms in environments with a high anthropic state and with nutrient inputs (Carrick, 2011; Davis, Berry, Boyer, &Gobler, 2009)

Studies linking functional diversity with loss of ecosystemic services in disturbed environments exemplifies the importance of having such metrics beyond the taxonomic facet (Jurotich, Dougherty, Hayford, & Clark, 2017). In our study we observed that both taxonomic and functional diversity respond similarly to recent disturbances, similar results were found by Cardoso *et. al.* (2017) in Amazonian floodplain lakes. The low functional richness, as observed in this study, represents that the resources (niche) potentially available to the individuals in the community are not used in their entirety, which for aquatic environments reduces productivity (Petchey & Gaston, 2006). Low functional uniformity, also observed in this study for stream

environments, indicates that some parts of the available niche for the species are sub utilized (Mason & Mouillot, 2005).

Conclusion

In summary, limnological variables (conductivity) was not affected by neither use change nor the distance among the sampled habitats, unlike our expectations. Considering the distance we found that it affects the dynamic in use shifts across landscape, which confirm our expectations at this matter. We found that both use change and conductivity had a direct and indirect affect in diversity (taxonomic and functional). Distance also played an important role in shaping biodiversity by its influence in the land use change. Also, diversity indexes respond similarly to the anthropogenic actions except for the CWM, which tells how the traits in phytoplankton change across the habitats, going from single-cell-silicous-small organisms (Bacillariophyceae) in undisturbed areas to big colonies, mucilaginous and toxin products organisms (Chlorophyceae and Cyanophyceae) in disturbed areas.

References

- Ang, S., Wezel, A., Vallod, D., & Oertli, B. (2014). Is eutrophication really a major impairment for small waterbody biodiversity? *Journal of Applied Ecology*, 51, 415–425. <http://doi.org/10.1111/1365-2664.12201>.
- Anneville, O., Dur, G., Rimet, F., & Souissi, S. (2017). Plasticity in phytoplankton annual periodicity: an adaptation to long-term environmental changes. *Hydrobiologia*. <http://doi.org/10.1007/s10750-017-3412-z>.
- Arthaud, F., Vallod, D., Robin, J., & Bornette, G. (2012). Eutrophication and drought disturbance shape functional diversity and life-history traits of aquatic plants in shallow lakes. *Aquatic Sciences*, 74(3), 471–481. <http://doi.org/10.1007/s00027-011-0241-4>.
- American Public Health Association (APHA), 2005. Standard methods for the examination of water and wastewater. Byrd Prepress Springfield, Washington.
- Battle-Bayer, L., N. H. Batjes & P. S. Bindraban, 2010. Changes in organic carbon stocks upon land use conversion in the Brazilian Cerrado: A review. *Agriculture, Ecosystems and Environment* 137: 47–58.
- Castelo, thiago bandeira. (2015). Brazilian forestry legislation and to combat deforestation government policies in the amazon (brazilian amazon). *Ambiente & Sociedade*, 18(4), 221-242. <https://dx.doi.org/10.1590/1809-4422ASOC1216V1842015>
- Bennett, E. M., S. R. Carpenter & N. F. Caraco, 2001. Human Impact on Erodable Phosphorus and Eutrophication: A Global Perspective: Increasing accumulation of phosphorus in soil threatens rivers, lakes, and coastal oceans with eutrophication. *BioScience* 51: 227-234.

- BICUDO, C. E. M.; MENEZES, M. 2006. Gêneros de algas de águas continentais do Brasil. 2a ed. RiMa, São Carlos. 489 p.
- Borges, P. P., Thomaz, P., Teresa, F. B., & Nabout, J. C. (2015). Relative influence of direct and indirect environmental effects on sestonic chlorophyll- a concentration in Cerrado streams. *Acta Limnologica Brasiliensia*, 27(3), 301–310.
- Borics, G., J. Gorgényi, I. Grigorszki, Z. László-Nagy, B. Tóthmérész, E. Krasznai & G. Várbíró, 2014. The role of phytoplankton diversity metrics in shallow lake and river quality assessment. *Ecological Indicators* 45: 28–36.
- Burcher C.L., Valett H.M. & Benfield E.F. 2007. The land-cover cascade: relationships coupling land and water. *Ecology*, 88, 228–242.
- Cardoso, S. J., Nabout, J. C., Farjalla, V. F., Lopes, P. M., Bozelli, R. L., Huszar, V. L. M., & Roland, F. (2017). Environmental factors driving phytoplankton taxonomic and functional diversity in Amazonian floodplain lakes. *Hydrobiologia*. <http://doi.org/10.1007/s10750-017-3244-x>
- Carrick, H. J. (2011). Niche Modeling and Predictions of Algal Blooms in Aquatic Ecosystems. *Journal of Phycology*, 47(4), 709–713. <http://doi.org/10.1111/j.1529-8817.2011.01042.x>
- Correll, D. L, 1998. The Role of Phosphorus in the Eutrophication of Receiving Waters: A Review. *Journal of Environment Quality* 27: 261-266.
- Diaz, S. & Cabido, M, 2001. Vive la difference: plant functional diversity matters to ecosystem processes: plant functional diversity matters to ecosystem processes. *Trends in ecology and evolution* 16: 646–655.
- DRAY, S.; LEGENDRE, P.; PERES-NETO, P. R. 2006. Spatial modelling: a comprehensive framework for principal coordinate analysis of neighbour matrices (PCNM). *Ecological Modelling*, v. 196, n. 3–4, p. 483–493.
- Edwards, K. F., E. Litchman & C. A. Klausmeier, 2013. Functional traits explain phytoplankton community structure and seasonal dynamics in a marine ecosystem. *Ecology Letters* 16: 56–63.
- Gamfeldt, L., & Hillebrand, H. (2011). Effects of total resources, resource ratios, and species richness on algal productivity and evenness at both metacommunity and local scales. *PLoS ONE*, 6(7). <http://doi.org/10.1371/journal.pone.0021972>
- Garnier, E., Cortez, J., Bill S, G., Navas, M.-L., Roumet, C., Debussche, et al., 2004. Plant Functional Markers Capture Ecosystem Properties During Secondary Succession. *Ecology*, 85(9), 2630–2637. <http://doi.org/10.1890/03-0799>
- Garver, M. S. and Mentzer, J.T. 1999. Logistics research methods: Employing structural equation modeling to test for construct validity, *Journal of Business Logistics*, 20, 1, 33-57.
- Gower, J. C, 1971. A General Coefficient of Similarity and Some of Its Properties. *Biometrics* 27: 857-871.
- Haase, P., Tonkin, J. D., Stoll, S., & Ja, S. C. (2016). Elements of metacommunity structure of river and riparian assemblages: Communities, taxonomic groups and deconstructed trait groups, 25, 35–43. <http://doi.org/10.1016/j.ecocom.2015.12.002>
- Hillebrand, H., C. D. Durselen, D. Kirschtel, U, Pollinger & T, Zohary, 1999. Biovolume calculation for pelagic and benthic microalgae. *Journal of Phycology* 35: 403–424.

- Houghton, R. A. & J. L. Hackler, 2001. Carbon Flux to the Atmosphere from Land-Use Changes: 1850 to 1990. ORNL/CDIAC-131, NDP-050/R1
- Huszar, V. L. M., Nabout, J. C., Appel, M. O., & Santos, J. B. O. (2015). Environmental and not spatial processes (directional and non-directional) shape the phytoplankton composition and functional groups in a large subtropical river basin, 37, 1190–1200. <http://doi.org/10.1093/plankt/fbv084>
- Jurotich, M. M., Dougherty, K., Hayford, B., & Clark, S. (2017). Linking Taxonomic Diversity and Trophic Function: A Graph-Based Theoretical Approach. *Transactions of the Nebraska Academy of sciences*, 37(November), 47–53.
- Laliberté, E. & P, Legendre, 2010. A distance-based framework for measuring functional diversity from multiple traits. *Ecology* 91: 299–305.
- Landis, J.R.; Koch, G.G, 1977. The measurement of observer agreement for categorical data. *Biometrics*, 33(1):159-174.
- Leboulanger, C., M. Bouvy, C. Carré, P. Cecchic, L. Amalri, A. Bouchez, M. Pagano & G. Sarazin, 2011. Comparison of the effects of two herbicides and an insecticide on tropical freshwater plankton in microcosms. *Archives of Environmental Contamination and Toxicology* 61: 599–613.
- Leibold, M. A., Holyoak, M., Mouquet, N., Amarasekare, P., Chase, et al., 2004. The metacommunity concept: A framework for multi-scale community ecology. *EcologyLetters*, 7(7), 601–613. <http://doi.org/10.1111/j.1461-0248.2004.00608.x>
- Leonilde, R., Elena, L., Elena, S., Francesco, C., & Alberto, B. 2017. Individual trait variation in phytoplankton communities across multiple spatial scales. *Journal of Plankton Research*, 0, 1–12. <http://doi.org/10.1093/plankt/fbx001>
- Litchman, E., de Tezanos Pinto, P., Klausmeier, C. A., Thomas, M. K., &Yoshiyama, K. (2010). Linking traits to species diversity and community structure in phytoplankton. *Hydrobiologia*, 653(1), 15–28. <http://doi.org/10.1007/s10750-010-0341-5>
- Maloney, K. O., & Weller, D. E. 2011. Anthropogenic disturbance and streams : land use and land-use change affect stream ecosystems via multiple pathways. *Freshwater Biology*, 56(3), 611–626. <http://doi.org/10.1111/j.1365-2427.2010.02522.x>
- Maloney K.O., Garten C.T. & Ashwood T.L., 2008. Changes in soil properties following 55 years of secondary forest succession at Fort Benning, Georgia, USA. *Restoration Ecology*, 16, 503–510.
- Maria, L., Guntram, S., & Carla, W., 2017. Seasonal and spatial functional shifts in phytoplankton communities of five tropical reservoirs. *AquaticEcology*. <http://doi.org/10.1007/s10452-017-9634-3>
- Maria, S., Oliveira, L. De, Machado, K. B., Carneiro, F. M., Ferreira, M. E., Carvalho, P., ... Nabout, J. C. (2016). Environmental factors affecting chlorophyll- a concentration in tropical floodplain lakes, Central Brazil. *Environmental Monitoring and Assessment*. <http://doi.org/10.1007/s10661-016-5622-7>
- Mason, N. W. H. & D. Mouillot, 2005. Functional richness, functional evenness and functional divergence: The primary components of functional diversity the primary components of functional diversity. *Oikos* 111: 112–118.

- Matson, P. A., W. J. Parton, A. G. Power & M. J. Swift, 1997. Agricultural intensification and ecosystem properties. *Science* 277: 504-509.
- May C.L. & Gresswell R.E., 2003. Processes and rates of sediment and wood accumulation in headwater streams of the Oregon Coast Range, USA. *Earth Surface Processes and Landforms*, 28, 409–424.
- Menéndez, R., González-megias, A., Collingham, Y., Fox, R., Roy, D., Ohlemuller, R., & Thomas, C., 2007. Direct and indirect effects of climate and habitat factors on butterfly diversity. *Ecology*, 88(3), 605–611.
- Meneses, P. R.; Almeida, T, 2012. Aritmética de bandas. in: *Introdução ao processamento de imagens de sensoriamento remoto*. universidade de Brasília.
- Nepstad, D. C., C. A. Klink, C. Uhl, Í. C. Vieira, P. Lefebvre, M. Pedlowski, E. Matricardi, G. Negreiros, I. F. Brown, E. Amaral, A. Homma & R. Walker, 1997. Land-use in Amazonia and the Cerrado of Brazil. *Environmental impact* 49: 73–86.
- Petchey, O. L. & K. J. Gaston, K. J, 2002. Functional diversity (FD), species richness and community composition. *Ecology Letters* 5: 402–411.
- Pimm, S. L. & P. Raven, 2000. Extinction by numbers. *Nature* 403: 843-845.
- Podani, J, 1999. Extending Gower's General Coefficient of Similarity to Ordinal Characters. *Taxon* 48: 331-340.
- R Core Team, 2017. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Austria. [disponível em: URL <https://www.R-project.org/>].
- Rose, M., Posa, C., Wijedasa, L. S., & Corlett, R. T. (2011). Biodiversity and Conservation of Tropical Peat Swamp Forests. *BioScience*, 61(49), 49–57. <http://doi.org/10.1525/bio.2011.61.1.10>
- Santos, J. B. O., Silva, L. H. S., Branco, C. W. C., & Huszar, V. L. M. (2015). The roles of environmental conditions and geographical distances on the species turnover of the whole phytoplankton and zooplankton communities and their subsets in tropical reservoirs. *Hydrobiologia*. <http://doi.org/10.1007/s10750-015-2296-z>
- Schiesari, L. & D. T. Corrêa, 2016. Consequences of agroindustrial sugarcane production to freshwater biodiversity. *GCB Bioenergy* 8: 644–657.
- Silva, J. F., Farinas, M. R., Felfili, J. M., & Klink, C. A. (2006). Spatial heterogeneity, land use and conservation in the cerrado region of Brazil. *Journal of Biogeography*, 33, 536–548. <http://doi.org/10.1111/j.1365-2699.2005.01422.x>
- Souto, R. de M. G., Facure, K. G., Pavanin, L. A., & Jacobucci, G. B. (2011). Influence of environmental factors on benthic macroinvertebrate communities of urban streams in Vereda habitats, Central Brazil. *Acta Limnologica Brasiliensia*, 23(3), 293–306. <http://doi.org/10.1590/S2179-975X2012005000008>
- Steiger, J. H. Structural model evaluation and modification: an interval estimation approach, *Multivariate Behavioral Research*, 25, 1990, pp. 173-180
- Striebel, M., Behl, S., & Stibor, H. (2009). The coupling of biodiversity and productivity in phytoplankton communities: Consequences for biomass stoichiometry. *Ecology*, 90(8), 2025–2031. <http://doi.org/10.1890/08-1409.1>

- Swank W.T., Vose J.M. & Elliott K.J. 2001. Long-term hydrologic and water quality responses following commercial clearcutting of mixed hardwoods on a southern Appalachian catchment. *Forest Ecology and Management*, 143, 163–178.
- Tilman, D, 2001. Functional diversity. *Encyclopedia of Biodiversity* 3: 109–120.
- Utermöhl, H, 1958. Zur Vervollkommnung der quantitativen phytoplankton-methodic. *Mitteilungen der Internationalen Vereinigung für Limnologie* 9: 1-38.
- Vieira, T. B., K. Dias-Silva, K & E. S. Pacífico, 2015. Effects of riparian vegetation integrity on fish and heteroptera communities. *Applied Ecology and Environmental Research* 13: 85–97.
- Villéger, S., N. W. H. Mason, D. Mouillot, 2008. New multidimensional functional diversity indices for a multifaceted framework in functional ecology. *Ecology* 89: 2290–2301.
- Violle, C., M. L. Navas, D. Vile, E. Kasakou, C. Fortunel, I. Hummel & E. Garnier, 2007. Let the concept of trait be functional! *Oikos* 116: 882–892.
- Walter R.C. & Merritts D.J. (2008) Natural streams and the legacy of water-powered mills. *Science*, 319, 299–304.
- Wantzen, K. M., E. G. Couto, E. E. Mund, R. S. S. Amorim, A. Siqueira, K. Tielborger & M. Seifan, 2012. Agriculture, Ecosystems and Environment Soil carbon stocks in stream-valley-ecosystems in the Brazilian Cerrado agroscape. *Agriculture, Ecosystems and Environment* 151: 70–79.
- Webb, C. O., D. D. Ackerly & S. W. Kembel, 2008. Phylocom: Software for the analysis of phylogenetic community structure and trait evolution. *Bioinformatics* 24: 2098–2100.
- Weithoff, G., M. R. Rocha, U. Gaedke, 2015. Comparing seasonal dynamics of functional and taxonomic diversity reveals the driving forces underlying phytoplankton community structure. *Freshwater Biology* 60 758–767.

Considerações finais

Nesse estudo, sobre o efeito do uso do solo tanto nos caracteres limnológicos quanto biológicos, encontramos que as variáveis limnológicas (condutividade) não foram significativamente afetadas pela mudança de uso nem pela distância entre os habitats amostrados, ao contrário de nossas expectativas iniciais. Por outro lado, confirmamos que a mudança no uso e a condutividade teve efeito direto e indireto na diversidade (taxonômica e funcional). A distância também desempenhou um papel importante, indiretamente, na formação da biodiversidade por sua influência da dinâmica do uso do solo. Com esses resultados suportamos a ideia de que o estado de uso da paisagem nas adjacências dos ambientes aquáticos é um importante fator para o entendimento da dinâmica interna desses sistemas, atuando direta e indiretamente na comunidade fitoplânctonica.