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Universidade Federal de Minas Gerais
Instituto de Ciências Biológicas
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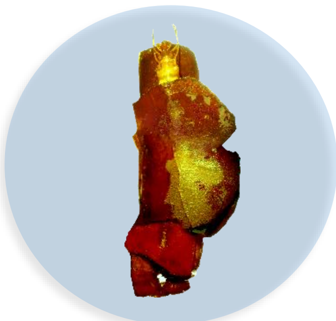
e Manejo de Vida Silvestre

Tese de Doutorado

RELAÇÕES DE HABITATS FÍSICOS, PARÂMETROS FÍSICOS E QUÍMICOS DA ÁGUA COM RIQUEZA, DISTRIBUIÇÃO E CONTEÚDO ALIMENTAR DE MACROINVERTEBRADOS BENTÔNICOS EM RIACHOS DE CABECEIRA NO CERRADO



WANDER RIBEIRO FERREIRA

Belo Horizonte, agosto de 2013

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Relações de fatores ambientais de habitats físicos com riqueza, distribuição e conteúdo alimentar de macroinvertebrados bentônicos em riachos de cabeceira no Cerrado

Tese apresentada ao Programa de Pós-Graduação em Ecologia, Conservação e Manejo de Vida Silvestre do Instituto de Ciências Biológicas da Universidade Federal de Minas Gerais, como requisito parcial para obtenção do título de Doutor em Ecologia.

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Dedico esta tese aos meus pais, irmãos, parentes, amigos e em especial à Elaine, minha esposa e companheira.

Ciência e sabedoria são coisas muito diferentes. Ciência é conhecimento do mundo. Sabedoria é degustação do mundo. A ciência se faz com os olhos. A sabedoria, com a boca.

Rubem Alves

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Resumo

Os ecossistemas lóticos são heterogêneos e complexos. As condições físicas variam da nascente à foz, incluindo características da largura, profundidade, declividade, velocidade de fluxo, temperatura e energia. Estas variações e dinâmica de nutrientes contribuem para determinar a composição funcional e distribuição de macroinvertebrados. Os objetivos desta tese foram avaliar o quanto as variáveis ambientais de habitats físicos explicam (i) a riqueza e distribuição de Ephemeroptera, Plecoptera e Trichoptera (EPT) e (ii) os itens alimentares encontrados no conteúdo estomacal de larvas de *Phylloicus* (Plecoptera: Calamoceratidae). Foram amostradas comunidades de macroinvertebrados bentônicos, quantificados os habitat físicos e mensurados parâmetros físicos e químicos de qualidade de água em 80 sítios amostrais selecionados aleatoriamente em duas bacias hidrográficas no Cerrado (alto rio Araguari e alto rio São Francisco), sudeste do Brasil. Métricas de habitats como largura do leito sazonal, porcentagem de seixos, proporção de abrigos, declividade, porcentagem de trechos com fluxo lento, largura média da área molhada e oxigênio dissolvido foram selecionadas por modelos de regressão múltipla (MLR) e contribuíram significativamente para explicar a riqueza de EPT em ambas as bacias. Métricas de habitats físicos foram mais importantes do que parâmetros de qualidade de água na estruturação de gêneros de EPT nas duas bacias. Foi estudada a dieta de *Phylloicus* considerando cinco instares e seis categorias de itens alimentares no trato digestivo (CPOM - partículas grossas de matéria orgânica, FPOM - partículas finas de matéria orgânica, algas, tecido animal, tecido vegetal e material mineral). Foi evidenciado, dentre nossas análises estatísticas, que CPOM no conteúdo foi maior nas das larvas de *Phylloicus* nos riachos na bacia do alto São Francisco e este variou entre os riachos e entre os instares nas duas bacias; FPOM foi maior nas larvas nos riachos na bacia do alto rio Araguari e variou entre riachos e entre instares nas duas bacias; material mineral foi maior no conteúdo das larvas nos riachos na bacia alto rio Araguari e variou entre riachos nas duas bacias. As principais métricas de habitats físicos relacionadas aos itens alimentares foram largura média do leito sazonal, largura média x profundidade, porcentagem de matéria orgânica total, cobertura ripária e presença de abrigo como pedaços de madeira grande. As larvas de *Phylloicus* apresentaram diferentes estratégias de alimentação nas duas bacias. Esta tese evidenciou a importância dos habitats físicos na distribuição da riqueza de EPT e as relações dos habitats com o conteúdo do trato digestivo de larvas de *Phylloicus*. Os resultados desta tese contribuem com informações das influências de habitats físicos para estruturação de comunidades de macroinvertebrados bentônicos e grupos tróficos funcionais em ecossistemas aquáticos.

Palavras-chave: bacia hidrográfica, EPT, itens alimentares, matéria orgânica particulada grossa, matéria orgânica particulada fina, *Phylloicus*.

ABSTRACT

Stream ecosystems are heterogeneous and complex. The physical conditions vary from headwater to mouth, including characteristics of width, depth, slope, flow velocity, temperature and energy. These variations and nutrient dynamics contribute to determine the functional composition and distribution of macroinvertebrates. The objectives of this thesis were to assess how environmental variables of physical habitats explain (i) the richness and distribution of Ephemeroptera, Plecoptera and Trichoptera (EPT) and (ii) the food items found in the stomach contents of larvae of *Phylloicus* (Plecoptera: Calamoceratidae). We sampled benthic macroinvertebrates cummunities, quantified physical habitats an measured physicochemical variables of water quality in 80 randomly selected sampling sites in two watersheds in the Cerrado (Upper Araguari River Basin and Upper São Francisco River Basin), southeastern Brazil. Habitat metrics bankfull width, percentage of pebbles, proportion of shelters, slope, percentage of slow flow, wetted area width and dissolved oxygen were selected by multiple regression models (MLR) and contributed significantly to explain the EPT richness in both basins. Physical habitats metrics were more important than water quality variables in the structuring EPT genera in the two basins. We studied the diet of *Phylloicus* considering five instars and six categories of food items in the gut content (CPOM - coarse particulate organic matter, FPOM - fine particulate organic matter, algae, animal tissue, plant tissue and mineral material). We showed through our statistical analyses that CPOM content was higher in the *Phylloicus* larvae of streams of Upper São Francisco River Basin, and it varied between streams and between instars larval in the two basins. FPOM was higher in the larvae of streams of Upper Araguari River Basin and varied between streams in the two basins; mineral material content was higher in the larvae of streams of upper Araguari and varied between streams in the two basins. The main physical habitat metrics related to food items were mean bankfull width, mean width x depth, percentage of total organic matter, riparian cover and shelter as the presence of large wood debris. *Phylloicus* larvae showed different feeding strategies in the two basins. This thesis showed the importance of physical habitats in the distribution of EPT richness and relations of habitats with the gut contents of *Phylloicus* larvae. The results of this thesis contribute with information regarding the influences of physical habitat for structuring benthic macroinvertebrate communities and functional trophic groups in aquatic ecosystems.

Key-words: watershed, EPT, gut contents, coarse particulate organic matter, fine particulate organic matter, *Phylloicus*.

INTRODUÇÃO

Ecossistemas lóticos, habitats físicos e macroinvertebrados bentônicos

Os ecossistemas lóticos são heterogêneos e complexos e apresentam condições físicas que variam da nascente à foz, incluindo largura, profundidade, declividade, velocidade de fluxo, temperatura e energia (Vannote et al. 1980; Covich et al. 1999; Kovalenko et al. 2012). Os diferentes rios e a organização de seus componentes estruturais de habitats físicos (ex. tipos de substratos, largura, profundidade, declividade), que caracterizam os tipos de fluxos lentos e rápidos, são determinadas pelas características geomorfológicas e clima nas distintas latitudes e biomas por onde percorrem (Allan & Castillo 2007).

O conceito de continuo fluvial (RCC) proposto por Vannote et al. (1980) postulam que as variações nas características estruturais dos habitats físicos e a dinâmica de nutrientes são fatores que contribuem para determinar a composição funcional e distribuição da biota aquática. Desta forma, os macroinvertebrados são distribuídos de acordo a disponibilidade de recursos alimentares e habitats necessários ao seu estabelecimento ao longo de um rio. Os macroinvertebrados tendem a se distribuir funcionalmente de forma a obter o melhor aproveitamento dos recursos alimentares, como por exemplo a matéria orgânica particulada grossa (MOPG) e fina (MOPF) disponível ao longo do rio.

Estudos têm mostrado que além da distribuição funcional, a riqueza e abundância de macroinvertebrados bentônicos são influenciados pela complexidade estrutural e heterogeneidade dos habitats (Garcia et al. 2012). A a variedade de substratos, variação hidráulica e regime de fluxo por proveem uma ampla variedade de condições físicas (Statzner & Higler 1986; Hughes et al. 2010; Ligeiro et al. 2012;

Kovalenko et al. 2012; Kaufmann & Faustini 2012). Assim, os macroinvertebrados bentônicos são os organismos indicados para avaliar as mudanças nos habitats (Maddock 1999; Bonada et al. 2006; Dohet et al. 2008) porque exibem preferencias hidráulicas (fluxos lentos e rápidos) e são encontrados de forma exclusiva em habitats físicos específicos, por exemplo em corredeiras e poças (Silveira et al. 2006; Mérigoux et al. 2009).

Os ecossistemas tropicais possuem rica biodiversidade (Dudgeon, 2000). Entretanto, os rios tropicais estão entre os ecossistemas mais ameaçados do mundo (Dudgeon et al. 2006). Nestes, a perda de diversidade de organismos bentônicos ocorre em um ritmo alarmante (Allan & Castillo 2007). As principais ameaças são: poluição da água, alterações nas características físicas e químicas, modificação de fluxos, degradação de hábitats (Dudgeon et al. 2006).

As variáveis físicas e químicas, independentemente dos habitats físicos, também são fatores estruturadores da biota aquática (Jowett 1997). A poluição da água e degradação de hábitats são marcantes, principalmente em áreas urbanas e industriais (Klein 1979; Rosenberg & Resh 1993; Souza & Tundisi 2003; Moreno & Callisto 2006; Ferreira et al. 2011). O crescimento populacional desordenado, a industrialização nas cidades e as atividades de agricultura e pecuária na transformação de áreas naturais, aumentam a pressão antrópica sobre os ecossistemas aquáticos (Diniz-Filho et al. 2009). Diariamente são lançados nos rios e córregos, esgotos domésticos, pesticidas e efluentes industriais sem tratamento adequado alterando a química da água e diminuindo drasticamente a integridade ecológica nesses ecossistemas (Ferreira et al. 2011). Como resultado, observa-se a morte dos organismos sensíveis e a simplificação das comunidades de macroinvertebrados bentônicos (Chapman & Chapman 2002;

Moreno & Callisto 2006; Feio et al. 20013) e são os principais problemas que têm afetado a qualidade dos corpos d'água no Brasil.

Papel funcional de macroinvertebrados bentônicos

Os invertebrados aquáticos são predominantes na estrutura trófica de riachos e o conhecimento de seu papel funcional é fundamental para o entendimento do funcionamento desses ecossistemas, incluindo o processamento da matéria orgânica (Motta & Uieda 2004; Cummins et al. 2005). Além disso fornecem importantes serviços ambientais, como ciclagem de nutrientes e fluxo de energia participando das cadeias alimentares (Covich et al. 1999) e de detritos (Graça 2001).

As atividades funcionais de alimentação de macroinvertebrados e as estratégias utilizadas para adquirir o alimento refletem as adaptações desses organismos às condições ambientais (Tomanova et al. 2006). Muitas espécies exploram de maneira semelhante um mesmo conjunto de recursos e são definidas como fazendo parte de uma mesma guilda trófica (Begon et al. 2007) e o seu reconhecimento baseia-se principalmente no tipo de dieta apresentada pelos *taxa* e, em alguns casos, no comportamento alimentar associado ao substrato no qual o alimento está disponível (Cummins 1973; Callisto & Esteves 1998; Silva et al. 2008). Além disso, a estratégia alimentar pode ser usada como uma forma de avaliação de condições ambientais (Tomanova et al. 2006; Cummins et al. 2005).

Os macroinvertebrados bentônicos fragmentadores reduzem o tamanho da matéria orgânica particulada grossa (MOPG) disponibilizando a porção fina (MOPF) para outros organismos detritívoros (Wallace & Webster 1996; Boyero et al. 2011). Os raspadores alimentam-se de algas aderidas a superfícies, chamadas de perifíton. Os coletores-catadores utilizam como recurso alimentar a MOPF depositada nos sedimentos. Os coletores-filtradores possuem estruturas anatômicas especializadas (cerdas no aparelho bucal em forma de leque ou escova) ou constroem uma rede de seda para coletar a MOPF em suspensão na coluna d'água transportada pela correnteza. Por fim, os predadores capturam e consomem presas vivas inteiras ou suas partes ou perfuram e sugam o conteúdo de seus corpos (Wallace & Webster 1996; Cummins et al. 2005).

A classificação dos grupos tróficos funcionais com base nos mecanismos morfo-comportamentais deve ser analisada com cuidado, uma vez que muitos macroinvertebrados bentônicos possuem dieta generalista e a escolha do alimento pode estar associada ao estágio de vida (instar) e à disponibilidade de recursos no ambiente (Merritt & Cummins 1996; Wallace & Webster 1996). Então a avaliação de itens alimentares no conteúdo estomacal de macroinvertebrados bentônicos auxilia na classificação mais precisa em grupos tróficos funcionais em riachos tropicais (Motta & Uieda 2004).

No Brasil há uma lacuna no conhecimento sobre os grupos tróficos funcionais (GTFs) dos macroinvertebrados bentônicos devido à escassez de estudos, assim como em todas as regiões tropicais (Callisto et al. 2001; Fossati et al. 2001; Buss et al. 2002; Baptista et al. 2007; Boyero et al. 2011; Chara-Serna et al. 2012). A classificação dos macroinvertebrados bentônicos em GTFs na América do Sul ainda é insipiente (Motta & Uieda 2004) e com isso persistem incertezas relacionadas à história de vida e à plasticidade alimentar dos macroinvertebrados bentônicos em rios tropicais. Assim, a classificação dos macroinvertebrados com base na literatura americana e europeia, pode levar a diferenças significativas na classificação das categorias tróficas porque a estratégia de alimentação de macroinvertebrados em riachos tropicais pode ser diferente devido à disponibilidade de recursos e características de habitats físicos (Tomanova et al. 2006).

CONTEXTUALIZAÇÃO

Esta tese de doutorado foi realizada no âmbito de um projeto financiado pelo Programa Peixe Vivo da Companhia Energética de Minas Gerais S.A. – CEMIG, intitulado "*desenvolvimento de índices de integridade biótica para a avaliação de qualidade ambiental e subsidio para a restauração de habitats em áreas de soltura de alevinos".* Este projeto conta com a parceria das instituições de pesquisas UFMG, UFLA, PUC-Minas e CEFET-MG, OSU (Oregon State University) e US-EPA (Oregon).

Esta tese utilizou os dados das campanhas de amostragens realizadas no período de seca em setembro de 2009 nos tributários da bacia hidrográfica do alto rio Araguari a montante do reservatório de Nova Ponte MG e, em setembro de 2010, nos tributários da bacia hidrográfica do alto rio São Francisco a montante do reservatório de Três Marias, MG. Foram descritas as relações de fatores ambientais de habitats físicos na explicação da riqueza e distribuição de macroinvertebrados bentônicos e a relação dos habitats físicos com o conteúdo alimentar de larvas do gênero *Phylloicus* (Trichoptera: Calamoceratidae).

Foram elaborados dois capítulos no formato de manuscritos científicos. No primeiro capítulo foram avaliados quais os fatores ambientais de habitats físicos e parâmetros físicos e químicos de qualidade de água melhor explicam a riqueza e distribuição das assembleias de Ephemeroptera, Plecoptera e Trichoptera (EPT). No segundo capítulo foram avaliados os fatores ambientais de habitats físicos relacionados aos itens alimentares encontrados no trato digestivo de larvas de *Phylloicus.*

OBJETIVOS

Objetivo Geral

Identificar quais os fatores ambientais de habitats físicos em escala de riachos melhor explicam a riqueza e a distribuição de EPT e quais se relacionam com itens alimentares no trato digestivo de larvas de *Phylloicus*.

Objetivos específicos do capítulo 1:

Importância de fatores ambientais na riqueza e distribuição de macroinvertebrados bentônicos em riachos de cabeceira tropicais

- Avaliar o estado ecológico de riachos utilizando protocolos adaptados para avaliação de habitats físicos;
- Avaliar as relações de habitats físicos e parâmetros físicos e químicos de qualidade de água com gêneros de macroinvertebrados bentônicos das ordens Ephemeroptera, Plecoptera e Trichoptera;
- Avaliar as relações de métricas de habitats físicos com a riqueza de EPT.

Objetivos específicos do capítulo 2:

A dieta de um típico fragmentador é relacionada com os habitats físicos em riachos de cabeceira no Cerrado brasileiro?

- Avaliar a importância de itens alimentares (CPOM, FPOM, algas, tecido animal, tecido vegetal e material mineral) no trato digestivo de larvas de *Phylloicus*;
- Avaliar as relações de métricas ambientais de habitats físicos com os itens alimentares.

ÁREA DE ESTUDO E SÍNTESE DO PROCEDIMENTO AMOSTRAL

Foram estudados 40 trechos de riachos que drenam a bacia hidrográfica do alto rio Araguari no trecho a montante do reservatório de Nova Ponte, e outros 39 que drenam a bacia do alto rio São Francisco a montante do reservatório de Três Marias (Figura 1). A bacia do Alto Rio Araguari está localizada na mesorregião do Triangulo Mineiro, abrangendo os municípios de Araxá, Ituiutaba, Nova Ponte e Patrocínio. A paisagem é intensamente modificada na maior parte de sua extensão, sendo a agricultura mecanizada e irrigada a atividade predominante de uso do solo. Entre as principais culturas destacam-se café, cana para produção de açúcar e álcool, soja e milho. A bacia do Alto Rio São Francisco está localizada na mesorregião Central Mineira, abrangendo os municípios de Três Marias, Abaeté, Pompéu e Morada Nova de Minas. As principais atividades na região são a agricultura familiar e a criação de gado de modo extensivo em pequenas fazendas. Ambas as bacias estão inseridas no bioma Cerrado, um dos "hotspots" de biodiversidade definidos por Myers et al. (2000), possuindo elevado endemismo de espécies de flora e fauna.

O clima no Cerrado é marcado por duas estações climáticas bem definidas: um período de seca que vai de maio a setembro e outro chuvoso, de outubro a abril. A precipitação média anual varia de 1200 a 1800 mm (Ratter et al. 1997). Embora sendo o segundo maior bioma brasileiro, ocupando atualmente cerca de 20% do território nacional, vem sendo progressivamente substituído por pastagem e agricultura (Wantzen et al. 2006; Diniz-Filho et al. 2009). Esse processo acelerou-se a partir da segunda metade do século XX em função do avanço da malha urbana e da implantação de empreendimentos agropastoris, grande parte deles destinados ao mercado externo.

Em cada bacia definiu-se como a região potencial de amostragem ("buffer") a área de 35 km no entorno a montante dos reservatórios. A seleção dos riachos foi realizada aleatoriamente seguindo a metodologia de Olsen & Peck (2008). Em cada trecho foi aplicado um protocolo de avaliação de habitats (Protocolos em Anexo) desenvolvido e utilizado pela Agencia de Proteção Ambiental Norte-Americana (US-EPA) (Peck et al. 2006).

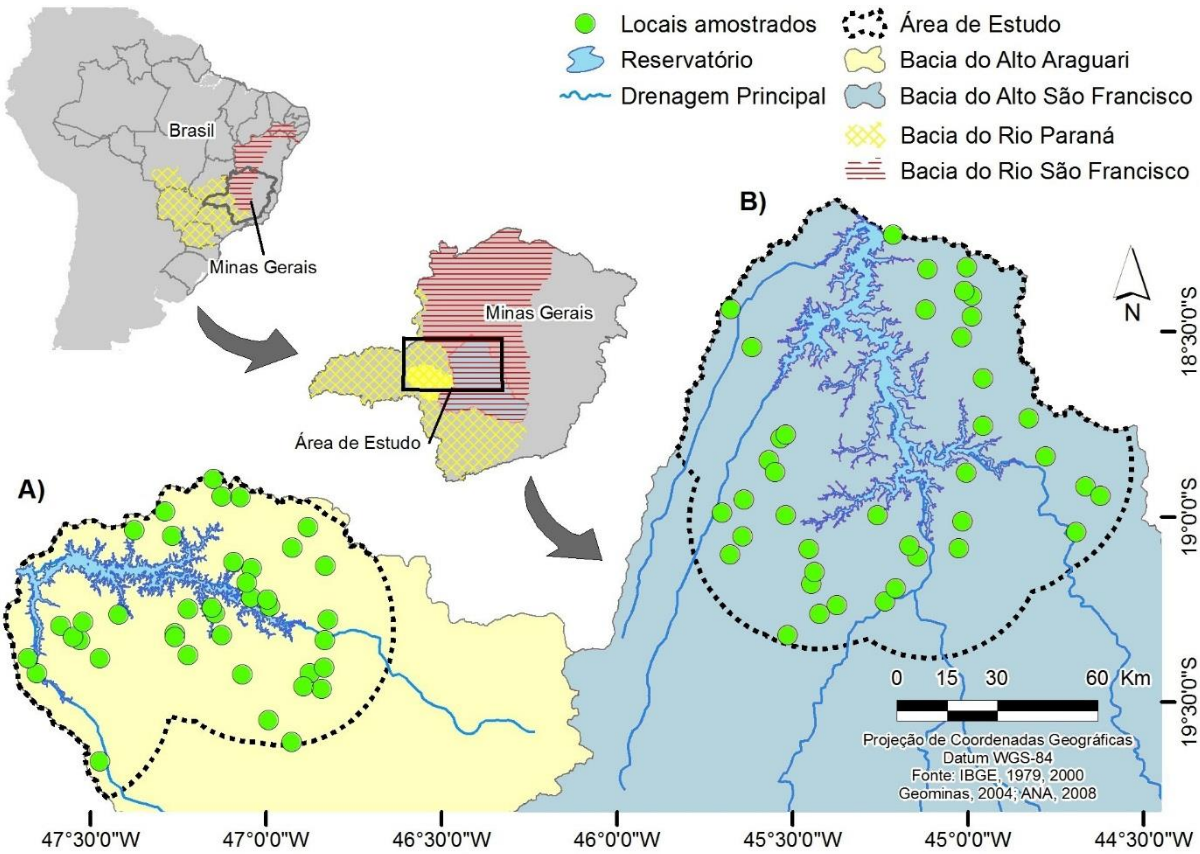

Figura 1. Localização das bacias hidrográficas estudadas e dos riachos amostrados. A) Bacia do Alto Rio Araguari (reservatório de Nova Ponte), e B) Bacia do Alto Rio São Francisco (reservatório de Três Marias).

O comprimento longitudinal de cada trecho amostrado foi definido como a média da largura molhada no ponto do trecho multiplicada por 40, tendo um comprimento mínimo de 150 m. Dentro de cada trecho foram definidos 11 transectos equidistantes, totalizando 10 seções (espaço entre transectos) em cada trecho (Figura 2). Em cada transecto e ao longo das seções foram sistematicamente avaliadas diversas características do leito dos riachos (p.ex., largura molhada, largura e altura do leito sazonal, profundidade, tipo de substrato, tipo de fluxo, etc.) e da vegetação riparia (p.ex., alterações humanas, cobertura vegetal, cobertura do dossel no leito, etc.). Esse protocolo tem como objetivo descrever da forma mais detalhada possível as características dos habitats físicos nos riachos.

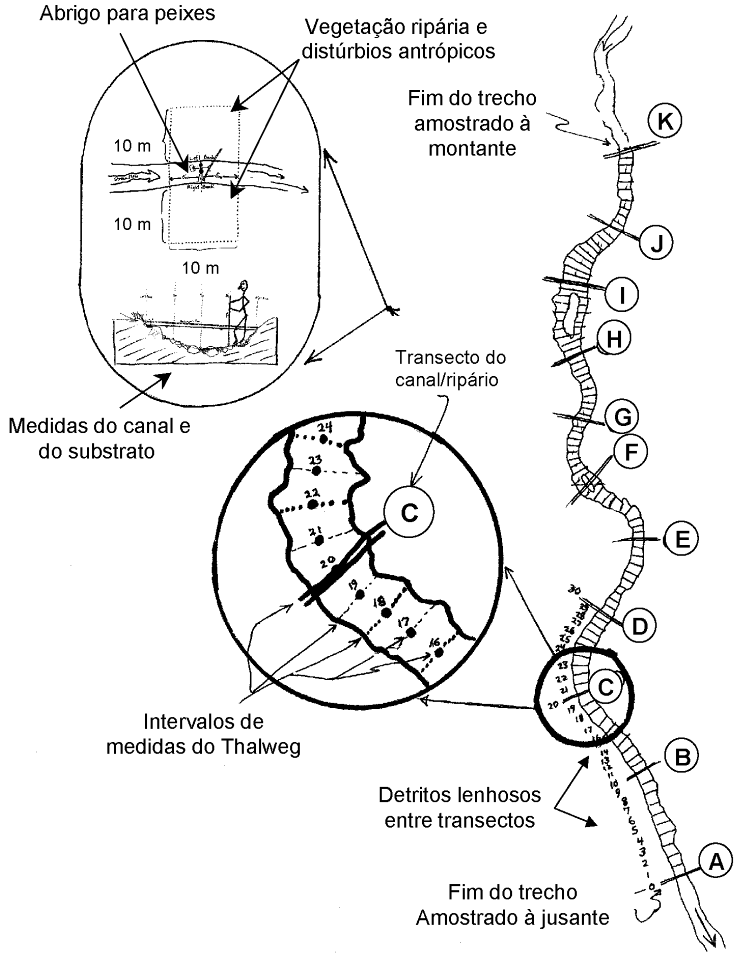

Figura 2. Desenho esquemático da metodologia amostral aplicada em campo (figura adaptada de Kaufmann et al. 1999).

Seguindo o mesmo protocolo, as amostragens de macroinvertebrados em cada trecho foram realizadas utilizando um amostrador tipo "kicking net" (30 cm abertura, 500 µm tamanho de abertura de malha). Esse amostrador é também conhecido como "D-net", em função de seu formato (Figura 3). Foram realizadas amostragens tipo "reach wide" e onze sub-amostras (0,09 m^2 cada) foram coletadas por trecho de riacho. Este método possibilita a amostragem de vários tipos de habitats e microhabitats existentes no trecho, podendo assim ser chamada de "amostragem multi-habitat”. Em laboratório os organismos coletados foram triados em bandejas e identificados em lupa (aumento 32x) ao nível de família e 80x ao nível de gênero com o auxílio de chaves taxonômicas (Pérez 1988; Fernandez e Domingues 2001; Costa et al. 2006). Os *taxa* EPT, utilizados por apresentarem padrões gerais da comunidade total e além disso, considerados como eficientes bioindicadores de boa qualidade de agua, foram identificados ao nível de gênero com auxílio de chaves de identificação taxonômicas (Hamada & Couceiro 2003; Salles et al. 2004; Pés et al. 2005; Domínguez et al. 2006; Wiggins 1996; Lecci & Froehlich 2007; Falcão et al. 2011).

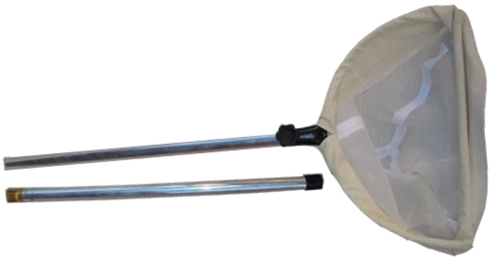

Figura 3. Amostrador do tipo “kicking net” para coleta de macroinvertebrados bentônicos.

Referências bibliográficas

Allan, J. D. & M. M. Castillo, 2007. Stream ecology: structure and function of running waters, 2nd edn. Springer, Dordrecht, The Netherlands.

Baptista, D. F., D. F. Buss, M. Egler, A. Giovanelli, M. P. Silveira & J. L. Nessimian, 2007. A multimetric index based on benthic macroinvertebrates for evaluation of Atlantic Forest streams at Rio de Janeiro State, Brazil. Hydrobiologia 575: 83-94.

Begon, M., C. R. Townsend & J. L. Harper, 2006. Ecology: from individuals to ecosystems, 4th edn. Wiley-Blackwell.

Bonada, N., N. Prat, V. H. Resh & B. Statzner, 2006. Developments in aquatic insect biomonitoring: a comparative analysis of recent approaches. Annual Review of Entomology 51: 495-523.

Boyero, L. & R. C. Bailey, 2001. Organization of macroinvertebrate communities at a hierarchy of spatial scales in a tropical stream. Hydrobiologia 464: 219-225.

Boyero, L., R. G. Pearson, D. Dudgeon, M. A. S. Graça, M. O. Gessner, R. J. Albariño, V. Ferreira, C. M. Yule, A. J. Boulton, M. Y. Arunachalam, M. Callisto, E. Chauvet, A. Ramírez, J. Chará, M. S. Moretti, J. F. G. JR., J. E. Helson, A. M. C. -Serna, A. C. Encalada, J. N. Davies, S. Lamothe, A. Cornejo, A. O. Y. Li, L. M. Buria, V. D. Villanueva, M. C. Zúñiga & C. M. Pringle, 2011. Global distribution of a key trophic guild contrasts with common latitudinal iversity patterns. Ecology 92: 1839–1848.

Buss, D. F., D. F. Baptista, M. P. Silveira, J. L. Nessimian & L. F. Dorvillé, 2002. Influence of water chemistry and environmental degradation on macroinvertebrate assemblages in a river basin in south-east Brazil. Hydrobiologia 481: 125-136.

Callisto, M. & F. Esteves, 1998. Categorização funcional dos macroinvertebrados bentônicos em quatro ecossistemas lóticos sob influência das atividades de uma mineração de bauxita na Amazônia Central (Brasil). Oecologia Australis 5: 223-234.

Callisto, M., P. Moreno & F. Barbosa, 2001. Habitat diversity and benthic functional trophic groups at Serra do Cipó, Southeast Brazil. Revista Brasileira de Biologia 61: 259-266.

Chara-Serna, A. M., J. D. Chara, M. D. Zuniga, R. G. Pearson & L. Boyero, 2012. Diets of leaf litter-associated invertebrates in three tropical streams. Annales De Limnologie-International Journal of Limnology 48: 139-144 doi:Doi 10.1051/Limn/2012013.

Costa, C., S. Ide & C. Simonka, 2006. Insetos imaturos. Metamorfose e identificação Ribeirão Preto, Holos Editora, 249p[Links].

Covich, A. P., M. A. Palmer & T. A. Crowl, 1999. The role of benthic invertebrate species in freshwater ecosystems: zoobenthic species influence energy flows and nutrient cycling. Bioscience 49: 119-127.

Cummins, K. W., 1973. Trophic relations of aquatic insects. Annual Review of Entomology 18: 183-206.

Cummins, K. W., Merritt R.W. & Andrade P.C. N., 2005. The use of invertebrate functional groups to characterize ecosystem attributes in selected streams and rivers in South Brazil. Studies on Neotropical Fauna and Environment 40: 69-89.

Diniz-Filho, J. A. F., Bini L.M., Oliveira Guilherme, Barreto Bruno de Souza, Silva Marcel Müller Fernandes Pereira, Terribile Levi Carina, Rangel Thiago Fernando LVB, Pinto Miriam Plaza, Sousa Nayara Pereira Rezende de & V. L. C. Galli, 2009.

Macroecologia, biogeografia e áreas prioritárias para conservação no cerrado. Oecologia Australis 13: 470-497.

Dohet, A., L. Ector, H.-M. Cauchie & L. Hoffmann, 2008. Identification of benthic invertebrate and diatom indicator taxa that distinguish different stream types as well as degraded from reference conditions in Luxembourg. Animal Biology 58: 419-472.

Domínguez, E., 2006. Ephemeroptera de América del Sur, vol 2. Pensoft Pub, Bulgaria.

Dudgeon, D., 2000. The ecology of tropical Asian rivers and streams in relation to biodiversity conservation. Annual Review of Ecology and Systematics: 239-263.

Dudgeon, D., A. H. Arthington, M. O. Gessner, Z. I. Kawabata, D. J. Knowler, C. Lévêque, R. J. Naiman, A. H. Prieur-Richard, D. Soto & M. L. Stiassny, 2006. Freshwater biodiversity: importance, threats, status and conservation challenges. Biological Reviews 81: 163-182.

Elosegi, A., 2009. Conceptos y técnicas en ecología fluvial. Fundacion BBVA.

Falcão, J. N., F. F. Salles & N. Hamada, 2011. Baetidae (Insecta, Ephemeroptera) ocorrentes em Roraima, Brasil: novos registros e chaves para gêneros e espécies no estágio ninfal. Revista Brasileira de Entomologia 55: 516-548.

Feio, M. J., R. Norris, M. Graça & S. Nichols, 2009. Water quality assessment of Portuguese streams: Regional or national predictive models? Ecological Indicators 9: 791-806.

Feio, M. J., Ferreira, W. R., Macedo, D. R., Eller, A. P., Alves, C. B. M., França, J. S., & Callisto, M. (2013). Defining and testing targets for the recovery of tropical streams based on macroinvertebrate communities and abiotic conditions. River Research and Applications. DOI: 10.1002/rra.2716.

Fernández, H. & E. Domínguez, 2001. Guía para la determinación de los arthrópodos bentónicos Sudamericanos. Entomotropica 16: 219.

Ferreira, W., L. Paiva & M. Callisto, 2011. Development of a benthic multimetric index for biomonitoring of a neotropical watershed. Brazilian Journal of Biology 71: 15-25.

Fossati, O., J.-G. Wasson, C. Hery, G. Salinas & R. Marin, 2001. Impact of sediment releases on water chemistry and macroinvertebrate communities in clear water Andean streams (Bolivia). Archiv für Hydrobiologie 151: 33-50.

Garcia, X. F., I. Schnauder & M. T. Pusch, 2012. Complex hydromorphology of meanders can support benthic invertebrate diversity in rivers. Hydrobiologia 685: 49-68.

Graça, M. A. S., 2001. The role of invertebrates on leaf litter decomposition in streams– a review. International Review of Hydrobiology 86: 383-393.

Hamada, N. & S. R. M. Couceiro, 2003. An illustrated key to nymphs of Perlidae (Insecta, Plecoptera) genera in Central Amazonia, Brazil. Revista Brasileira de Entomologia 47: 477-480.

Hughes, R. M., A. T. Herlihy & P. R. Kaufmann, 2010. An Evaluation of Qualitative Indexes of Physical Habitat Applied to Agricultural Streams in Ten US States1. JAWRA Journal of the American Water Resources Association 46: 792-806.

Jowett, I., 1997. Instream flow methods: a comparison of approaches. Regulated Rivers: Research & Management 13: 115-127.

Kaufmann, P. R. & J. M. Faustini, 2012. Simple measures of channel habitat complexity predict transient hydraulic storage in streams. Hydrobiologia 685: 69-95.

Kovalenko, K. E., S. M. Thomaz & D. M. Warfe, 2012. Habitat complexity: approaches and future directions. Hydrobiologia: 1-17.

Lecci, L.S. & Froehlich, C.G. 2007. Plecoptera. *In*: Guia *on-line*: Identificação de larvas de Insetos Aquáticos do Estado de São Paulo. Froehlich, C.G. (org.). Disponível em: http://sites.ffclrp.usp.br/aguadoce/guiaonline.

Ligeiro, R., R. M. Hughes, P. R. Kaufmann, D. R. Macedo, K. R. Firmiano, W. R. Ferreira, D. Oliveira, A. S. Melo & M. Callisto, 2013. Defining quantitative stream disturbance gradients and the additive role of habitat variation to explain macroinvertebrate taxa richness. Ecological Indicators 25: 45-57.

Maddock, I., 1999. The importance of physical habitat assessment for evaluating river health. Freshwater Biology 41: 373-391.

Mérigoux, S., N. Lamouroux, J. M. Olivier & S. Doledec, 2009. Invertebrate hydraulic preferences and predicted impacts of changes in discharge in a large river. Freshwater Biology 54: 1343-1356.

Merritt, R. W. & K. W. Cummins, 1996. An introduction to the aquatic insects of North America. Kendall Hunt.

Moreno, P. & M. Callisto, 2006. Benthic macroinvertebrates in the watershed of an urban reservoir in southeastern Brazil. Hydrobiologia 560: 311-321.

Motta, R. L. & V. S. Uieda, 2004. Diet and trophic groups of an aquatic insect community in a tropical stream. Brazilian Journal of Biolology 64: 809-817.

Myers, N., R. A. Mittermeier, C. G. Mittermeier, G. A. Da Fonseca & J. Kent, 2000. Biodiversity hotspots for conservation priorities. Nature 403: 853-858.

Olsen, A. R. & D. V. Peck, 2008. Survey design and extent estimates for the Wadeable Streams Assessment. Journal of the North American Benthological Society 27: 822-836.

Peck, D. V., Herlihy A.T., Hill B. H., Hughes R. M., Kaufmann P.R., Klemm D.J., Lazorchak J.M., McCormick F.H., Peterson S.A., Ringold P.L., Magee T. &

Cappaert M.R., 2006. Environmental Monitoring and Assessment Program - Surface Waters. Western Pilot Study: field operations manual for wadeable streams. EPA Report EPA EPA/620/R-06/003. U.S. Environmental Protection Agency, Washington, DC.

Pérez, R. G., 1988. Guía para el estudio de los macroinvertebrados acuáticos del Departamento de Antioquia. Antioquia: Universidad de Antioquia.

Pes, A. M. O., N. Hamada & J. L. Nessimian, 2005. Chaves de identificação de larvas para famílias e gêneros de Trichoptera (Insecta) da Amazônia Central, Brasil. Revista Brasileira de Entomologia 49: 181-204.

Ratter, J., J. Ribeiro & S. Bridgewater, 1997. The Brazilian cerrado vegetation and threats to its biodiversity. Annals of Botany 80: 223-230.

Salles, F. F., Da-Silva, E. R., Serrão, J. E., & Francischetti, C. N. (2004). Baetidae (Ephemeroptera) na Região Sudeste do Brasil: novos registros e chave para os gêneros no estágio ninfal. *Neotropical Entomology* 33: 725-735.

Silva, F. L., S. S. Ruiz, G. L. Bochini & D. C. Moreira, 2008. Functional feeding habits of Chironomidae larvae (Insecta, Diptera) in a lotic system from Midwestern region of São Paulo State, Brazil. Pan-American Journal of Aquatic Sciences 3: 135-141.

Silveira, M., D. Buss, J. Nessimian & D. Baptista, 2006. Spatial and temporal distribution of benthic macroinvertebrates in a southeastern Brazilian river. Brazilian Journal of Biology 66: 623-632.

Souza, A. D. G. d. & J. G. Tundisi, 2003. Water quality in watershed of the Jaboatão River (Pernambuco, Brazil): a case study. Brazilian Archives of Biology and Technology 46: 711-721.

Statzner, B. & B. Higler, 1986. Stream hydraulics as a major determinant of benthic invertebrate zonation patterns. Freshwater Biology 16: 127-139.

Tomanova, S., E. Goitia & J. Helešic, 2006. Trophic levels and functional feeding groups of macroinvertebrates in neotropical streams. Hydrobiologia 556: 251-264.

Vannote, R. L., G. W. Minshall, K. W. Cummins, J. R. Sedell & C. E. Cushing, 1980. The river continuum concept. Canadian Journal of Fisheries and Aquatic Sciences 37: 130-137.

Wallace, J. B. & J. R. Webster, 1996. The role of macroinvertebrates in stream ecosystem function. Annual Review of Entomology 41: 115-139.

Wantzen, K. M., A. Siqueira, C. N. d. Cunha, P. de Sá & M. de Fátima, 2006. Stream-valley systems of the Brazilian Cerrado: impact assessment and conservation scheme. Aquatic Conservation: Marine and Freshwater Ecosystems 16: 713-732.

Wiggins, G. B., 1996. Larvai of the North American Caddisfly Genera. University of Toronto Press, Toronto.

Capítulo 1

“Importance of environmental factors on the richness and distribution of benthic macroinvertebrates in tropical headwater streams”

Abstract. It is essential to understand the interactions between local environmental factors (e.g., physical habitat and water quality) and aquatic assemblages to conserve biodiversity in tropical and subtropical headwater streams. Therefore, we evaluated the relative importance of multiple physical and chemical habitat variables influencing the richness of typically more sensitive Ephemeroptera, Plecoptera and Trichoptera (EPT) assemblages in wadeable Brazilian Cerrado (savanna) streams. To do so, we sampled macroinvertebrate assemblages and quantified physical and chemical habitat in 79 randomly selected sites in two Cerrado basins in southeastern Brazil. The environmental variables, selected by multiple regression models (MLRs) via corrected Akaike Information Criteria (AICc), contributed significantly to the variation in EPT taxa richness. The variance explained by physical habitat variables in the Upper Sao Francisco Basin (adjusted r^2 = 0.53) was slightly greater than in the Upper Araguari Basin (adjusted r^2 = 0.46), and both were greater than the variance explained by a combined biome model (adjusted $r^2 = 0.39$). In our study, physical habitat variables were more important than water quality variables in structuring EPT genera in savanna streams with catchments dominated by agriculture or pasture land uses. We conclude that regional models can be improved by incorporating basin-specific information, in this way refining biological assessments and better understanding the interactions that maintain biodiversity in stream networks.

Key-words: EPT assemblages, physical habitat, hydromorphology, stream conservation, macroinvertebrate bioindicators, Cerrado headwater streams

Introduction

Agriculture, pasture, and riparian deforestation hinder stream conservation through their effects on instream habitat conditions (Dovciak and Perry 2002, Pinto et al. 2006, Egler et al. 2012). Both physical habitat structure and water quality have received attention in recent years as important elements for assessing environmental quality and as agents structuring aquatic biotic assemblages (Karr and Dudley 1981, Sály et al. 2011; Ligeiro et al. 2013). To conserve headwater streams, it is essential to assess and understand the interactions among physical habitat features, water chemistry, and aquatic assemblages (Maddock 1999; Nerbonne and Vondracek 2001, Pinto et al. 2009). Site-scale research has shown that physical habitat complexity (e.g., structural cover, substrates, and water flow) influence assemblage composition, richness, and temporal stability as well as ecological processes (Hughes et al. 2010, Kaufmann and Faustini 2012, Kovalenko et al. 2012).

Benthic macroinvertebrates are frequently recommended for biological assessments of environmental changes (Barbour et al. 1996, Lammert and Allan 1999, Bonada et al. 2006) because they exhibit a continuum of responses to environmental variables (Rosenberg and Resh 1993, Maddock 1999, Dohet et al. 2008). These organisms are often used to assess water body condition in spatially extensive biomonitoring programs (Hering et al. 2006, Paulsen et al. 2008, USEPA 2013), through the use of multimetric indices (Baptista et al. 2007, Klemm et al. 2003, Stoddard et al. 2008, Ferreira et al. 2011, Mugnai et al. 2011, Oliveira et al. 2011), and predictive models (Feio et al. 2009, Moya et al. 2011, Chen et al. In Press).

Ephemeroptera, Plecoptera and Trichoptera (EPT) taxa are sensitive indicators of high quality ecological conditions because of their low tolerance to stressors (Usseglio-Polatera et al. 2000, Callisto et al. 2001, Klemm et al. 2003, Ferreira et al. 2011). The EPT also play important roles in nutrient cycling (Righi-Cavallaro et al. 2010), in processing coarse organic matter (Graça et al. 2001, Boyero et al. 2011), and in the diet of vertebrates and other invertebrates (Ferro and Sites 2007). Altered environmental conditions can adversely affect EPT taxa richness and composition. For example, riparian vegetation removal may increase erosion, turbidity, water temperature, streambed sedimentation, and habitat losses (Chapman and Chapman 2002, Kaufmann et al. 2009). Increased fine sediments are detrimental to many EPT taxa (Bryce et al. 2010) and reductions in wood and leaves reduce the food and shelter for EPT assemblages (Melody and Richardson 2007).

The Cerrado biome (Brazilian tropical savanna) covers more than two million km^2, mostly inside Brazil, and is considered a priority hotspot for biodiversity conservation on a global scale because it supports many endemic species (Myers et al. 2000). In the past 60 years, more than half the Cerrado has been deforested (Klink and Machado 2005, Wantzen et al. 2006), and large natural areas have been transformed into livestock pasture and croplands (Diniz-Filho et al. 2009). Replacement of native vegetation by pasture and intensive agriculture is associated with degradation of water quality, increased soil erosion, siltation of water bodies, and degradation of physical habitat (Dovciak and Perry 2002, Wantzen et al. 2006). Thus, the objective of this study was to evaluate the relative importance of site-scale physical habitat and water quality variables driving EPT generic richness in Brazilian Cerrado streams. The aim is to use this information to better manage headwater streams and their catchments. Because two adjacent basins in the same biome can differ in land uses, ecological conditions, geomorphology and precipitation, we hypothesized that 1) the two studied basins would differ in EPT assemblage structure and composition, 2) different sets of habitat metrics would explain EPT richness in each basin, and 3) that a combined model would explain less variability.

Methods

Study Area

We conducted this study in 79 1st to 3rd order (at 1:100,000 scale) wadeable stream sites in the Upper São Francisco and Upper Araguari River Basins, Minas Gerais, southeastern Brazil (Figure 1). Both basins are located in the Cerrado biome at altitudes between 520 and 1300 m. There is a distinct May to September dry season with rainfall between 10 and 55 mm/month, and a distinct October to April rainy season with rainfall between 100 and 300 mm/month, for a total mean annual rainfall around 1600 mm (Brasil 1992). In the Upper Araguari Basin, lithology is mostly metamorphic rock and its land use is primarily agricultural (mainly soy, coffee, corn and sugar cane). In the Upper São Francisco Basin, the predominant lithology consists of sedimentary rocks and the land use is mostly pasture and small family farms (Ligeiro et al. 2013).

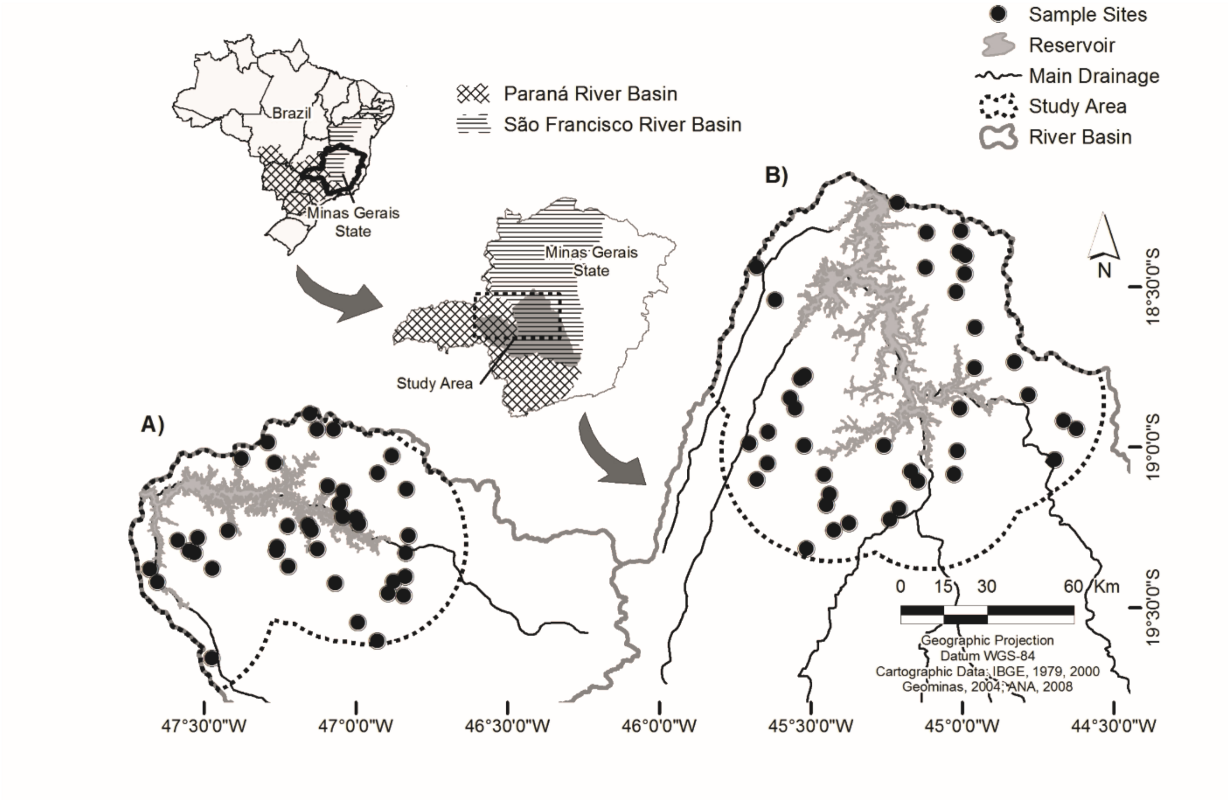

Figure 1. Study area and site locations in the Upper Araguari (A) and Upper São Francisco (B) Basins.

Site Selection

We selected sites as described by Stevens and Olsen (2004) for the USA Wadeable Stream Assessment (Olsen and Peck 2008, USEPA 2013). Following this methodology, randomly selected sites are drawn from a digital hydrographic map to produce a spatially balanced network of sites with a minimum distance of 1 km between sites. We sampled 40 sites in September 2009 in the Upper Araguari Basin and 39 sites in September 2010 in the Upper São Francisco Basin.

Physical Habitat

At each site, we sampled a longitudinal distance equal to 40 times the average width, with a minimum distance of 150 meters. Then, eleven equidistant transects were established perpendicular to the longitudinal axis of the streams, defining ten sections of the same length. In each transect and along the sections we measured stream physical habitat variables as described in Peck et al. (2006). At the eleven transects, we recorded channel dimensions (e. g., wetted and bankfull width and depth), bank angle, riparian vegetation (e.g., percent cover of tree, understory, ground layer), presence and proximity of human disturbances (e.g., buildings, trash, land use), and presence of fish cover (e.g., undercut banks, trees and fallen branches, filamentous algae, aquatic macrophytes). We determined bed substrate (e.g., sand, gravel, boulder) at 100 points, In addition, we measured flow type (e.g., pools, riffles), thalweg depths, sinuosity and channel slope between each transect. We generated quantitative physical habitat metrics as described in Kaufmann et al. (1999); however, relative bed stability was calculated as in Kaufmann et al. (2009).

Water Quality

Temperature, electrical conductivity, pH, turbidity and total dissolved solids were measured in situ using a multiparameter probe (Yellow Springs - YSI - 650 MDS - Probe 6920). In the laboratory, we determined the concentrations of total phosphorus, total nitrogen and dissolved oxygen (APHA et al. 2005) from a water sample taken from each site and retained in a chilled cooler.

Benthic Macroinvertebrates

We collected benthic macroinvertebrates using a D-frame kick net (30 cm aperture, 500 µm mesh). One sample unit (0.09 m^2) was taken per transect, totaling 1 m^2 of sampled area per site. The sampling followed a systematic zig-zag pattern (right, center, left) along the site. We preserved the composite samples with 4% formalin solution. In the UFMG Benthic Ecology Laboratory, we washed the samples through a 500 µm sieve and sorted the organisms. We identified EPT individuals to genus through use of a stereomicroscope (80x) with the aid of taxonomic keys (Merritt and Cummins 1996, Wiggins 1996, Hamada and Couceiro 2003, Salles et al. 2004, Pés et al. 2005, Mugnai et al. 2010, Falcão et al. 2011).

Data Analyses

Selection of physical habitat and water quality variables

We first analyzed the data from the two basins separately, and limited regression analyses to 4 predictor variables (10% of the number of sites per basin) to avoid model over fitting (Gotelli and Ellison, 2004). Then we analyzed all 79 sites in the two studied basins of Cerrado biome, restricting the number of predictor metrics to 8. In each case, we followed the procedures suggested by Marzin et al. (2012a) and first separated a total of 158 habitat metrics into six groups of metrics that describe key stream habitat characteristics (channel morphology, bed substrate, flow type, riparian vegetation, fish cover, and water quality). Then, within each group of metrics, we examined correlation matrices (Pearson product moment) to eliminate redundant metrics ($\geq$ |0.8| correlation), retaining the most ecologically meaningful ones. For instance, the % pools metric was highly correlated with the % trench pools metric (r = |0.94|), so we chose % pools because we consider it a more comprehensive metric describing slowly flowing habitat types. After this screening step we retained a total of 83 metrics (15 in the channel morphology group, 15 in the bed substrate group, 6 in the flow type group, 19 in the riparian vegetation group, 23 in the fish cover group, and 5 in the water quality group).

In a second metric screening step, within each metric group, we selected the metrics that contributed most to the dispersion of the data in the multivariate space of a principal components analysis (PCA). We achieved in this manner a total of 29 metrics (Table 1). The first axis of each PCA (PCA1) represents the clearest univariate gradient formed by the habitat metrics of each group. The coordinate values of the metrics express the relative contribution of each individual metric to the PCA1s. For instance, the PCA1 performed for the channel morphology metric group in the Upper Araguari Basin represents a contrast between channel slope and channel size (depth and width) (Table 1).

Table 1. Description of physical habitat metrics and physical-chemical water variables. Significant results are followed by an asterisk (n/a: not assessed).

Variable code	Habitat groups and metric names	Upper Araguari Basin	Upper São Francisco Basin	*t*-test	PCA: factor coordinates - based on correlations: Upper Araguari Basin	PCA: factor coordinates - based on correlations: Upper São Francisco Basin
	Channel morphology	Mean (SD)	Mean (SD)	*p*	1st axis (23.94%)	1st axis (30.73%)
xdepth_s	Mean depth of cross-section (cm)	20.63 (10.36)	27.77 (11.68)	0.005*	-0.61	-0.54
xwidth	Mean wetted width (m)	2.54 (1.08)	3.68 (2.44)	0.005*	-0.69	-0.89
xbkf_w	Mean bankfull width (m)	5.20 (1.74)	6.50 (3.61)	0.044*	-0.40	-0.85
rp100	Mean residual depth (cm)	10.27 (5.63)	23.72 (12.81)	< 0.001*	-0.82	0.04
xslope	Channel water surface slope – reach mean (%)	1.01 (0.62)	0.60 (0.59)	0.003*	0.45	-0.28
Sinu	Channel sinuosity (m/m)	3.53 (15.48)	1.05 (0.07)	0.314	0.04	0.54
	Bed substrate				(32.09%)	(35.13%)
xembed	Mean embeddedness of channel & margin (%)	64.08 (19.67)	58.38 (24.81)	0.259	0.56	0.79
vembed	Standard deviation of embeddedness in channel + margin (%)	35.77 (9.73)	35.63 (11.22)	0.955	-0.27	-0.48
lrbs	Relative bed stability	-2.52 (0.86)	-2.06 (1.33)	0.070	-0.78	-0.59
lsub_dmm	Substrate - log10 (geometric mean diameter mm)	-0.76 (0.87)	-0.64 (1.47)	0.645	-0.92	-0.96
pct_cb	Substrate % cobbles (diameter 64 – 250 mm)	0.05 (0.07)	0.06 (0.1)	0.618	-0.69	-0.45
	Riparian				(25.32%)	(34.73%)
xcdenmid	Mean mid-channel canopy density (%)	77.06 (21.54)	73.03 (24.83)	0.440	0.70	-0.32
vcdenmid	Standard deviation – mid-channel canopy density (%)	13.35 (10.50)	14.16 (8.59)	0.708	-0.57	0.21
xcmg	Riparian vegetation canopy+mid+ground cover (%)	102.59 (30.81)	94.28 (43.19)	0.325	-0.31	-0.78
	Flow type				(37.16%)	(49.21%)
pct_gl	Glide (% of reach)	0.12 (0.17)	0.38 (0.31)	< 0.001*	0.45	0.76
pct_pool	Pools – all types (% of reach)	0.28 (0.16)	0.52 (0.37)	< 0.001*	0.61	0.86
pct_slow	Slow water habitat (% glide + pool)	0.40 (0.20)	0.89 (0.12)	< 0.001*	0.88	-0.80
	Shelter				(20.22%)	(29.32%)
pct_bf	Coarse litter (%)	0.001 (0.01)	0.07 (0.15)	0.006*	n/a	-0.17
c1w_msq	Large wood debris in bankfull channel (number/m^2 – all sizes)	0.07 (0.013)	0.05 (0.07)	0.296	-0.74	-0.77
xfc_brs	Brush and small debris (areal proportion)	11.98 (0.0, 87.5)	7.01 (9.49)	0.088	0.14	-0.81
xfc_ucb	Undercut banks (areal proportion)	5.06 (5.41)	3.65 (5.28	0.242	0.54	-0.40
xfc_ant	Anthropogenic fish cover (areal proportion)	5.66 (17.02)	6.71 (11.82)	0.749	-0.39	0.22
	Water quality				(31.54%)	(33.09%)
DO	Dissolved oxygen (mg/L)	7.47 (1.16)	7.67 (2.86)	0.694	0.62	-0.71
pH	Negative log hydrogen ion concentration	6.90 (0.46)	7.67 (0.49)	< 0.001*	0.82	-0.12
Turbidity	Material in suspension (NTU)	7.56 (10.52)	8.22 (14.55)	0.816	-0.56	0.88
N-total	Total nitrogen (mg/L)	0.05 (0.01)	0.24 (0.98)	0.236	0.23	0.07
Cond.	Electrical conductivity (µS/cm)	23.2 (17.7)	76.1 (92.3)	< 0.001*	-	-
TDS	Total dissolved solids (mg/L)	15.2 (11.8)	41.1 (33.5)	< 0.001*	-	-
T ^{0}C	Temperature of water	20.3 (1.8)	17.2 (1.8)	< 0.001*	-	-

To identify the best predictor variables for explaining EPT generic richness, we performed a multiple linear regression (MLR) for each basin and for all 79 studied sites combined. Because the predictors were measured over a variety of numerical scales they were mean centered and standardized before performing the analyses. We used the best-subsets procedure (Harrell and Frank 2001) for creating MLR models, including a maximum of four explanatory variables in the models made for each individual basin and eight explanatory variables in the model made for the two basins combined, in this way avoiding model overfitting. We used the corrected Akaike Information Criteria (AICc) values for searching for the best models (Burnham and Anderson 2002). The AICc is suitable for small datasets like ours. We also checked if the models could be simplified, i.e., if the number of explanatory variables could be reduced in each case. When the difference between the AICc values of two models (ΔAICc) is ≤ 2, the reduced model can be considered equivalent and, in this manner, preferable. For these analyses, we used Statistica for Windows (StatSoft, Inc. 1984-2004, version 7).

For each basin we also used the PCA1s coordinate values as surrogate variables representing each of the dimensions of habitat quantified by the “habitat groups” (table 1) in a canonical correspondence analysis (CCA) to assess EPT assemblage composition relative to the site environmental conditions. The CCAs were performed using just EPT genera with counts greater then 10 individuals, to avoiding misinterpretation of the results. Invertebrate abundances were square root transformed because of the wide range in abundances. The CCAs were performed in R version 2.15.1 (Team 2012), package vegan (Oksanen et al. 2012).

To evaluate dissimilarities in the taxonomic composition of benthic assemblages between the two basins we performed a MDS (Metrical Multidimensional Scaling) ordination. To perform the MDS we used the altered Gower distance based on relative abundances, with $\log_2 X + 1$ transformed data (following Anderson et al. 2006), and the Jaccard dissimilarity on presence/absence data. We also conducted t-tests to detect significant differences ($p < 0.05$) in EPT richness, density, and habitat and water quality metrics between the two basins. We used PERMANOVA tests (Permutational Multivariate Analysis of Variance, Anderson 2001), with 10,000 simulations, to test the difference in EPT assemblage composition between the two basins. The t-tests, the MDS, and the PERMANOVAS were also performed in R version 2.15.1.

Results

Physical & Chemical Variables

In general, sites in the two basins had good quality water, with low values for TDS, nitrogen and phosphorus, and high concentrations of dissolved oxygen. The largest differences in water quality between the two basins were observed for electrical conductivity ($t_{(1, 77)} = -3.55$, $p < 0.001$), total dissolved solids ($t_{(1, 77)} = -4.63$, $p < 0.001$), and water temperature ($t_{(1, 77)} = 7.75$, $p < 0.001$). Sites in the Upper São Francisco Basin had higher mean electrical conductivity (76.1 μS cm^{-1}) and total dissolved solids (41.1 mg L^{-1}) whereas Upper Araguari sites had higher mean water temperature (20.3 ˚C) (Table 1).

The site physical habitats in the two basins differed also. Regarding channel morphology, the Upper Araguari sites had higher mean slopes and sinuosities, whereas the Upper São Francisco sites had greater depths and larger cross-section widths. The highest average amount of cover (coarse litter) and flow types (glide, pools) were observed in the Upper São Francisco Basin (Table 1).

EPT Assemblages

In the Upper Araguari Basin we collected 5,463 individuals distributed in 19 families and 61 genera and in the Upper São Francisco Basin 15,133 individuals distributed in 20 families and 65 genera (Table 2). We observed a non-significant difference in the total richness of EPT genera between the basins. The Upper São Francisco Basin had fewer sites with EPT richness between 1 and 10 (15%) and more sites with taxa richness between 20 and 30 (36%). The Upper Araguari Basin had more sites (48%) with taxa richness between 10 and 20 and both basins had the same number of sites (5%) with taxa richness between 30 and 37 (Figure 2a). Upper São Francisco sites supported significantly higher EPT densities than Upper Araguari sites ($t_{(1,77)}$ = -3.54, p = 0.001) (Figure 2b).

Table 2. EPT taxa list from sites of the Upper Araguari and Upper São Francisco Basins. Genera collected from only one basin are indicated in bold italic.

Upper Araguari Basin						Upper São Francisco Basin					
Ephemeroptera	Individual	Plecoptera	Individual	Trichoptera	Individual	Ephemeroptera	Individual	Plecoptera	Individual	Trichoptera	Individual
Americabaetis	211	*Anacroneuria*	288	*Alisotrichia*	1	*Americabaetis*	1761	*Anacroneuria*	210	*Alisotrichia*	3
Apobaetis	10	*Gripopteryx*	33	*Atopsyche*	5	*Apobaetis*	84	*Gripopteryx*	1	***Anchitrichia***	3
Askola	49	***Kempnyia***	57	*Austrotinodes*	9	*Askola*	16	***Macrogynoplax***	1	*Atopsyche*	48
Aturbina	26	***Paragrypopteryx***	278	***Barypenthus***	34	***Asthenopus***	56			*Austrotinodes*	5
Baetodes	87	***Tupiperla***	215	*Chimarra*	25	*Aturbina*	365			*Chimarra*	749
Caenis	116			***Grumicha***	2	*Baetodes*	190			***Cyrnellus***	27
Callibaetis	4			*Helicopsyche*	4	*Caenis*	1156			*Helicopsyche*	33
Camelobaetidius	19			*Hydroptila*	4	*Callibaetis*	1438			*Hydroptila*	145
Campylocia	9			***Itaura***	12	*Camelobaetidius*	84			*Leptonema*	41
Cloeodes	167			*Leptonema*	42	***Campsurus***	88			*Macronema*	86
Criptonympha	64			*Macronema*	12	*Campylocia*	31			*Macrostemum*	7
Farrodes	151			*Macrostemum*	9	*Cloeodes*	1117			*Marilia*	99
Hagenulopsis	33			*Marilia*	100	*Criptonympha*	33			*Metrichia*	71
Hydrosmilodon	2			*Metrichia*	4	*Farrodes*	757			*Mortoniella*	6
Hylister	1			*Mortoniella*	185	*Hagenulopsis*	38			*Nectopsyche*	80
Leptohyphes	71			*Nectopsyche*	81	***Hermanella***	32			*Neotrichia*	2
Massartella	37			*Neotrichia*	2	***Hexagenia***	6			*Ochrotrichia*	2
Miroculis	52			*Ochrotrichia*	3	*Hydrosmilodon*	353			*Oecetis*	48
Needhamella	1			*Oecetis*	22	***Latineosus***	20			*Oxyetira*	68
Paracloeodes	64			*Oxyetira*	7	*Leptohyphes*	26			*Phylloicus*	44
Rivudiva	1			*Phylloicus*	53	*Massartella*	43			*Polycentropus*	116
Terpides	6			*Polycentropus*	3	*Miroculis*	317			*Polyplectropu*	95
Thraulodes	786			*Polyplectropus*	35	*Needhamella*	1			*Protoptila*	3
Traverella	1			*Protoptila*	5	*Paracloeodes*	184			*Smicridea*	591
Traverhyphes	589			*Smicridea*	526	***Paramaka***	6			***Taraxitrichia***	1
Tricorythodes	60			*Triplectides*	116	***Simothraulopsis***	40			*Triplectides*	18
Tricorythopsis	468					***Spiritiops***	8			***Wormaldia***	1
Ulmeritoides	104					*Terpides*	1				
Varipes	15					*Thraulodes*	631				
Waltzoyphius	21					*Traverhyphes*	2729				
Zelusia	67					*Tricorythodes*	200				
						Tricorythopsis	45				
						Ulmeritoides	267				
						Waltzoyphius	339				
						Zelusia	67				

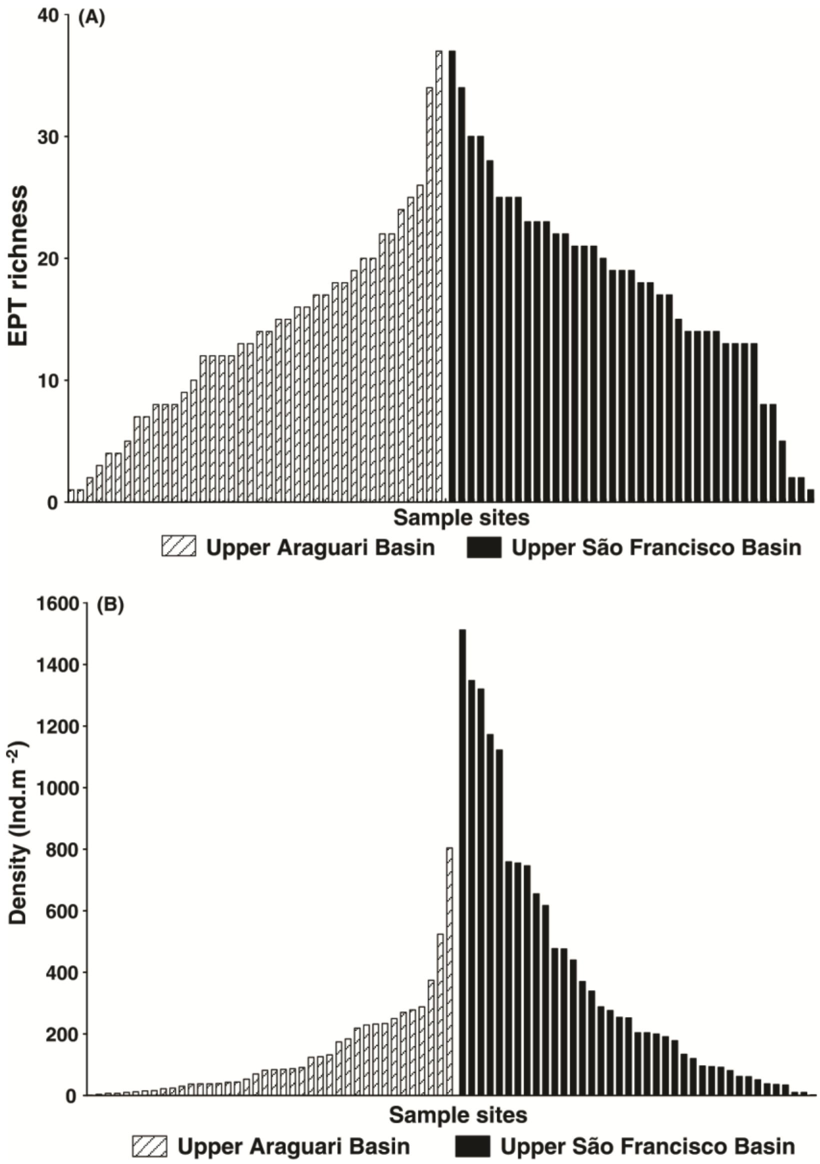

Figure 2. Distribution of (A) EPT richness and (B) individual densities in sites of the Upper Araguari Basin and Upper São Francisco Basin.

Based on the AICc, the best model selected for the Upper Araguari Basin had three predictor variables, achieving an adjusted R^2 = 0.46, and the best model for the Upper São Francisco Basin had four, for an adjusted R^2 = 0.53 (Table 3). The best model selected for the combination of sites of the two basins had four predictor variables, achieving an adjusted R^2 = 0.39. The best models selected for both basins included stream bottom substrate (% cobble, log relative bed stability) and channel size (mean bankfull width, mean width) variables. Additionally, brush cover was important in the Upper Araguari Basin, and the percent of slow water and dissolved oxygen were important in the Upper São Francisco Basin. The combined model again included size (mean bankfull width) and substrate (% cobble) variables, together with mean slope and the variation (SD) in mid-channel canopy density. We analyzed regression residuals to evaluate the validity of model assumptions.

Table 3. Best subsets multiple linear regression (MLR) models of environmental variables explaining EPT richness.

Sites	Model	Metrics	Beta	Beta Std. Err.	*AICc*	Δ*AICc*
Upper Araguari Basin	Four variables	xbkf_w	0.40	0.13	271.65	1.16
		pct_cb	0.43	0.12		
		xfc_brs	0.29	0.12		
		xslope	-0.28	0.13		
		R^2 adj. = 0.51; $F_{(4.38)} = 11.19$; $p < 0.001$				
	Three variables	Metrics	Beta	Beta Std. Err.		
		xbkf_w	0.51	0.12	272.81	
		pct_cb	0.32	0.12		
		xfc_brs	0.23	0.19		
		R^2 adj. = 0.46; $F_{(4.38)} = 12.19$; $p < 0.001$				
Upper São Francisco Basin	Four variables	Metrics	Beta	Beta Std. Err.		
		pct_slow	-0.64	0.14	256.04	-
		lrbs	0.33	0.11		
		xwidth	0.34	0.13		
		DO	-0.36	0.14		
		R^2 adj. = 0.53; $F_{(4.39)} = 13.15$; $p < 0.001$				
Combined Upper Araguari and Upper São Francisco Basins	Eight variables	Metrics	Beta	Beta Std. Err.		
		xbkf_w	0.44	0.10	530,932	0,005
		vcdenmid	-0.16	0.10		
		Pct_cb	0.21	0.10		
		xslope	-0.22	0.10		
		xembed	-0.17	0.10		
		pct_pool	188.87	71.34		
		Pct_gl	168.18	63.50		
		Pct_slow	-180.64	68.20		
		R^2 adj. = 0.44; $F_{(8.79)} = 8.69$; $p < 0.001$				
	Four variables	Metrics	Beta	Beta Std. Err.		
		xbkf_w	0.53	0.10	530,927	
		xslope	-0.19	0.10		
		Pct_cb	0.26	0.10		
		vcdenmid	-0.20	0.10		
		R^2 adj. = 0.39; $F_{(8.79)} = 13.96$; $p < 0.001$				

The CCA axes accounted for little of the variability of EPT assemblages in both basins, achieving a total explanation of only 21% in the Upper Araguari Basin (8% and 4% for axes 1 and 2, respectively, Figure 3a). In this basin, *Hagenulopsis*, *Camelobaetidius* and *Varipes* abundances were correlated with the channel morphology PCA axis. The abundances of those organisms were higher in streams having lower average depths, lower average widths, lower average bankfull widths, and higher slopes and sinuosities. *Cloeodes* and *Polyplectropus* abundances were associated with the riparian PCA1 axis and *Chimarra, Leptohyphes,* and *Phylloicus* abundances were associated with the flow type PCA1 axis. Bed substrate and water quality PCA1 were associated with *Itaura* and *Leptonema* abundances.

In the Upper São Francisco Basin, the CCA axes explained 24% of the total variability in EPT assemblages (axes I and 2 explaining only 9% and 4% of the variability, respectively, Figure 3b). The abundances of *Cyrnellus*, *Campsurus*, and *Macronema* were associated with the channel morphology and water quality PCA1s. Those results indicate that those genera were associated with streams of smaller widths, depths and slopes; lower dissolved oxygen concentrations; and higher sinuosities and turbidities. *Triplectides* and *Asthenopus* abundance was associated with the bed substrate PCA1 axis; *Hermanella, Camelobaetidius,* and *Leptohyphes* were associated with the flow type PCA1 axis; and *Helicopsyche and Massartella* was associated with the shelter PCA1 axis. Although there was considerable overlap in genera occurrences in the two basins (Table 2), we observed no common correlations between individual genera abundances and physical and chemical habitat predictors.

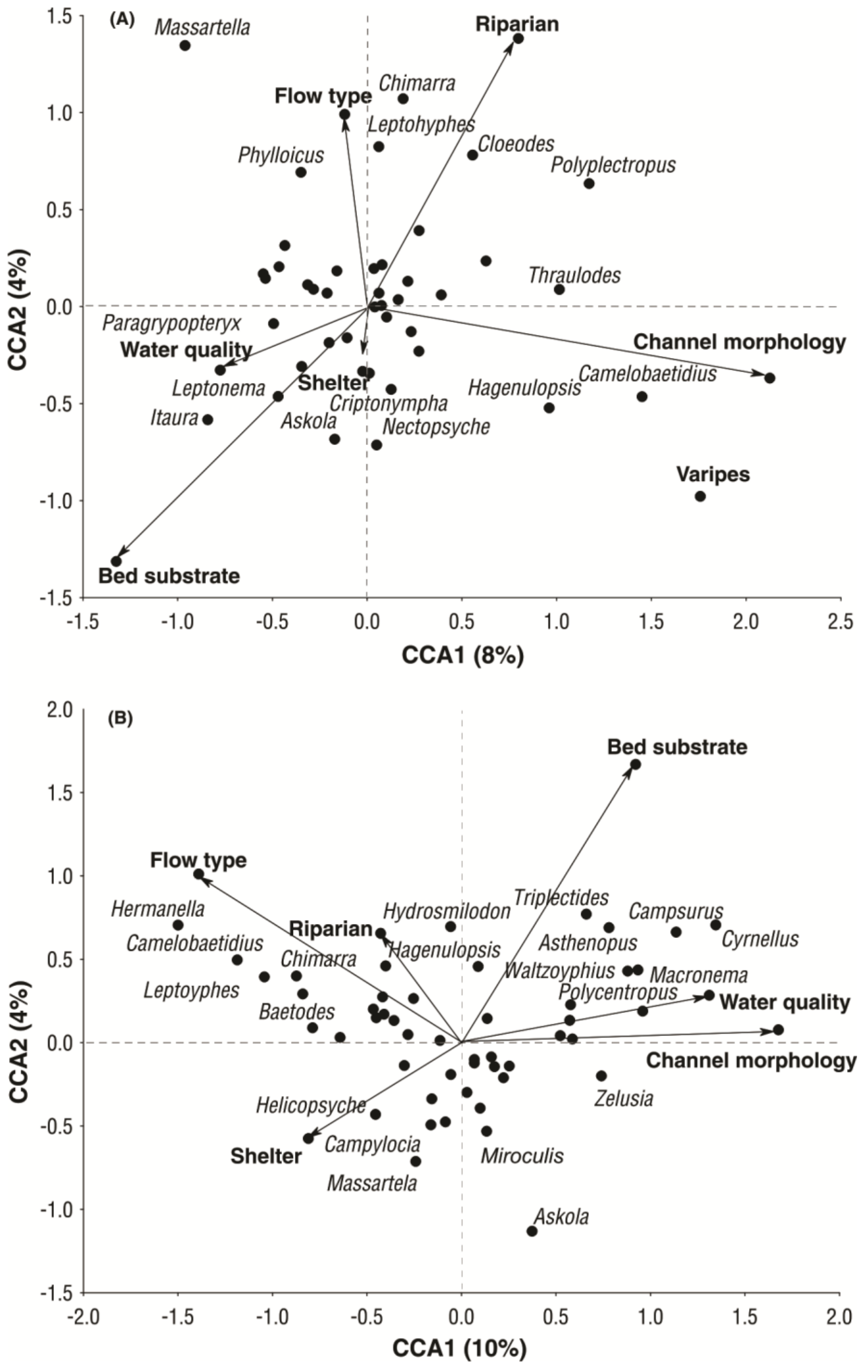

Figure 3. Multivariate relationships (CCAs) between EPT genera and environmental axes in sites of (A) the Upper Araguari Basin and (B) the Upper São Francisco Basin.

The MDS indicated dissimilarity in the composition of EPT genera. The MDS performed on the Jaccard index in the two basins revealed clear dissimilarity (Figure 4a). This separation was confirmed by the PERMANOVA test ($F_{(1, 77)} = 9.91$, $p < 0.001$). The MDS performed with the modified Gower distance (Figure 4b) indicated greater overlap of stream sites of the two basins, although the separation of the basins was also confirmed by the PERMANOVA test ($F_{(1, 77)} = 7.99$, $p < 0.001$).

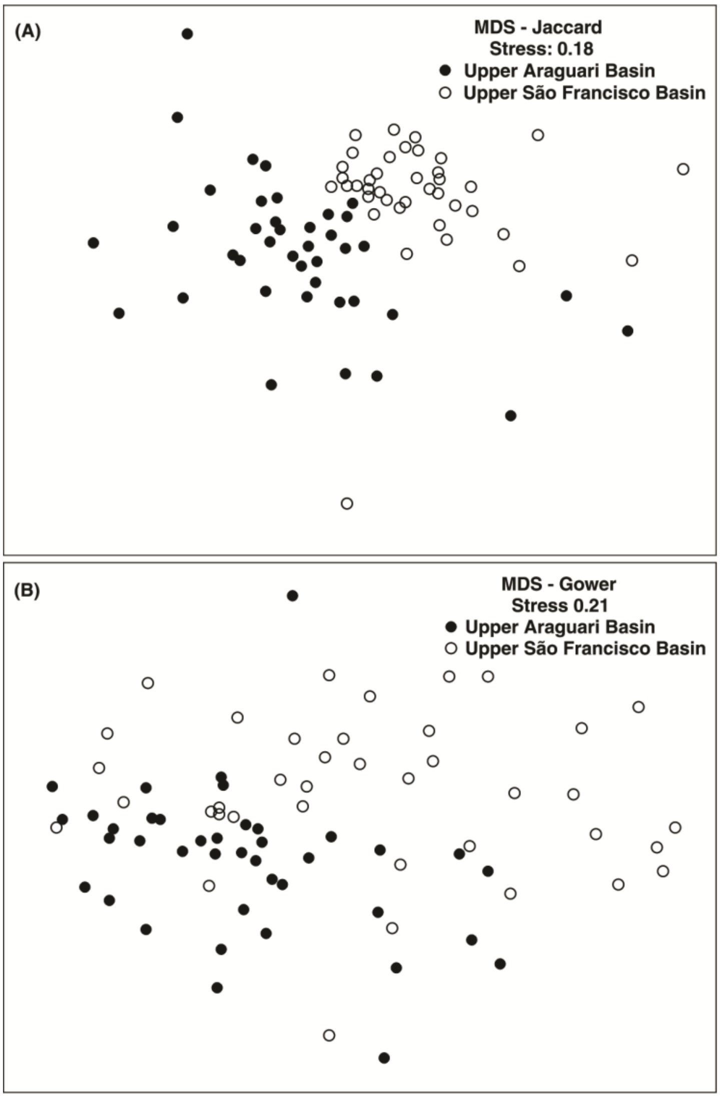

Figure 4. Dissimilarities of Upper Araguari Basin and Upper São Francisco Basin sites in MDS ordinations of (A) Jaccard and (B) altered Gower dissimilarities.

Discussion

Despite significantly greater EPT densities and fewer genera-depauperate sites in the Upper São Francisco Basin (Figure 2), the two basins had similar total EPT generic richness. Nonetheless we found some distinct genera in each basin (Table 2) and the dissimilarity indices revealed differences between the two basins in the structure and composition of their EPT assemblages (Figure 4). The significance of those differences were confirmed in the MDS plots and the PERMANOVA tests, thereby supporting our first hypothesis (EPT assemblage structure and composition differed between basins).

In both basins individually and in the combined model, channel size, streambed substrate, and slope/flow metrics were significant predictors of EPT genera richness, as found by Klemm et al. (2003). However, the specific metrics explaining taxa richness in each of those categories differed slightly between basins: log relative bed stability versus percent cobble, and mean width versus mean bankfull width for the Upper São Francisco Basin versus the Upper Araguari Basin, respectively. In addition, dissolved oxygen was an important predictor in the Upper São Francisco Basin and brush cover was an important predictor in the Upper Araguari Basin. Although the explanatory variables were similar, they differed enough to accept our second hypothesis that different basins would yield different predictors of EPT genera richness. The combined model selected by the AICc, containing four predictor variables, explained a little less of the EPT genera richness than the models of the individual basins according to the adjusted R^2 values, supporting our third hypothesis. This suggests that general regional models can be improved somewhat by incorporating basin-specific information, and is in agreement with Stoddard et al. (2008) and USEPA (2013) who reached similar conclusions for national versus ecoregional models.

The importance of the many naturally varying metrics we analyzed in our models supports the use of such variables or their surrogates in predictive models used in bioassessments. If natural variables in minimally disturbed sites are not incorporated in developing model expectations for macroinvertebrate assemblage condition in disturbed or test sites, the biological assessments will be confounded and inaccurate. For this reason the effects of natural variability on various biological metrics are incorporated in predictive multimetric models to assess the effects of anthropogenic disturbances on assemblages (e.g., Pont et al. 2009, Moya et al. 2011, Marzin et al. 2012a, b, Chen et al. In Press). Future studies should include these approaches, combining field data with laboratory experiments (Woodward et al. 2012) and predictive modeling.

Our MLRs explained nearly half the variation in EPT genera richness. Marzin et al. (2012b), using partial constrained redundancy analyses, reported that reach-scale environmental variables explained only 11% of the variability in macroinvertebrate taxonomic composition of 301 French stream sites. These results may indicate the value of obtaining multiple quantitative physical habitat measurements versus the qualitative observations commonly used in stream surveys (Marzin et al. 2012a, b; Barbour et al. 1999). According to Kaufmann and Faustini (2012) streams with minimally disturbed riparian forest contribute branches and large wood to channels, thereby increasing habitat complexity and habitats that favor increased abundance of macroinvertebrates. Ligeiro et al. (2013) reported that the Upper São Francisco Basin experienced lower levels of agriculture and general anthropogenic disturbance than the Upper Araguari Basin. The small towns and agriculture in the Upper Araguari Basin may be affecting EPT taxa via increased erosion, stream sedimentation, and the resulting degradation of physical habitats and water quality. This, combined with physicochemical parameters (e.g., electrical conductivity, total dissolved solids) and different flow types (Table 1), may have affected site level EPT richness and abundance.

Streambed sediment size is a major factor governing macroinvertebrate richness and abundance. Bryce et al. (2010) described the importance of sediment size for structuring benthic macroinvertebrate assemblages and recommended levels of fine sediments that would protect sediment-sensitive macroinvertebrate and fish taxa in mountain streams of the western USA. Duan et al. (2008) reported a positive relationship between benthic macroinvertebrates, pebbles, and cobbles, which are more stable substrates than sand and fine sediments.

Water quality and the relative occurrence of stream habitat types also affect macroinvertebrate assemblage composition. For example, *Hydroptila* (Trichoptera: Hydroptilidae), are more frequently found in slowly flowing waters and pools (Dolédec et al. 2007). In the case of water quality, the distribution and composition of benthic assemblages is affected by dissolved oxygen (Baptista et al. 2007, Ferreira et al. 2011), and conductivity (Kennedy et al. 2004; Pond 2010).

Our site-scale physical habitat measurements explained little of the distribution and abundance variability of EPT genera composition through use of CCAs. On the other hand, MLR models were better able to explain relationships between taxonomic richness and habitat variables. We stress that MLR models are developed to analyze the variability of a single response variable (in our case, taxonomic richness), whereas CCA analyzes the variability of the whole assemblage composition. Clearly, it is easier to explain the variability of a single response variable than to explain simultaneously the variability of multiple species, which partly explains the differing performances of MLR models versus CCA. Both analyses offer important and complementary insights that help us understand assemblage structure, independently of which analysis explains the greater amount of variability.

In summary, our study showed the importance of site-scale physical habitat factors in understanding differences in EPT assemblage richness of headwater Cerrado streams. Because we used a randomized and spatially balanced survey design, we can confidently assume that the ecological data were representative of the studied region (Stevens and Olsen 2004). We believe that the information contained in this study may be useful for suggesting improved ecological assessment programs, watershed management practices, aquatic ecosystem rehabilitation measures, and protection strategies for Brazilian Cerrado aquatic biota, especially those that limit the amount of sand and fine sediments entering streams.

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Literature Cited

ANDERSON, M. J. 2001. A new method for non-parametric multivariate analysis of variance. Austral Ecology 26:32–46.

ANDERSON, M. J., K. E. ELLINGSEN, AND B. H. MCARDLE. 2006. Multivariate dispersion as a measure of beta diversity. Ecology Letters 9: 683-693.

APHA (American Public Health Association). 2005. Standard methods for the examination of water and wastewater, 21st edition. American Public Health Association. Washington, DC.

BAPTISTA, D. F., D. F. BUSS, M. EGLER, A. GIOVANELLI, M. P. SILVEIRA, AND J. L. NESSIMIAN. 2007. A multimetric index based on benthic macroinvertebrates for evaluation of Atlantic Forest streams at Rio de Janeiro State, Brazil. Hydrobiologia 575: 83–94.

BARBOUR, M. T., J. GERRITSEN, G. E. GRIFFITH, R. FRYDENBOURG, E. MCCARRON, J. S. WHITE, AND M. L. BASTIAN. 1996. A framework for biological criteria for Florida streams using benthic macroinvertbrates. Journal of the North American Benthological Society 15: 185–211.

BARBOUR, M.T., J. GERRITSEN, B. D. SNYDER, AND J.B. STRIBLING. 1999. Rapid bioassessment protocols for use in streams and wadeable rivers: periphyton, benthic macroinvertebrates and fish. 2nd edition. EPA 841-B-99-002. US Environmental Protection Agency, Office of Water, Washington, DC.

BONADA, N., N. PRAT, V. H. RESH, AND B. STATZNER. 2006. Developments in aquatic insect biomonitoring: a comparative analysis of recent approaches. Annual Review of Entomology 51: 495-523.

BOYERO, L., R. G. PEARSON, D. DUDGEON, M. A. S. GRAÇA, M. O. GESSNER, R. J. ALBARIÑO,V. FERREIRA, C. M. YULE, A. J. BOULTON, M. Y ARUNACHALAM, M. CALLISTO,

E. CHAUVET, A. RAMÍREZ, J. CHARÁ, M. S. MORETTI, J. F. GONÇALVES, JR., J. E. HELSON, A. M. CHARÁ -SERNA, A. C. ENCALADA, J. N. DAVIES, S. LAMOTHE, A. CORNEJO, A. O. Y. LI, L. M. BURIA, V. D. VILLANUEVA, M. C. ZÚÑIGA, AND C. M. PRINGLE. 2011. Global distribution of a key trophic guild contrasts with common latitudinal diversity patterns. Ecology Letters 92: 1893-1848.

BRASIL. 1992. Normais climatológicas (1960-1990). Brasília: Ministério da Agricultura e Reforma Agrária, Secretaria Nacional de Irrigação, Departamento Nacional de Meteorologia. 84p.

BRYCE, S. A., G. A. LOMNICKY, AND P. R. KAUFMANN. 2010. Protecting sediment-sensitive species in mountain streams through the application of biologically based streambed criteria. Journal of the North American Benthological Society 29: 657-672.

BURNHAM, K., AND D. ANDERSON. 2002. Model selection and multimodel inference: a practical information-theoretical approach. Springer. New York, New York, USA.

CALLISTO, M., M. MORETTI, AND M. GOULART. 2001. Macroinvertebrados bentônicos como ferramenta para avaliar a saúde de riachos. Revista Brasileira de Recursos Hídricos 6: 71-82.

CHEN, K., R.M. HUGHES, S. XU, J. ZHANG, D. CAI, and B. WANG. In Press. Evaluating performance of macroinvertebrate-based predictive and null modeled multimetric indices (MMI) using multi-season and multi-year samples. Ecological Indicators.

CHAPMAN, L. J., AND C. A. CHAPMAN. 2002. Tropical forest degradation and aquatic ecosystems: our current state of knowledge. Pages 237-249 *in* M. J. Collares-Pereira, I.G. Cowx and Coelho, M. M. (editors). Conservation of freshwater fishes: options for the future. Oxford: Fishing News Books, Blakwell Science.

DINIZ-FILHO J. A. F., L. M. BINI, G. OLIVEIRA, B. S. BARRETO, M. M. F. P. SILVA, L. C. TERRIBILE, T. F. L.V.B. RANGEL, M. P. PINTO, N. P. R. SOUSA, L. C. G. VIEIRA, A. S. MELO, P. DEMARCO JR., C. M. VIEIRA, D. BLAMIRES, R. P. BASTOS, P. CARVALHO, L. G. FERREIRA, M. P. C. TELLES, F. M. RODRIGUES, D. M. SILVA, N. J. SILVA JR., AND T. N. SOARES. 2009. Macroecologia, biogeografia e áreas prioritárias para conservação no Cerrado. Oecologia Brasiliensis 13: 470-497.

DOHET, A., L. ECTOR, H. CAUCHIE, AND L. HOFFMANN. 2008. Identification of benthic invertebrates and diatom indicator taxa that distinguish different stream types as well as degraded from reference conditions in Luxembourg. Animal Biology 58: 419-417.

DOLÉDEC, S., N. LAMOUROUX, U. FUCHS, AND S. MÉRIGOUX. 2007. Modelling the hydraulic preferences of benthic macroinvertebrates in small European streams. Freshwater Biology 52: 145-164.

DOVCIAK, A. L., AND J. A. PERRY. 2002. In search of effective scales for stream management: does agroecoregion, watershed, or their intersection best explain the variance in stream macroinvertebrate communities? Environmental Management 30: 365–377.

DUAN, X., Z. WANG, AND S. TIAN. 2008. Effect of streambed substrate on macroinvertebrate biodiversity. Frontiers of Environmental Science & Engineering in China 2: 122-128.

EGLER, M., D. F. BUSS, J. C. MOREIRA, AND D. F. BAPTISTA. 2012. Influence of agricultural land-use and pesticides on benthic macroinvertebrate assemblages in an agricultural river basin in southeast Brazil. Brazilian Journal of Biology 72: 437-443.

FALCÃO, J. N., F. F. SALLES, AND N. HAMADA. 2011. Baetidae (Insecta, Ephemeroptera) ocorrentes em Roraima, Brasil: novos registros e chaves para gêneros e espécies no estágio ninfal. Revista Brasileira de Entomologia 55**:** 516-548.

FEIO, M. J., R. H. NORRIS, M. A. S. GRAÇA, AND S. NICHOLS. 2009. Water quality assessment of Portuguese streams: regional or national predictive models? Ecological Indicators 9: 791-806.

FERREIRA, W. R., L. T. PAIVA, AND M. CALLISTO. 2011. Development of a benthic multimetric index for biomonitoring of a neotropical watershed. Brazilian Journal of Biology 71: 15-25.

FERRO, M. L., AND R. W. SITES. 2007. The Ephemeroptera, Plecoptera, and Trichoptera of Missouri State Parks, with notes on biomonitoring, mesohabitat associations, and distribution. Journal of the Kansas Entomological Society 80: 105-129.

GOTELLI, N. J. AND A. M. ELLISON. 2004. A primer of ecological statistics. Sinauer Associates Inc., Sunderland, Massachusetts 479p.

GRAÇA, M. A. S., R. C. F. FERREIRA, AND C. N. COIMBRA. 2001. Litter processing along a stream gradient: the role of invertebrates and decomposers. Journal of the North American Benthological Society 20: 408-420.

HAMADA, N., AND S. R. M. COUCEIRO. 2003. An illustrated key to nymphs of Perlidae (Insecta, Plecoptera) genera in Central Amazonia, Brazil. Revista Brasileira de Entomologia 47**:** 477-480.

HARRELL JR., AND E. FRANK. 2001. Regression Modeling Strategies, with Applications to Linear Models, Logistic Regression, and Survival Analysis. 1st edition. Springer-Verlag, New York.

HERING, D., R. JOHNSON, S. KRAMM, S. SCHMUTZ, K. SZOSZKIEWICZ, AND P. F. M. VERDONSCHOT. 2006. Assessment of European streams with diatoms, macrophytes, macroinvertebrates, and fish: a comparative metric-based analysis of organism response to stress. Freshwater Biology 51: 1757-1785.

HUGHES, R. M., A. T. HERLIHY, AND P. R. KAUFMANN. 2010. An evaluation of qualitative indexes of physical habitat applied to agricultural streams in ten U. S. States. Journal of the American Water Resource Association 46: 792-806.

KARR, J., AND D. R. DUDLEY. 1981. Ecological perspectives on water quality goals. Environmental Management 5: 55-68.

KAUFMANN, P. R., AND J. M. FAUSTINI. 2012. Simple measures of channel habitat complexity predict transient hydraulic storage in streams. Hydrobiologia 685: 69–95.

KAUFMANN, P.R., D.P. LARSEN, AND J.M. FAUSTINI, 2009. Bed stability and sedimentation associated with human disturbances in Pacific Northwest streams. Journal of the American Water Resources Association 45:434-459.

KAUFMANN, P. R., P. LEVINE, E. G. ROBISON, C. SEELIGER, AND D. V. PECK.1999. Quantifying physical habitat in wadeable streams. EPA/620/R-99/003. U. S. Environmental Protection Agency, Washington, D. C.

KENNEDY, A.J., D.S. CHERRY, AND R.J. CURRIE. 2004. Evaluation of ecologically relevant bioassays for a lotic system impacted by a coal-mine effluent, using Isonychia. Environmental Monitoring and Assessment 95: 37−55.

KLEMM, D. J., K. A. BLOCKSOM, F.A. FULK, A.T. HERLIHY, R. M. HUGHES, P. R. KAUFMANN, D.V. PECK, J. L. STODDARD, W.T. THOENY, M. B. GRIFFITH, AND W.S. DAVIS. 2003. Development and evaluation of a macroinvertebrate biotic integrity index (MBII) for regionally assessing Mid-Atlantic highlands streams. Environmental Management 31: 656-669.

KLINK, C. A., AND R. B. MACHADO. 2005. Conservation of the Brazilian Cerrado. Conservation Biology 19: 707-713.

KOVALENKO, K. E., S. M. THOMAZ, AND D. M. WARFE. 2012. Habitat complexity: approaches and future directions. Hydrobiologia 685: 1–17.

LAMMERT, M., AND J. D. ALLAN. 1999. Assessing biotic integrity of streams: effects of scale in measuring the influence of land use/cover and habitat structure on fish and macroinvertebrates. Environmental Management 23: 257-270.

LIGEIRO, R., R. M. HUGHES, P. R. KAUFMANN, D. R. MACEDO, K. R. FIRMIANO, W. FERREIRA, D. OLIVEIRA, A. S. MELO, AND M. CALLISTO. 2013. Defining quantitative stream disturbance gradients and the additive role of habitat variation to explain macroinvertebrate taxa richness. Ecological Indicators 25: 45-57.

MADDOCK, I. 1999. The importance of physical habitat assessment for evaluating river health. Freshwater Biology 41: 373-391.

MARONEZE, D. M., T. H. TUPINAMBAS, C. B. M. ALVES, F. VIEIRA, P. S. POMPEU, AND M. CALLISTO. 2011. Fish as ecological tools to complement biodiversity inventories of benthic macroinvertebrates. Hydrobiologia 673**:** 29-40.

MARZIN, A., V. ARCHAIMBAULT, J. BELLIARD, C. CHAUVIN, F. DELMAS, AND D. PONT. 2012a. Ecological assessment of running waters: do macrophytes, macroinvertebrates, diatoms and fish show similar responses to human pressures? Ecological Indicators 23: 56-65.

MARZIN, A., P. VERDONSCHOT, AND D. PONT. 2012b. The relative influence of catchment, riparian corridor and local anthropogenic pressures on fish and macroinvertebrate assemblages in French rivers. Hydrobiologia DOI 10.1007/s10750-012-1254-2.

MELODY, K. J. AND J. S. RICHARDSON. 2007. Riparian forest havesting and its influence on benthic communities of small streams of sub-boreal British Columbia. Canadian Journal of Forest Research 37: 907-918.

MERRITT, R.W., AND K.W. CUMMINS. 1996. An introduction to the aquatic insects of North America. 3rd edition. Kendall/Hunt Publishing Company, Dubuque, Iowa.

MOYA, N., R. M. HUGHES, E. DOMINGUEZ, F. M. GIBON, E. GOITIA, AND T. OBERDORFF. 2011. Macroinvertebrate-based multimetric predictive models for evaluating the human impact on biotic condition of Bolivian streams. Ecological Indicators 11: 840-847.

MUGNAI, R., D. F. BUSS, R. B. OLIVEIRA, C. SANFINS, A. L. CARVALHO, AND D. F. BAPTISTA. 2011. Application of the biotic index IBE-IOC for water quality assessment in wadeable streams in southeast Brazil. Acta Limnologica Brasiliensia 23: 74-85.

MUGNAI, R., J. L. NESSIMIAN, AND D. F. BAPTISTA. 2010. Manual de identificação de macroinvertebrados aquáticos do Estado do Rio de Janeiro. 1ª edição. Technical Books Editora. Rio de Janeiro, RJ, Brasil.

MYERS, N., R. A. MITTERMEIER, C. G. MITTERMEIER, G. A. B. FONSECA, AND J. KENT. 2000. Biodiversity hotspots for conservation priorities. Nature 403: 853-858.

NERBONNE, B. A., AND B. VONDRACEK. 2001. Effects of local land use on physical habitat, benthic macroinvertebrates, and fish in the Whitewater River, Minnesota, USA. Environmental Management 28: 87–99.

OKSANEN, J., F.G. BLANCHET, R. KINDT, P. LEGENDRE, P.R. MINCHIN, R.B. O'HARA, G.L. SIMPSON, P. SOLYMOS, M. HENRY, H. STEVENS, AND H. WAGNER. 2012. Vegan: community ecology package. R package version 2.0.4. http://CRAN.R-project.org/package=vegan

OLIVEIRA, R. B. S, R. MUGNAI, C.M. CASTRO, D. F. BAPTISTA , AND R.M. HUGHES. 2011. Towards a rapid bioassessment protocol for wadeable streams in Brazil: development of a multimetric index based on benthic macroinvertebrates. Ecological Indicators 11: 1584-1593.

OLSEN, A. R., AND D. V. PECK. 2008. Monitoring design and extent estimates for the national Wadeable Stream Assessment. Journal of the North American Benthological Society 27: 822-836.

PAULSEN, S. G., A. MAYIO, D. V. PECK, J. L. STODDARD, E. TARQUINIO, S. M. HOLDSWORTH, J. V. SICKLE, L. L. YUAN, C. P. HAWKINS, A. T. HERLIHY, P. R. KAUFMANN, M. T. BARBOUR, D. P. LARSEN, AND A. R. OLSEN. 2008. Condition of stream ecosystems in the US: an overview of the first national assessment. Journal of the North American Benthological Society 27: 812-821.

PECK, D. V., A. T. HERLIHY, B. H. HILL, R. M. HUGHES, P. R. KAUFMANN, D.J. KLEMM, J. M. LAZORCHAK, F. H. MCCORMICK, S. A. PETERSON, P. L. RINGOLD, T. MAGEE, AND M. R. CAPPAERT. 2006. Environmental Monitoring and Assessment Program - Surface Waters. Western Pilot Study: field operations manual for wadeable streams. EPA Report EPA EPA/620/R-06/003. U.S. Environmental Protection Agency, Office of Research and Development, Washington, DC.

PÉS, A. M. O., N. HAMADA, AND J. L. NESSIMIAN. 2005. Chaves de identificação de larvas para famílias e gêneros de Trichoptera (Insecta) da Amazônia Central, Brasil. Revista Brasileira de Entomologia 49: 181-204.

PINTO, B. C. T., F. G. ARAUJO, AND R. M. HUGHES. 2006. Effects of landscape and riparian condition on a fish index of biotic integrity in a large southeastern Brazil river. Hydrobiologia 556: 69-83.

PINTO, B. C. T., F. G. ARAUJO, V. D. RODRIGUES, AND R. M. HUGHES. 2009. Local and ecoregion effects on fish assemblage structure in tributaries of the Rio Paraíba do Sul, Brazil. Freshwater Biology 54: 2600-2615.

POND, G.J. 2010. Patterns of Ephemeroptera taxa loss in Appalachian headwater streams (Kentucky, USA). Hydrobiologia 641:185−201.

PONT, D., R. M. HUGHES, T. R. WHITTIER, AND S. SCHMUTZ. 2009. A predictive index of biotic integrity model for aquatic-vertebrate assemblages of western U.S. streams. Transactions of the American Fisheries Society 138: 292-305.

RIGHI-CAVALLARO, K. O., K. F. ROCHE, O. FROEHLICH, AND M. R. CAVALLARO. 2010. Structure of macroinvertebrate communities in riffles of a Neotropical karst stream in the wet and dry seasons. Acta Limnologica Brasiliensia 22: 306-316.

ROSENBERG, D.M. AND RESH, V.H. 1993. Freshwater biomonitoring and benthic macroinvertebrates. Chapman and Hall, New York.

SALLES, F. F., E. R. DA-SILVA, M. D. HUBBARD, AND J. E. SERRÃO. 2004. As espécies de Ephemeroptera (Insecta) registradas para o Brasil. Biota Neotropica 4**:** 1-34.

SÁLY, P., P. TAKÁCS, I. KISS, P. BÍRÓ, AND T. ERŐS. 2011. The relative influence of spatial context and catchment- and site-scale environmental factors on stream fish assemblage in a human-modified landscape. Ecology of Freshwater Fish 20: 251-262.

STEVENS D.L. AND OLSEN A.R. 2004. Spatially Balanced Sampling of Natural Resources. Journal of the American Statistical Association 99: 262–278.

STODDARD, J. L, A. T. HERLIHY, D. V. PECK, R. M. HUGHES, T. R. WHITTIER, AND E. TARQUINIO. 2008. A process for creating multi-metric indices for large-scale aquatic surveys. Journal of the North American Benthological Society 27: 878-891.

TEAM, R. D. C. 2012. R: A language and environment for statistical computing. Vienna, Austria: R Foundation for Statistical computing. Retrieved from http://www.R-project.org/.

USEPA (U.S. ENVIRONMENTAL PROTECTION AGENCY). 2013. National rivers and stream assessment 2008-2009: a collaborative survey. Office of Wetlands, Oceans and Watersheds and Office of Research and Development, Washington, DC.

USSEGLIO-POLATERA, P., M. BOURNAUD, P. RICHOUX, AND H. TACHET. 2000. Biomonitoring through biological traits of benthic macroinvertebrates: how to use species trait databases? Hydrobiologia 422/423: 153–162.

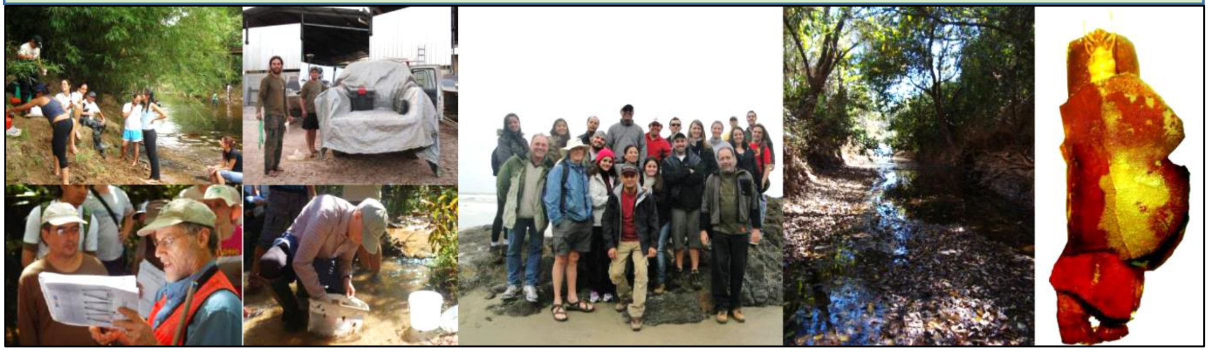
WANTZEN, K. M., A. SIQUEIRA, C. N. CUNHA, AND M. F. P. SÁ. 2006. Stream-valley systems of the Brazilian Cerrado: impact assessment and conservation scheme. Aquatic Conservation: Marine Freshwater Ecosystems 16: 713-732.

WIGGINS, G. B. 1996. Larvae of the North American caddisfly genera (Trichoptera). 2nd edition. University of Toronto Press, Toronto, Canada.

WOODWARD G., M. O. GESSNER, P. S. GILLER, V. GULIS, S. HLADYZ, A. LECERF, B. MALMQVIST, B. G. MCKIE, S. D. TIEGS, H. CARISS, M. DOBSON, A. ELOSEGI, V. FERREIRA, M. A.S. GRAÇA, T. FLEITUCH, J. O. LACOURSIÈRE, M. NISTORESCU, J. POZO, G. RISNOVEANU, M. SCHINDLER, A. VADINEANU, L. B. M. VOUGHT, AND E. CHAUVET. 2012. Continental-scale effects of nutrient pollution on stream ecosystem functioning. Science 336: 1438-1440.

Capítulo 2

"Is the diet of a typical shredder related to the physical habitat of headwater streams in the Brazilian Cerrado?"



Abstract. Macroinvertebrates are important for processing leaf detritus in temperate streams, but their role in tropical streams has been less frequently studied and with conflicting results. We assessed the diet of five instars of *Phylloicus* (Trichoptera: Calamoceratidae) larvae via stomach content analyses, and classified food items into six categories (CPOM – coarse particulate organic matter; FPOM – fine particulate organic matter, algae; animal tissue; vascular plant tissue, and mineral material). Next, we related food categories to stream physical habitat variables (e.g., riparian vegetation, organic matter availability, and morphological characteristics). We sampled sites in two river basins of the Cerrado (Brazilian savanna) with differing types and intensities of land use. We hypothesized that *Phylloicus* larvae from the different river basins would have different feeding strategies and that their diets would be related to the physical habitat. We found that CPOM content was higher in *Phylloicus* larvae of Upper São Francisco sites, and it varied between instars in the two basins. Mineral matter and FPOM were higher in larvae of Upper Araguari sites. FPOM, mineral material, and animal tissue were best explained by multiple linear regression (MLR) models between food items and physical habitat metrics, and plant tissue had the lowest variance. The key physical habitat metrics were mean bankfull height, mean width times mean depth, percentage of total organic matter, average riparian cover, and presence of twigs and snags. We found greater biomass of *Phylloicus* larvae in the Upper São Francisco Basin. We concluded that the larvae had different feeding strategies and fed on different foods in the two river basins. Therefore, trusting in published classifications may be inaccurate, and regional studies of feeding habits are needed for a precise classification of the invertebrate groups in trophic guilds.

Keywords: Savanna, gut contents, hotspot, trophic guilds, tropical river basin.

Introduction

Organic matter from riparian vegetation is the main energy source for detritivorous aquatic organisms of headwater streams and this processing is important for nutrient cycling (Mathuriau and Chauvet, 2002; Gonçalves *et al.*, 2006; Rincon and Martinez, 2006; Davies and Boulton, 2009). The riparian vegetation of Neotropical rivers is rich in plant species, which generate an input of leaf detritus throughout the year (Cheshire *et al.*, 2005; Carvalho and Uieda, 2009; Gonçalves and Callisto, 2013). Leaf decomposition in aquatic ecosystems occurs gradually through the actions of chemical, physical, and biological agents (Gonçalves *et al.*, 2007; França *et al.*, 2009).

Detritivorous invertebrates play an important role in the decomposition of leaves that fall and are transported and accumulated in stream bottoms. Shredder macroinvertebrates feed on these leaves (also known as coarse particulate organic matter - CPOM) and reduce their size, making them available in the form of fine particulate organic matter (FPOM) to other detritivorous organisms and decomposers (Boyero *et al.*, 2011). Usually, shredders exhibit preferences for certain types of leaves according to leaf lignification, nutritional quality, conditioning by microorganisms, and presence of secondary toxic compounds (Graça and Cressa, 2010; Jabiol *et al.*, 2013).

The importance of shredder macroinvertebrates in the decomposition of CPOM in temperate regions has been well documented (Graça, 2001; Graça *et al.*, 2001; Li and Dudgeon, 2008). Some authors have considered the abundance and diversity of shredders higher in temperate streams than in tropical streams because of a stronger adaptation of these organisms to low temperatures (Yule *et al.*, 2009; Boyero *et al.*, 2011) and to the higher nutritional quality and palatability of CPOM in temperate regions (Graça, 2001; Davies and Boulton, 2009; Jabiol *et al.*, 2013).

In contrast, studies of the importance of shredder macroinvertebrates in tropical streams are scarce (e. g. Gonçalves *et al.*, 2006; Becker *et al.*, 2009; Moretti *et al.*, 2009; Boyero *et al.*, 2011; Chara-Serna *et al.*, 2012) and have conflicting results. Some authors emphasized the importance of shredder invertebrates in the dynamics of organic matter in tropical ecosystems (e. g. Motta and Uieda, 2004; Cheshire *et al.*, 2005; Motta and Uieda, 2005). Chará-Serna *et al*. (2012), who studied tropical streams in Colombia, highlighted the importance of stomach content analysis to assess the ecological dynamics of shredder macroinvertebrates. On the other hand, there are studies that point to the scarcity of shredders in tropical streams (Wantzen and Wagner, 2006; Gonçalves *et al.*, 2007; Boyero *et al.*, 2011), where bacteria and fungi are likely more important in the decomposition process (Graça, 2001; Mathuriau and Chauvet, 2002; Gonçalves *et al.*, 2006).

The Cerrado (Brazilian savanna) is the second largest biome in Brazil and harbors considerable animal and plant biodiversity , with a high incidence of endemism; at a global scale the Cerrado is considered a biodiversity hotspot (Myers *et al.*, 2000). However, for over six decades, much of the natural Cerrado vegetation has been replaced by pastures and crops (Diniz-Filho *et al.*, 2009). The removal of the riparian vegetation increases erosion, turbidity, temperature, bed sedimentation and the abundance of aquatic macrophytes, leads to habitat loss, and affects the distribution, richness, and abundance of aquatic invertebrates (Chapman and Chapman, 2002; Kaufmann *et al.*, 2009; Hughes *et al.*, 2010; Kaufmann and Faustini, 2012). For these reasons, shredder diets also can be affected by the availability of CPOM and FPOM.

We assessed the diet of a typical shredder, the *Phylloicus* larvae (Trichoptera: Calamoceratidae), through analysis of stomach contents, aiming at unveiling the relationship between the composition of food items and physical habitat metrics in Cerrado headwater streams. We studied sites in two river basins that differ in land use and disturbance. The main activity in the Upper Araguari River Basin is agriculture, whereas in the Upper São Francisco River Basin the main activity is livestock ranching on small farms (Ligeiro *et al.*, 2013). We hypothesized that *Phylloicus* larvae in different river basins have different feeding strategies and that their diets are related to characteristics of the physical habitat, which in turn are related to riparian vegetation, organic matter availability, and stream morphology. Therefore, we sought to test whether prior trophic classifications long-accepted by invertebrate researchers were dependent on the environmental context.

Methods

Study area

We studied 80 sites in wadeable first to third order streams (Strahler, 1957), in the basins of the Upper São Francisco River (44^{0}30’0”W - 46^{0}0’0”W; 17^{0}0’0”S - 19^{0}30’0”S) and the Upper Araguari River (46^{0}30’0”W - 48^{0}0’0”W; 19^{0}0’0”S - 20^{0}0’0”S), state of Minas Gerais, southeastern Brazil (Figure 1). Both regions are located within the Cerrado biome and have similar climates (humid tropical and high-altitude temperate). Their elevations vary from 520 to 1,300 m a.s.l. The dry season lasts from May to September, with monthly rainfall between 10 and 55 mm, and the rainy season lasts from October to April, with monthly rainfall between 100 and 300 mm. The average annual rainfall is 1,600 mm (Brasil, 1992). The Cerrado is dominated by four major vegetation types (woodland savanna, grassy-woody savanna, savanna park, wetland palm swamps).

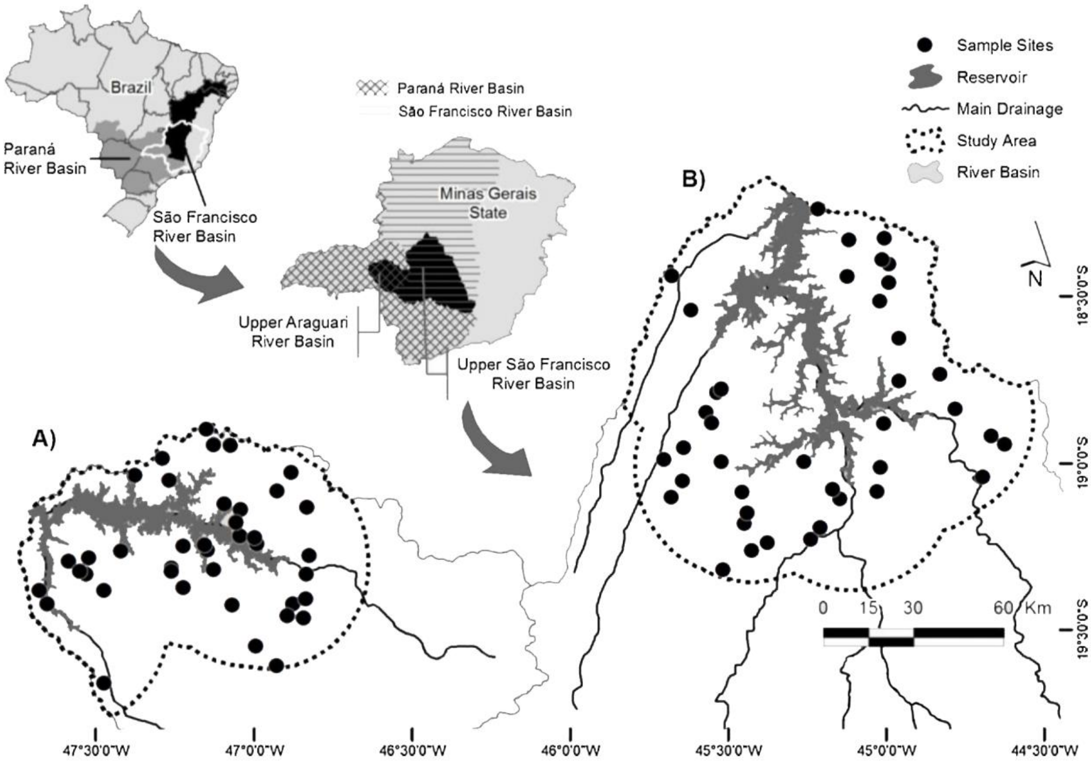


Figure 1. Study area and location of sampling sites in the Upper Araguari River (A) and Upper São Francisco River (B) basins, southeastern Brazil.

Site selection

We selected sites following the method used in the USEPA-EMAP West Wadeable Stream Survey (Olsen and Peck, 2008). This method is based on random selection of sampling points, with a minimum distance of 1 km between points, from a digitized hydrographic network map (master sample). We selected 40 sites in each river basin. We sampled during the dry season, in September 2009 and 2010, in the Upper Araguari River and Upper São Francisco River Basins, respectively.

Physical habitat

We measured physical habitat structure of the stream sites as described by Peck *et al.* (2006). The length of each site was defined as the average width multiplied by 40, with 150 m the minimum length sampled. In each site, we established 11 transversal transects, which were equidistant and perpendicular to the stream and defined 10 longitudinal sections of the same length. In each transect, and along the sections, we assessed physical habitat characteristics, such as channel dimensions (e.g., wetted width and depth, bankfull width and depth), riparian forest conditions (e.g., presence and cover of arboreal canopy and understory), presence of cover in the channel (e.g., undercut banks, fallen trees and twigs, filamentous algae, macrophytes), sediment (e.g., fine and coarse sediments), surface flow types (e.g., fine and coarse sediments, pools, glides and riffles), and presence of organic material (e.g., plant detritus, leaf pack). The calculation of metrics based on physical habitat characteristics measured in the field followed Kaufmann *et al.* (1999).

Collection of benthic macroinvertebrates

In each of the 11 transects we sampled benthic macroinvertebrates with a D-frame net (30 cm wide, 500 µm mesh) in an area of 0.09 m^2, totaling 1 m^2 of sampled area per site. We fixed the samples in the field in 4% formalin. In our laboratory, we washed the samples through a 500-µm sieve and sorted the organisms.

Determination of size classes of Phylloicus larvae

We related larval size classes to development instars, considering the width of the head capsule (mm), following Oliveira and Froehlich (1997). We measured the head capsules under a Leica magnifier (Model MSV266) with a magnification of 50x.

We examined and measured *Phylloicus* larvae under low magnification (5x), and each micrometric unit (MU) was equal to 0.18 mm. The results were expressed in mm. We classified five larval instars (Oliveira and Froehlich 1997): I = 2.52 to 3.06 mm; II = 3.07 to 5.76 mm; III = 5.77 to 8.46 mm; IV = 8.47 to 11.34 mm; and V ≧ 11.35 mm.

Assessment of stomach contents and quantification of food items in* Phylloicus *larvae

We extracted the digestive tract of 72 larvae collected in both river basins at 15 sites with a scalpel under a stereoscopic microscope. We diluted and distributed the food items homogeneously on a Sedgewick Rafter counting cell. Next, we separated and quantified the items (count per field) under the microscope at a magnification of 100x. We quantified the items using 20 random fields (Chara-Serna *et al.*, 2012), which corresponded to 40% of the counting cell, and classified them into six categories following Cheshire *et al.* (2005). The categories were; CPOM (> 50 µm) mainly from leaves, FPOM (≤ 50 µm), algae, vascular plant tissue including roots, animal tissue (carapaces, cerci, legs), and mineral material.

Biomass assessment

We estimated the dry biomass (DM) of *Phylloicus* larvae following Becker et al (2009). This methodology uses the coefficients (a, b) obtained from the regression of dry mass of larvae and Phylloicus body length (L). Then the biomass is estimated by the formula ($DM = a + bL$). We used the values of the regression coefficients obtained by Becker et al. (2009) for *Phylloicus* larvae. Larval length was determined by measuring the distance between the abdominal end to the end of the head through use of a millimetric graduated plate.

Data analysis

Stomach contents of Phylloicus larvae

To test for differences in the composition of food items of *Phylloicus* larvae among size classes and between the two river basins, we carried out a factorial two-way ANOVA, followed by a post-hoc Tukey test. For each food item, we arcsine-transformed data on the proportion of food items counted in the twenty random fields analysed. We analyzed differences in each food item among sites and size classes, as well as the interaction between sites and size classes.

Physical habitats and stomach contents

We used the Pearson product-moment correlation coefficient with 52 physical habitat metrics. We excluded redundant metrics ($r > 0.8$) and retained the metrics that were ecologically more meaningful. For example, average percent canopy density at mid-stream (xcdenmid) was strongly correlated with average percent canopy density at the bank (xcdenbk) ($r = 0.88$). Therefore, we chose the metric xcdenbk, because it was considered more comprehensive. Hence, we selected 20 physical habitat metrics for each river basin (Table 1). We used multiple linear regressions to test for a relationship between each proportion of food item (arcsine-transformed data) and the physical habitat predictor variables, considering sites in both river basins. As *Phylloicus* larvae were found only in 15 sites, we limited the final model to two predictor variables to avoid overfitting. We used the procedure top sub (Harrell, 2001) for creating MLR models. We used the Akaike information criteria corrected values (AICc) to search for the best models (Burnham and Anderson, 2002) and to verify whether the models could be simplified by reducing the number of explanatory variables in each case. When the difference between the values of two models AICC (ΔAICc) was ≤ 2, the reduced model was considered equivalent and thus preferable. For these analyses, we used Statistica for Windows (StatSoft, Inc. from 1984 to 2004 , version 7) and Systat for Windows (version 13.00.05, 2009).

Table 1. Physical habitat metrics. Metrics selected by the MLR model are marked with an asterisk.

Code	Physical habitat	Range: mean (SD)	
		Upper Araguari	Upper São Francisco
xbkf_w	Mean bankfull width (m)	5.11 (1.36)	7.29 (3.36)
xbkf_h	Mean bankfull height (m)*	0.79 (0.17)	0.93 (0.37)
xinc_h	Mean height incision (m)	2.61 (1.38)	3.22 (0.89)
xwxd	Mean width x mean depth (m)*	0.37 (0.22)	1.14 (0.29)
xslope	Channel water surface slope – reach mean (%)	1.19 (0.26)	0.63 (0.65)
sinu	Channel sinuosity (m/m)	11.9 (32.6)	1.02 (0.01)
pct_org	Total organic matter (%)*	0.001 (0.002)	0.22 (0.35)
xcdenmid	Mean mid-channel canopy density (%)	86.5 (6.61)	81.7 (9.98)
xcdenbk	Middle riparian canopy (%)*	91.7 (3.74)	89.7 (7.40)
xmh	Riparian meddle layer herbaceous – cover*	7.57 (2.52)	11.9 (6.50)
xgh	Riparian ground layer herbaceous - cover	19.1 (8.99)	18.0 (5.79)
xgb	Mean exposed soil	34.3 (31.7)	43.1 (13.1)
xc	Riparian canopy (>5 m high) cover	27.2 (16.0)	17.8 (13.3)
xm	Media riparian cover – ground layer intermediary*	34.0 (12.5)	32.1 (8.46)
xg	Media riparian cover – ground layer cover*	34.8 (11.3)	25.3 (6.52)
xcmg	Total riparian cover (%) (all vegetation layers)	96.2 (26.6)	75.3 (15.2)
xpcan	Riparian canopy presence (> 5m high)	0.97 (0.02)	0.85 (0.09)
xpmid	Riparian meddle layer present (fraction reach)*	0.98 (0.02)	0.98 (0.03)
xfc_brs	Brush and small debris (areal proportion)	20.0 (26.9)	3.90 (4.97)
pfc_brs	Brush and small debris presence*	0.85 (0.17)	0.43 (0.42)
xfc_nat	Natural cover in the stream (all)	54.8 (33.6)	65.4 (24.2)

Results

In the Upper Araguari River Basin, we collected 23,348 macroinvertebrates; shredders represented 5.4% of the sample (1,258 individuals). In the Upper São Francisco River Basin, we collected 72,973 macroinvertebrates; shredders represented 1% of the sample (760 individuals). Trophic guilds were classified according to Merritt and Cummins (1996), Cummins et al. (2005), and Chara-Serna et al. (2012). We analyzed 96 larvae: 50 (2.8% of all shredders) from nine Upper Araguari River Basin sites and 46 (6%) from six Upper São Francisco River Basin sites. We found food in the digestive tract of 72 (75%) of the *Phylloicus* larvae; in 25% of the larvae either there was no food or the digestive tract was damaged. The body length range of the larvae was 3.0 - 18 mm and the dry biomass average was of 71.35 mg in the Upper Araguari River Basin. In the Upper São Francisco River Basin, the body length range was 2.5 - 18 mm and the dry biomass average was 96.17 mg (Table 2). FPOM and CPOM were the predominant food items, and together represented over 90% of the total.

Table 2. Estimated average dry biomass of *Phylloicus*.

Site	Body length range (mm)	Regression coefficient		Dry mass (mg) mean (range)	*n*	Dry mass total (mg)
		a	*b*			
Upper Araguari Basin	3.0 – 18.0	-20.24	1.93	13.96 (3.55 – 32.50)	50	71.35
Upper São Francisco Basin	2.5 – 18.0			11.54 (2.59 – 32.50)	46	96.17

FPOM was the main food of larvae of all instars collected from Upper Araguari River Basin sites, followed by CPOM (Figure 2). The lowest percentage of FPOM (86%) was found in instar II and the highest percentage (94%), in instar I. The highest percentage of CPOM was found in instar III (7.4%) and the lowest, in instar I (3.6%). The highest percentage of algae was found in instar II (7.3%) and the lowest, in instar IV (0.6%). Fragments of animal tissue, plant tissue, algae, and mineral material were rare (< 0.2%) in the digestive tracts of *Phylloicus* larvae.

In the Upper São Francisco River Basin sites, FPOM predominated in all larval instars in terms of items per field observed under the microscope, followed by CPOM (Figure 2). The highest percentage of FPOM was found in instar I (90.5%) and the lowest (50.5%), in instar IV. The highest percentage of CPOM was found in instar IV

(42.4%) and the lowest, in instar I (5.6%). Other food items and mineral material were rare in the digestive tract of *Phylloicus* larvae (< 6.0 %).

There was no significant interaction between instars and basins, but there were significant differences between basins. CPOM was more common in the Upper São Francisco River Basin ($F_{(1:14)} = 22.76$; $p < 0.001$) and differed among instars ($F_{(4:72)} = 3.33$; $p = 0.016$) (Figure 2). FPOM differed among sites of the two river basins ($F_{(1:14)} = 29.71$; $p < 0.001$) and among instars ($F_{(4:72)} = 4.24$; $p = 0.004$). Mineral material differed among sites of the two river basins ($F_{(1:14)} = 13.37$; $p = 0.001$). There was no significant differences in algae, plant tissue, or animal tissue between basins (Figure 2).

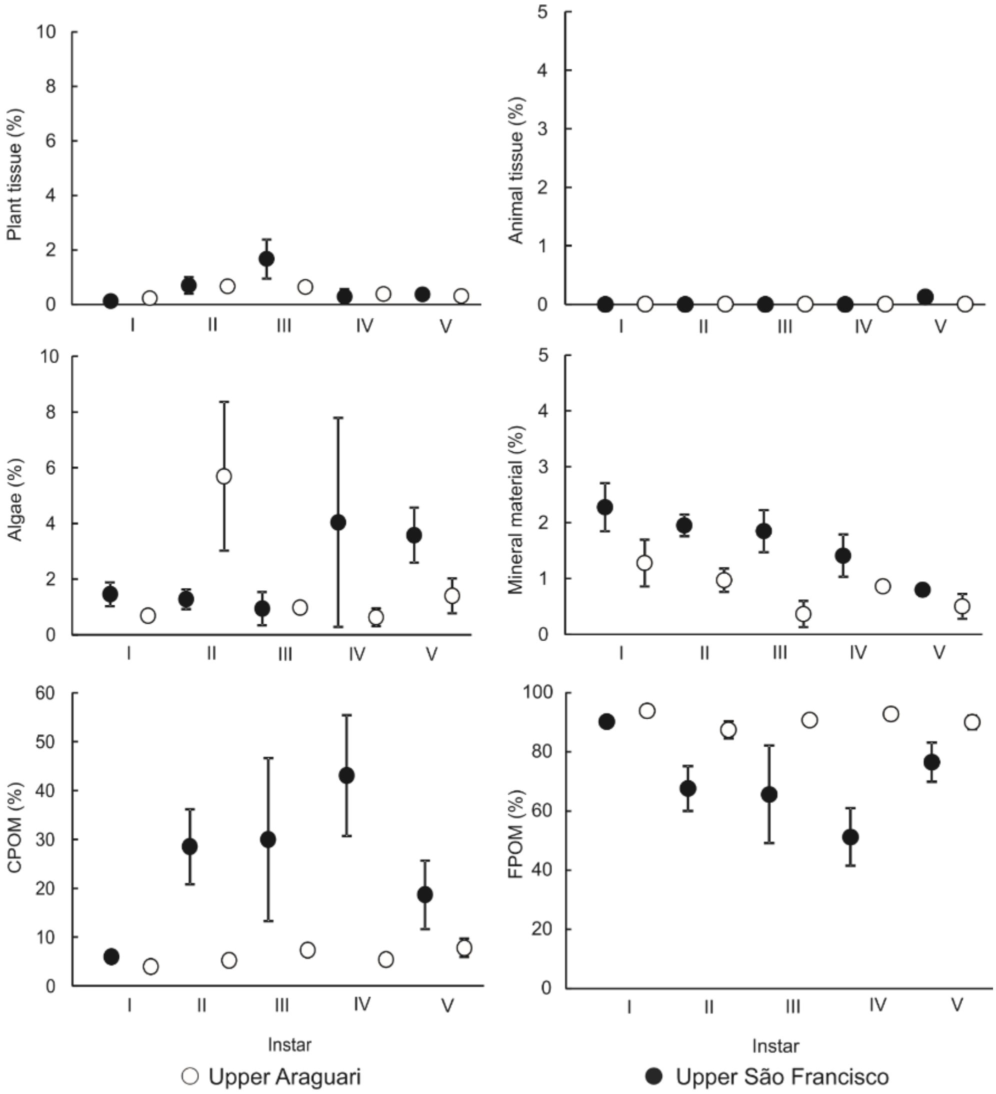


Figure 2. Average proportion and standard error of the food items (proportion of fields in the counting cell that presented each item) for different *Phylloicus* larval instars in the Upper Araguari River and Upper São Francisco River basins. Note the different scales in the Y-axes.

Based on the Akaike criteria (AICc), the best model selected for explaining CPOM had one predictor variable, achieving an adjusted (R2 adj.) = 0.48; FPOM had one variable (R2 adj. = 0.50); algae had two predictor variables (R2 adj. = 0.49); plant tissue had one variable (R2 adj. = 0.05); animal tissue had one variable (R2 adj. = 0.23) and mineral material had two variables (R2 adj. = 0.40) (Table 3). The best models selected for food items of *Phylloicus* included channel morphology (mean bankfull height, mean width x mean depth), organic matter (% total organic matter), riparian cover, and shelter in the channel (instream brush and small debris presence) (Table 3).

Table 3. Multiple linear regressions (best subsets) that explain the composition of food items of *Phylloicus* larvae in the Upper Araguari River Basin and the Upper São Francisco River Basin. See Table 1 for metric definitions.

Sites	food content	Model	Predictor metrics	Beta	Beta Std. Err.	*AICc*	Δ*AICc*
Combined model of the Upper Araguari and Upper São Francisco Basins	CPOM	Two variables	xg	-0.32	0.19	-20.51	0.78
			pfc_brs	-0.58	0.19		
				R^2 aj. = 0.54	$F_{(2, 14)}$ = 9.2		
		One variable	pfc_brs	-0.29	-0.71	-19.73	
				R2 adj. = 0.48	$F_{(2, 14)}$ = 13.95		
	FPOM	Two variables	xwxd	-0.36	0.17	-17.71	0.76
			xg	0.63	0.17		
				R^2 aj. = 0.59	$F_{(2, 14)}$ = 11.46		
		One variable	xg	0.12	0.73	-16.95	
				R^2 aj. = 0.50	$F_{(2, 14)}$ = 14.88		
	Algae	Two variables	xmh	0.46	0.19	-20.66	-
			xg	-0.51	0.19		
				R^2 aj. = 0.49	$F_{(2, 14)}$ = 7.78		
	Plant tissue	Two variable	xcdenbk	0.54	0.24	-89.40	1.3
			xm	-0.54	0.24		
				R^2 aj. = 0.26	$F_{(2, 14)}$ = 3.56		
		One variable	xcdenbk	0,013	0.34	-88.10	
				R^2 aj. = 0.05	$F_{(2, 14)}$ = 1.73		
	Animal tissue	Two variables	xbkf_h	-0.62	0.21	-20.31	1.4
			xwxd	0.46	0.21		
				R^2 aj. = 0.40	$F_{(2, 14)}$ = 5.81		
		One variable	xbkf_h	-0.43	-0.53	-18.92	
				R^2 aj. = 0.23	$F_{(2, 14)}$ = 5.09		
	Mineral material	Two variables	pct_org	1.038	0.22	-67.74	-
			xpmid	0.660	0.22		
				R^2 aj. = 0.40	$F_{(2, 14)}$ = 7.78		

Discussion

Food items and instars

Our study showed the importance of assessing *Phylloicus* diets of different instars to understand changes in the composition and proportion of food items in different instars in headwater streams of the Brazilian Cerrado. As *Phylloicus* larvae are typical shredders, we expected to find significant differences in the composition of items at different larval stages with a predominance of CPOM at the most advanced stages. However, it is usually accepted that tropical stream invertebrates usually exhibit a high plasticity in their feeding habitats, being considered generalists in most cases (Moretti *et al.*, 2007). We found that among the six food items assessed, FPOM predominated in all instars, which makes it possible to relate feeding strategy to physical characteristics of the streams.

Feeding strategies and availability of food resources

The relative proportions of FPOM and CPOM in the digestive tracts suggest that *Phylloicus* larvae of the Upper Araguari River Basin were collector-gatherers, whereas those in the Upper São Francisco River Basin were collector-shredders. FPOM is abundant in small streams of both basins and represents an important food for consumers (Callisto and Graça, 2013). Carvalho and Graça (2007), in a laboratory experiment, showed that larvae of *Seriscotoma vitatum* (Trichoptera) have feeding plasticity according to the availability of CPOM and FPOM. Tomanova *et al.* (2006) observed that the availability of CPOM and FPOM in a tropical Bolivian stream was influenced by physical abrasion and microbial activity. In those environments, it was observed that rapid processing of organic matter resulted in increased availability of FPOM relative to CPOM. The shredder *Adensiops* (Ephemeroptera: Baetidae) was considered a collector-gatherer because of the high proportion of FPOM in its digestive tract, similar to the *Phylloicus* larvae from the Upper Araguari River Basin in our study.

Relationships between physical habitat and food items

Previous studies have shown that the complexity of the physical habitat, at the site scale, influences the composition, biomass and richness of benthic macroinvertebrates, the temporal stability of assemblages, and several ecological processes (Hughes *et al.*, 2010; Kaufmann and Faustini, 2012; Kovalenko *et al.*, 2012; Quinn and Hickey, 1990). We believe that physical habitat characteristics, such as morphology, flow, and substrate types, influence the availability of organic matter and, therefore, influence the diet of macroinvertebrates and biomass. Hence, the different proportions of FPOM and CPOM in the digestive tracts of larvae and biomass differences found in the present study were probably related to environmental differences in disturbance and physical habitat in the Upper Araguari River Basin and the Upper São Francisco River Basin (Ligeiro *et al.*, 2013).Regarding biomass, Quinn and Hickey (1990) observed higher biomass of shredders in streams with greater riparian vegetation densities. Regarding feeding guilds, Tomanova *et al.* (2006) stated that, in order to save energy, shredder larvae tend to change their feeding strategy in streams that are naturally more disturbed, for example, by increased flows resulting from increased rainfall.

Other factors related to human alterations in the physical habitat, for example removal of riparian vegetation, also affect the diet of macroinvertebrates and affect their feeding strategies in response to resource availability. Yule *et al.* (2010) observed that grazing macroinvertebrates exhibited a collector-gatherer behavior given higher FPOM availability in Indonesian streams with physical habitats altered by mining. Our multiple regression analysis showed that FPOM had a close relationship with average stream width and depth, as well as with the presence of riparian vegetation. CPOM showed a close relationship with riparian vegetation and with the availability of cover, such as brush and small debris on the streambed, which are also sites for accumulation of organic matter. Our results corroborate those of Cummins *et al.* (2005) on food and attributes of the physical habitat in streams of southern Brazil.

Abundance of macroinvertebrates shredders in the Cerrado

The relatively low abundance of typical shredders (< 5%) in the two river basins corroborates the literature (Wantzen and Wagner, 2006; Gonçalves *et al.*, 2007; Boyero *et al.*, 2011). However, Brazil is a country with a wide variety of biomes, such as Atlantic Forest, Amazon Forest, Caatinga, Pampa, Cerrado, and Pantanal. Hence, the abundance and importance of shredders likely differs among biomes. Oliveira *et al.* (1999) observed a high abundance of Trichoptera shredders in Amazon Basin streams with dense riparian vegetation. Baptista *et al.* (2007), in an assessment of environmental quality in Atlantic Forest streams, developed a benthic multimetric index and concluded that shredder abundance was important and related to the physical habitat. In contrast, Ferreira *et al.* (2011) observed a low abundance of shredders; collector-gatherers had a stronger relationship with physical habitat in Cerrado streams.

Although *Phylloicus* is often considered a typical shredder, our hypothesis was corroborated because the larvae exhibited different collector-gatherer strategies in the two river basins and the food items showed different relationships with physical habitat. We recommend that classification of benthic macroinvertebrates into feeding guilds should be made on the basis of an analysis of digestive tract contents and from studies of streams experiencing differing degrees of disturbance in multiple biomes or ecoregions. Such studies would reduce the number of misclassifications because aquatic organisms change their feeding strategies according to local environmental characteristics and food availability. We also recommend trophic studies of multiple macroinvertebrate genera in multiple tropical aquatic ecosystems to assess the importance of shredders and collector-gatherers in tropical aquatic food webs relative to those in temperate ecosystems.

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References

Baptista D.F., Buss D.F., Egler M., Giovanelli A., Silveira M.P. and Nessimian J.L. 2007. A multimetric index based on benthic macroinvertebrates for evaluation of Atlantic Forest streams at Rio de Janeiro State, Brazil. *Hydrobiologia*, 575, 83-94.

Becker B., Moretti M.S. and Callisto M. 2009. Length–dry mass relationships for a typical shredder in Brazilian streams (Trichoptera: Calamoceratidae). *Aquat. Insects*, 31, 227-234.

Boyero L., Pearson R.G., Dudgeon D., Graça M.A.S., Gessner M.O., Albariño R.J., Ferreira V., Yule C.M., Boulton A.J., Arunachalam M., Callisto M., Chauvet E., Ramírez A., Chará J., Moretti M.S., Gonçalves Jr J.F., Helson J.E., Chará-Serna A.M., Encalada A.C., Davies J.N., Lamothe S., Cornejo A., Li A.O.Y., Buria L.M., Villanueva V.D., Zúñiga M.C. and Pringle C.M. 2011. Global distribution of a key trophic guild contrasts with common latitudinal diversity patterns. *Ecology*, 92, 1839-1848.

Brasil. 1992. *Normais climatológicas (1960-1990)*. Brasília: Ministério da Agricultura e Reforma Agrária, Secretaria Nacional de Irrigação, Departamento Nacional de Meteorologia, Brasília. 84 p.

Burnham K. and Anderson D. 2002. Model selection and multimodel inference: a practical information-theoretical approach. Springer. *New York, New York, USA*.

Callisto M. and Graça M.A.S. 2013. The quality and availability of fine particulate organic matter for collector species in headwater streams. *Int. Rev. Hydrobiol.*, 98, 132-140.

Carvalho E.M. and Graça M.A.S. 2007. A laboratory study on feeding plasticity of the shredder *Sericostoma vittatum* Rambur (Sericostomatidae). *Hydrobiologia*, 575, 353-359.

Carvalho E.M. and Uieda V.S. 2009. Diet of invertebrates sampled in leaf-bags incubated in a tropical headwater stream. *Zoologia (Curitiba)*, 26, 694-704.

Chapman L. and Chapman C. 2002. Tropical forest degradation and aquatic ecosystems: our current state of knowledge. *Conservation of freshwater fishes: options for the future (MJ Collares-Pereira, IG Cowx & MM Coelho, ed.). Blackwell Science, Oxford*, 237-249.

Chara-Serna A.M., Chara J.D., Zuniga M.D., Pearson R.G. and Boyero L. 2012. Diets of leaf litter-associated invertebrates in three tropical streams. *Ann Limnol-Int J Lim*, 48, 139-144.

Cheshire K.I.M., Boyero L. U. Z. and G. P.R. 2005. Food webs in tropical Australian streams: shredders are not scarce. *Freshwat. Biol.*, 50, 748-769.

Cummins K.W., Merritt R.W. and Andrade P.C. N. 2005. The use of invertebrate functional groups to characterize ecosystem attributes in selected streams and rivers in South Brazil. *Stud. Neotrop. Fauna Environ.*, 40, 69-89.

Davies J.N. and Boulton A.J. 2009. Great house, poor food: effects of exotic leaf litter on shredder densities and caddisfly growth in 6 subtropical Australian streams. *J. N. Am. Benthol. Soc.*, 28, 491-503.

Diniz-Filho J.A.F., Bini L.M., de Oliveira G., Barreto B.S., da Silva M.M.F.P., Terribile L.C., Rangel T.F.L.V.B., Pinto M.P., de Sousa N.P.R., Vieira L.C.G., Melo A.S., de Marco Júnior P.P., Vieira C.M., Blamires D., Bastos R.P., de Carvalho P., Ferreira L.G., Telles M.P.C., Rodrigues F.M., e Silva D.M., da Silva Jr N.J. and Soares T.N. 2009. Macroecology, biogeography and prioritary areas for conservation in the brazilian cerrado. *Macroecologia, biogeografia e áreas prioritárias para conservação no cerrado*, 13, 470-497.

Ferreira W., Paiva L. and Callisto M. 2011. Development of a benthic multimetric index for biomonitoring of a neotropical watershed. *Braz. J. Biol.*, 71, 15-25.

França J.S., Gregório R.S., Paula J.D.A., Gonçalves J.F.J., Ferreira F.A. and Callisto M. 2009. Composition and dynamics of allochthonous organic matter inputs and benthic stock in a Brazilian stream. *Marine and Freshwater Research*, 60, 990-998.

Gonçalves J.F.J. and Callisto M. 2013. Organic-matter dynamics in the riparian zone of a tropical headwater stream in Southern Brasil. *Aquat. Bot.*

Gonçalves J.F.J., Graça M.A.S. and Callisto M. 2007. Litter decomposition in a Cerrado savannah stream is retarded by leaf toughness, low dissolved nutrients and a low density of shredders. *Freshwat. Biol.*, 52, 1440-1451.

Gonçalves J.F.J., Graça M.A.S. and Callisto M. 2006. Leaf-litter breakdown in 3 streams in temperate, Mediterranean, and tropical Cerrado climates. *J. N. Am. Benthol. Soc.*, 25, 344-355.

Graça M.A.S. 2001. The role of invertebrates on leaf litter decomposition in streams–a review. *Int. Rev. Hydrobiol.*, 86, 383-393.

Graça M.A.S. and Cressa C. 2010. Leaf quality of some trropical and temperate tree species as food resource for stream shredders. *Int. Rev. Hydrobiol.*, 95, 27-41.

Graça M.A.S., Cressa C.M.O.G., Gessner T.M.O., Feio M.J., Callies K.A. and Barrios C. 2001. Food quality, feeding preferences, survival and growth of shredders from temperate and tropical streams. *Freshwat. Biol.*, 46, 947-957.

Harrell F.E. 2001. *Regression modeling strategies: with applications to linear models, logistic regression, and survival analysis*. Springer.

Hughes R.M., Herlihy A.T. and Kaufmann P.R. 2010. An evaluation of qualitative indexes of physical habitat applied to agricultural streams in ten U.S. States. *Journal of the American Water Resources Association*, 46, 792-806.

Jabiol J., McKie B.G., Bruder A., Bernadet C., Gessner M.O. and Chauvet E. 2013. Trophic complexity enhances ecosystem functioning in an aquatic detritus-based model system. *Journal of Animal Ecology*.

Kaufmann P.R. and Faustini J.M. 2012. Simple measures of channel habitat complexity predict transient hydraulic storage in streams. *Hydrobiologia*, 685, 69-95.

Kaufmann P.R., Larsen D.P. and Faustini J.M. 2009. Bed Stability and Sedimentation Associated With Human Disturbances in Pacific Northwest Streams1. *JAWRA Journal of the American Water Resources Association*, 45, 434-459.

Kaufmann P.R., Levine P., Peck D.V., Robison E.G., Seeliger C., Health N. and Division E.E.R.L.W.E. 1999. *Quantifying physical habitat in wadeable streams*. Environmental Monitoring and Assessment Program, National Health and Environmental Effects Research Laboratory, Office of Research and Development, US Environmental Protection Agency.

Kovalenko K.E., Thomaz S.M. and Warfe D.M. 2012. Habitat complexity: approaches and future directions. *Hydrobiologia*, 1-17.

Li A.O. and Dudgeon D. 2008. Food resources of shredders and other benthic macroinvertebrates in relation to shading conditions in tropical Hong Kong streams. *Freshwat. Biol.*, 53, 2011-2025.

Ligeiro R., Hughes R.M., Kaufmann P.R., MacEdo D.R., Firmiano K.R., Ferreira W.R., Oliveira D., Melo A.S. and Callisto M. 2013. Defining quantitative stream disturbance gradients and the additive role of habitat variation to explain macroinvertebrate taxa richness. *Ecological Indicators*, 25, 45-57.

Mathuriau C. and Chauvet E. 2002. Breakdown of leaf litter in a neotropical stream *J. N. Am. Benthol. Soc.*, 21, 384-396.

Merritt R.W. and Cummins K.W. 1996. *An introduction to the aquatic insects of North America*. Kendall Hunt.

Moretti M.S., Loyola R.D., Becker B. and Callisto M. 2009. Leaf abundance and phenolic concentrations codetermine the selection of case-building materials by Phylloicus sp.(Trichoptera, Calamoceratidae). *Hydrobiologia*, 630, 199-206.

Motta R.L. and Uieda V.S. 2004. Diet and trophic groups of an aquatic insect community in a tropical stream. *Brazilian Journal of Biolology*, 64, 809-817.

Motta R.L. and Uieda V.S. 2005. Food web structure in a tropical stream ecosystem. *Austral Ecol.*, 30, 58-73.

Myers N., Mittermeier R.A., Mittermeier C.G., Da Fonseca G.A. and Kent J. 2000. Biodiversity hotspots for conservation priorities. *Nature*, 403, 853-858.

Oliveira L., Bispo P., Crisci V. and Sousa K. 1999. Distribuições de categorias funcionais alimentares de larvas de Trichoptera (Insecta) em uma região serrana do Brasil Central. *Acta Limnol. Brasil.*, 11, 173-183.

Oliveira L.G. and Froehlich C.G. 1997. Diversity and community structure of aquatic insects (Ephemeroptera, Plecoptera and Trichoptera) in a mountain stream in Southeastern Brazil. *Acta Limnol. Brasil.*, 9, 139-148.

Olsen A.R. and Peck D.V. 2008. Survey design and extent estimates for the Wadeable Streams Assessment. *J. N. Am. Benthol. Soc.*, 27, 822-836.

Peck D.V., Herlihy A.T., Hill B. H., Hughes R. M., Kaufmann P.R., Klemm D.J., Lazorchak J.M., McCormick F.H., Peterson S.A., Ringold P.L., Magee T. and

Cappaert M.R. 2006. *Environmental Monitoring and Assessment Program - Surface Waters. Western Pilot Study: field operations manual for wadeable streams*. EPA Report EPA EPA/620/R-06/003. U.S. Environmental Protection Agency, Washington, DC.

Quinn J.M. and Hickey C.W. 1990. Characterisation and classification of benthic invertebrate communities in 88 New Zealand rivers in relation to environmental factors. *N. Z. J. Mar. Freshwat. Res.*, 24, 387-409.

Rincon J. and Martinez F. 2006. Food quality and feeding preferences of Phylloicus sp (Trichoptera : Calamoceratidae). *J. N. Am. Benthol. Soc.*, 25, 209-215.

Strahler A.N. 1957. Quantitative analysis of watershed geomorphology. *Transactions of the American Geophysical Union*, 38, 913-920.

Tomanova S., Goitia E. and Helešic J. 2006. Trophic levels and functional feeding groups of macroinvertebrates in neotropical streams. *Hydrobiologia*, 556, 251-264.

Wantzen K.M. and Wagner R. 2006. Detritus processing by invertebrate shredders: a neotropical-temperate comparison. *J. N. Am. Benthol. Soc.*, 25, 216-232.

Yule C.M., Boyero L. and Marchant R. 2010. Effects of sediment pollution on food webs in a tropical river (Borneo, Indonesia). *Marine and Freshwater Research*, 61, 204-213.

Yule C.M., Leong M.Y., Liew K.C., Ratnarajah L., Schmidt K., Wong H.M., Pearson R.G. and Boyero L. 2009. Shredders in Malaysia: abundance and richness are higher in cool upland tropical streams. *J. N. Am. Benthol. Soc.*, 28, 404-415.

CONCLUSÕES

- Os valores de riqueza taxonômica foram semelhantes nas duas bacias. Entretanto, a densidade de organismos foi pelos menos três vezes maior na bacia do alto rio São Francisco, devido ao melhor estado de conservação dos riachos.
- Os modelos estatísticos aplicados foram importantes na explicação da distribuição e abundância dos gêneros de EPT. Entretanto, o modelo de regressão múltipla apresentou os maiores valores de explicação da riqueza do que o modelo CCA para ambas as bacias estudadas.
- Em ambas as bacias a riqueza de EPT foi explicada principalmente por métricas de habitats físicos relacionadas aos componentes estruturais morfológicos das bacias como tipos de fluxos rápidos e lentos, profundidade, largura e declividade, mas os valores diferiram entre as duas bacias.
- Os parâmetros físicos e químicos de coluna d'água apresentaram baixo potencial de explicação de riqueza de EPT, com exceção do oxigênio dissolvido que foi importante na bacia do alto rio São Francisco. O baixo potencial de explicação pode ser devido aos baixos valores encontrados mesmo nas áreas mais perturbadas que apresentaram valores abaixo dos limites estabelecidos pela Resolução CONAMA 357/2005 para águas de classe 2, com exceção dos poucos riachos localizados dentro das cidades e que recebem esgotos sem tratamento adequado.
- Larvas de *Phylloicus* foram mais abundantes na bacia do alto rio São Francisco, devido às melhores condições ecológicas dos riachos.
- Os *Phylloicus* apresentaram estratégias alimentares diferentes na duas bacias devido à maior disponibilidade de MOPF na bacia do alto rio Araguari.

PERSPECTIVAS FUTURAS

Os resultados desta tese são frutos de um grande esforço na busca do melhor entendimento das relações de macroinvertebrados aquáticos com os habitats físicos. Entender os processos e padrões ecológicos em ecossistemas aquáticos e como os organismos interagem com o ambiente pode ser fundamental no processo decisório e na proposição de medidas de conservação desses ecossistemas.

Futuros estudos devem considerar:

- Avaliar influências das características dos habitas físicos na riqueza, distribuição e abundância de macroinvertebrados nas diferentes escalas espaciais levando em conta desde a microescala (micro-habitat) a escalas maiores (escala de bacia), considerando métodos de partição de diversidade e modelos nulos.
- Ampliar a abordagem de análises de conteúdos alimentares que levem em conta os grupos tróficos funcionais evitando assim classificações imprecisas tendo em vista que os macroinvertebrados em diferentes ambientes podem exibir estratégias alimentares distintas.
- Relacionar a integridade de zonas ripárias com a abordagem de grupos tróficos funcionais de macroinvertebrados bentônicos em riachos de cabeceira no Cerrado.

Anexos

Tabela 7. Macroinvertebrados coletados em riachos (*Nova Ponte Master Sample* - NPMS) na bacia do alto rio Araguari a montante do reservatório de Nova Ponte, MG.

	NPMS																			
Taxa	8	12	16	28	47	52	54	55	75	92	95	96	97	100	108	110	112	128	132	139
Annelida																				
Hirudinea				4	2						1	1					2	1		2
Oligochaeta	3	1			56	16	14	2	12	2	26	1	254	12	30		16	10	2	108
Arthropoda																				
Arachnida																				
Hidracarina				2	2		4									1		1		
Crustacea																				
Ostracoda																				
Insecta																				
Coleoptera																				
Dryopidae					5						1							1		1
Dytiscidae	2	2	4				2		2					5			2		1	
Elmidae	44	19	90	2	2	16	333	26	115	1	193	22	77	130	9	7	14	19	27	267
Gyrinidae	1		1					1	2			1		2						1
Hydrophilidae		1	3		1	1	55		2				4	3			64	1		
Lutrochidae											2				3			1		
Psephenidae		10	8				2		8			1	5	10	1	5	6			2
Ptilodactilidae																			1	
Scirtidae						1														
Staphylinidae																				1
Diptera																				
Ceratopogonidae	1	2	3	2	3		5	1	9		5			24	3	1	10	7	1	8
Chironomidae	47	141	305	106	20	44	325	393	463	51	492	64	231	597	145	14	249	254	65	592
Dolichopodidae					3				3					7						
Empididae		13		2		5	3	2	8		6			5	9		3	5	2	12
Muscidae					1															
Psychodidae											1									
Simuliidae	15	1	4	1	1	3	6	10	2	4	3	7	57	36	56	35		5		72
Syrphidae					2															
Tabanidae			2		1			6	1					1			4		1	
Tipulidae	3		52			1	99	6	43		2	10		8	3		1		1	3
Ephemeroptera																				
Baetidae	5	6	10		1	10	26	1	206		2	7	31	99	22	18		1	6	41
Caenidae	1	2	9				1	2	4	8	19	1	6	53			1	2	5	
Euthyplociidae		1	2											1						
Leptohyphidae	17	13	52	3		12	12	9	165		61	12	226	150	18	23	2		42	12
Leptophlebiidae		8	206				107	1	447	3	73	5	60	179			4		9	123
Heteroptera																				
Belostomatidae		1												1			1			
Mesoveliidae																		1		
Naucoridae		6	6		8		7		14	6	2	2		24		1		4	2	10
Notonectidae																		1		1
Pleidae		1	3						10		28		1	2						
Veliidae	1	3		1	1		1		5				12	1	2					1
Lepidoptera																				
Pyralidae	1			1							1		1	1	2		2		2	
Megaloptera																				
Corydalidae	1		8		1	1	2	1	3				1		3				1	1
Sialidae	3							2			4									

Continuação da Tabela 7.

Odonata																				
Aeshnidae		1	1																	
Calopterygidae		1				4	2	1	4			1	2	6	1		7	1	3	1
Coenagrionidae	2	4	12	3		2	11	2	11			1	12	9			7		1	8
Corduliidae						1														
Gomphidae				11	8			2	5		4		5	1	2	1	4	5		13
Libellulidae	1	1	2	2	7	5	4		2	1	1		8	14	2		4			1
Megapodagrionidae			1				3		1		1		5	3					1	
Plecoptera																				
Perlidae	9	5	16			7	14		22			1	28	25	3	1	1		16	70
Grypopterygidae						212			9		66		15	2	22	10	1		1	
Trichoptera																				
Calamoceratidae		1		2				1	4		1			1					3	
Ecnomidae	1								11			1	1	4						
Glossosomatidae		3	3				97		3				7	11	30	3				3
Helicopsychidae			1				2		3					2						
Hydrobiosidae			1				2						1	1						
Hydropsychidae		3	11		10	12	30	2	43		1	9	45	29	45	8	2		1	14
Hydroptilidae			1				2		2					3						
Leptoceridae	8	1	3			21	4		11		47	1	7	11			3		18	
Odontoceridae	10	5	3			2	4	6	4		8	1	1	11	3		1	2	1	11
Philopotamidae									5				23							
Polycentropodidae		1	6						24										3	
Mollusca																				
Bivalvia					61		1	2	2		6		2	1						
Nemathelminthes																				
Nematoda					2														2	
Platyhelminthes																				
Turbellaria																				
Planariidae																		1		11
Total/Indivíduos	176	257	829	142	198	376	1180	479	1690	76	1057	149	1128	1485	414	128	411	323	218	10716

Continuação da Tabela 7.

	NPMS																			
Taxa	144	187	192	203	228	240	251	287	368	375	443	511	1524	2991	5612	7308	9611	9757	12892	15048
Annelida																				
Hirudinea						2				1								4		1
Oligochaeta	5	1	4	14	1	11	6	8	11	16	6	3	11	14	16	13	2	66	11	39
Arthropoda																				
Arachnida																				
Hidracarina		1					1	2			1	9				1		1	2	
Entognatha																				
Collembola	1	1																		
Crustacea																				
Ostracoda																		3		
Insecta																				
Coleoptera																				
Curculionidae										1										
Dryopidae							1													
Dytiscidae	1	5		10		1	4	1	1	2				6		1		1		1
Elmidae	30	25	77	27	10	6	39	144	53	70	80	117	394	59	28	21	11		17	22
Gyrinidae		4					1	2			2	3	2	1				1	1	
Hydrophilidae	1	1		5						5	2				1	1	1		1	
Lutrochidae											2					2				1
Noteridae								1												
Psephenidae	1	4	8	9			4		17	3		1					4			
Ptilodactilidae							1													
Scirtidae				3									7							
Staphylinidae																	1			
Diptera																				
Ceratopogonidae		2		5		2		6	4	25	5	1	1	1	1	13		1	2	
Chironomidae	170	108	29	358	97	665	113	370	312	407	98	275	132	573	98	279	71	144	154	125
Dixidae										2						2				
Dolichopodidae				1																
Empididae		4		4	3		4	17	3	10	1	12	2	10	1	8	1	18	7	2
Muscidae		1							2											
Phoridae								1												
Psychodidae		1																		
Simuliidae	66	14		37	123	3	20	98	24	1	13	7	486	45	42	43	15	760	59	238
Stratiomyidae										2										
Tabanidae	4						3			2			1							
Tipulidae	2	1	5	10	2	7		4	13	10	4	3	7		6	4	5		6	
Ephemeroptera																				
Baetidae	24	15		89	18		18	5	3	3	6	6	60	37	2	8	12		29	34
Caenidae	15	3					3		2		2					3				
Euthyplociidae				3			1									1				
Leptohyphidae	62	10	2	17	59	6	97	18	34	36	15	66		59	3	50	23		4	43
Leptophlebiidae	29	7		88		5	22	7	18		2	1		81		11			7	

Continuação da Tabela 7.

Heteroptera																				
Belostomatidae				1		1												1		
Corixidae	1													1						
Gerridae				1										1						
Naucoridae	16	1	1				8	8	3	7	3	12	4	19		2			7	
Pleidae				1							1			6		6				
Veliidae				1		10			1		1		4							
Lepidoptera																				
Pyralidae				3	2		2	1	1	1						5	2			
Megaloptera																				
Corydalidae		1	1	2	1		1			1		1	2	1		1	1			1
Sialidae						1		1		1										
Odonata																				
Aeshnidae				1																
Calopterygidae	2	1		1			2	1	1	13	1	3	2	3				2	1	
Coenagrionidae	3	2		7		1		3		7	1	1	8	2		1	1		1	
Corduliidae				3		1														
Gomphidae		2				3		3		3	5	1		5		1				
Libellulidae	1			3	1			2		4				1	1			5	1	2
Megapodagrionidae				3			1			1										1
Plecoptera																				
Perlidae	2	8	4	8		4	28	9	2	3		9	44	18		4	10		12	1
Grypopterygidae	13	5	9	54	43	1	5	2			15			10	4	40	9		7	1
Trichoptera																				
Calamoceratidae	1			27		6				2						4				
Ecnomidae										1										
Glossosomatidae	2	1			8		1		1	2	2	10		18			2		6	6
Hydropsychidae	8	1	9	19	45		15	6	13	1	2	4	131	39		3	24		13	4
Hydroptilidae					1		4	1		2		3		3						
Leptoceridae	2	1		9	1	21		3	13		1	6				19	5			
Odontoceridae	5	3		12	7	1	5	2	5		1	1	18	4	7	9	1	1	2	
Polycentropodidae				2			2	1												
Mollusca																				
Bivalvia				1				24		2	2			2						
Nemathelminthes																				
Nematoda																		3		
Platyhelminthes																				
Turbellaria																				
Planariidae											1	1	1							9
Total/Indivíduos	467	234	149	839	422	758	412	751	537	647	275	556	1317	1019	210	556	201	1011	350	531

Tabela 8. Macroinvertebrados coletados em riachos (*Três Marias Master Sample* - TMMS) na bacia do alto rio Araguari a montante do reservatório de Três Marias, MG.

	TMMS																			
Taxa	3	7	9	27	28	33	40	43	58	72	82	88	90	91	106	119	126	133	134	137
Annelida																				
Hirudinea							1		2		5									4
Oligochaeta	27	6	32		177	13	60	19	46	11	33	42	1	43	32	15	6	16	2	49
Arthropoda																				
Arachnida																				
Hydracarina	1							2	5						5	4	2			4
Entognatha																				
Collembola	2		1			4						1						2		
Insecta																				
Coleoptera																				
Chrysomelidae																				
Curculionidae																1	1			
Dryopidae																1				
Dytiscidae		1	4					3	4		3	9	1	15		19	1		3	2
Elmidae	55	23	41	12	20	49	33	26	97	104	267	70	33	137	7	184	60	28	56	656
Gyrinidae	7	1								1				1		1				1
Hydrophilidae	1	1				1	3		1	1		1	2						8	
Lutrochidae	11															8	12			7
Noteridae											3									
Psephenidae					4	19	23		2			10							11	
Ptilodactylidae																2				
Scirtidae							1												2	
Diptera																				
Ceratopogonidae	7	15	52	4	73	18	34	48	121	27	18	73	22	32	16	15	33	35	36	11
Chaoboridae									2			8			3					3
Chironomidae	705	458	1927	88	1070	209	693	589	1446	309	527	2114	324	602	204	579	425	690	1747	482
Culicidae	1	2	52			6			17		2	8	9		6	2	22	3	3	5
Dolichopodidae					4					1										
Empididae	3										3			9		6		3	1	
Muscidae	1																			1
Psychodidae									1											
Simuliidae	2621	3		11	8			2820	387	120			36	742		41		229		
Tabanidae					4	1		3		1		1	1	1				1	2	
Tipulidae	24	1	4		2	1	2	1	14	3		4	3	12			1	3	9	
Ephemeroptera																				
Baetidae	75	60	178	34	151	118	603	90	649	33	5	240	284	274	34	10	98	18	27	49
Caenidae		5	7	1	115	15	65	20	202	53		56	11	13	17	1	4	3	8	153
Ephemeridae		4																		
Euthyplociidae							4	1					18						1	
Leptohyphidae	156		12	9	428		39	14	65	39	12	88	1	106		1	2	1	14	21
Leptophlebiidae	401	20	10		92	66	60	59	361	30	10	83	174	224	7	7	70	5	61	39
Polymitarcyidae										1	9					3	2			22
Heteroptera																				
Corixidae			2			2		2	13	3		6	14							3
Gelastocoridae														1						
Gerridae								1				1								
Hebridae				1								1								
Mesoveliidae						2														
Naucoridae		9	8						2	3		4	2	40		7	13	5	4	2
Notonectidae				2								2		1						4
Pleidae		1			1		11				4									
Veliidae	3			3		3	1	1	6	1				1		1				

Continuação da Tabela 8.

Lepdoptera																				
Pyralidae	1			1		1														
Megaloptera																				
Corydalidae				1					1	2			2	3						
Sialidae		2				1										2	1	6		
Odonata																				
Aeshnidae				1																
Calopterygidae	1	1		25		1		2		1			1	1		4		1		
Coenagrionidae	14	6	8	5		8	4	3	18	8		1	26	12		15	4	11	24	4
Corduliidae						2	3													
Gomphidae	6	12	12			2	6	13	3	2	21	1	2	1		19	5	1	1	11
Libellulidae	3	1	14	17	1	6	5	9	23	1	3		7	13	1	3	4	11	2	3
Megapodagrionidae				1			2	4					3					1		
Perilestidae					3								1							
Plecoptera																				
Perlidae	1				8	1		1	10	11			22	42		5				
Gripopterygidae					1															
Trichoptera																				
Calamoceratidae									1	1	1								24	
Ecnomidae						1							1							
Helicopsychidae							3	10	2			12								
Hydrobiosidae								2	7					1						
Hydropsychidae	135	5		2	1	1			66	91	2			32	1	72	6	1		19
Hydroptilidae			5	4	51			2	1	5		6	5	18						
Leptoceridae	2	5			1	4	5	7	2				2	8		11	8	5		5
Odontoceridae			12			4	2	2	5	6		3	5	1	3			4		
Philopotamidae	3	1		1					26	2				689						
Polycentropodidae	9	10		4	3	5			3	6	1		13			1	30	2	1	8
Mollusca																				
Bivalvia	1	2		2			1	7		4	33		1			162	26	12		80
Gastropoda																				
Ancylidae							4				6									49
Hydrobiidae											5					37				
Physidae											1					5				
Limnaeidae			1																	
Planorbiidae				1							3				8	11		6		26
Nemathelminthes																				
Nematoda														8		3				
Platyhelminthes																				
Turbellaria																				
Planariidae									33											
Total de indivíduos	4277	655	2382	230	2218	564	1668	3761	3644	881	977	2845	1027	3083	344	1258	836	1103	2047	1723

Continuação da Tabela 8.

	TMMS																			
Taxa	159	171	178	183	187	193	209	214	220	279	283	290	296	381	391	437	1865	3195	3962	6757
Annelida																				
Hirudinea							5	2					2	9	1	12	14		12	
Oligochaeta	35	179	46	54	13	259	194	76	143	237	3	3	193	45	24	227	215	47	240	448
Arthropoda																				
Arachnida																				
Hydracarina	1	2	3		24	3	2		8	2		1				7	3	11	1	
Entognatha																				
Collembola																				
Insecta																				
Coleoptera																				
Chrysomelidae			1																	
Curculionidae																		1		
Dryopidae												1	2							
Dytiscidae	2				9			3	1			1			2	1		6	22	
Elmidae	104	355	258	69	124	36	11	3	205	124	11	1	217	1	18	1048	958	10	96	
Gyrinidae						1			1				2					1		
Hydrophilidae								3				1		1	1		1		1	
Lutrochidae		2			1	2											5			
Noteridae														1						
Psephenidae									9				4							
Salpingidae														1						
Scirtidae								1	1			4								1
Staphylinidae								1				1								
Diptera																				
Ceratopogonidae	37	36	67	39	50	1	38	118	22	6	12	12	75	5	66	27	8	5	44	
Chaoboridae				1													17		30	
Chironomidae	570	599	1281	1248	553	881	769	300	677	788	469	181	752	328	596	1056	249	763	1277	2751
Culicidae				4	1		4	3	10			21	1	2			15	1	20	37
Dolichopodidae		1							1						3					
Empididae	1	5	7	4	5	5	1		2	12	2		3			11				
Psychodidae									4				4							
Simuliidae		140	73	282	108	4			277	293	347	62	127	2	51	2153				
Stratiomyidae													1							
Tabanidae					17			1	2								2			
Tipulidae	8	5	17		3	11			2	2	1			1	3	1				
Ephemeroptera																				
Baetidae	112	216	355	14	246	20	19	9	229	124	299	35	178		45	1050	164	6	87	
Caenidae	9	1	237	4	18	1	4		72		1	1	41		1	11	21	1	39	
Ephemeridae										2										
Euthyplociidae	2	2			2								2							
Leptohyphidae	172	199	355	79	28	25			878	82	22		193		6	33	38		7	
Leptophlebiidae	17	118	94	19	157	4			273	16	34		95		9	40	20		10	
Polymitarcyidae		1			16		30						16			39	6		1	
Heteroptera																				
Belostomatidae									1			2				1	2		1	1
Corixidae		11			11								12		1	3			18	
Gerridae	1		1										2				1	1		
Mesoveliidae									3				1		6					
Naucoridae	6	5	3		7	6			8	1	4	1	7			12	5	10	2	
Notonectidae	1		1	1																
Pleidae	1	3			2	3			12		1									
Veliidae			1	1					1						1					

Continuação da Tabela 8.

Lepdoptera																				
Pyralidae		11	1						1		6		3		7	1			2	
Megaloptera																				
Corydalidae		1		1	2															
Sialidae					1		2					1					1			
Odonata																				
Aeshnidae																		1		
Calopterygidae	1				8	1										6	1		14	
Coenagrionidae		3		19	5	5	3	3	5	5	6	4	15		4	15	5	4	11	
Corduliidae																				
Gomphidae	3	2	6	4	24	1	2				2	1	2		6	7	11	4	1	
Libellulidae	10	16	3	25	3	7	1	10	27	1	4	17	16	3	13	10	5	3	21	
Megapodagrionid					4															
Perilestidae					1															
Plecoptera																				
Perlidae		15	36		24				25	6	2		14			2				
Trichoptera																				
Calamoceratidae					17				5				1							
Ecnomidae					2				1				2							
Glossosomatidae	1		5		1								2							
Helicopsychidae		2			4						1		4							
Hydrobiosidae			20	3	3				1		11									
Hydropsychidae		50	16	1	11	4		1	56	20	33		44		14	70	10		2	
Hydroptilidae	34	8	33	4	10				4	11		2	74		4	12	3		1	
Leptoceridae	5		27	7	6	3	4		21	1			4	2	2		7		9	
Odontoceridae		1			10	2					1		2				8	3	1	
Philopotamidae		39	9						14		1		10		1					
Polycentropodida	2		19	8	1	6	38		7	8	1		10		3	15	6		24	
Mollusca																				
Bivalvia		39	26	9	4	22	24			32	1		1	20	3	128	240	641	3	
Gastropoda																				
Ancylidae				3					10	1					1	1	13		1	
Thiaridae			1													8	1			
Physidae																	1		1	9
Planorbiidae								19								17	37			
Nemathelminthes																				
Nematoda			1									1								
Platyhelminthes																				
Turbellaria																				
Planariidae	1	12	1		1								6			7	10			
Total/Indivíduos	113	207	300	190	153	131	115	55	301	177	127	35	214	42	89	603	210	151	199	324

Protocolo de caracterização de habitats físicos desenvolvido e utilizado pela Agencia de Proteção Ambiental Norte-Americana (US-EPA) (Peck et al. 2006).

PROTOCOLO DE VERIFICAÇÃO DO CANAL - RIACHOS/RIOS

Revisado por (iniciais): ____

NOME DO LOCAL:		DATA: __ / __ / ____	VISITA: 0 1 2 3
IDENTIFICAÇÃO DO PONTO (ID):		Não se esqueça de registrar o comprimento do trecho na volta.	EQUIPE:

COORDENADAS GPS - UTM (m)	Seção	Alt. (m)	Coordenada Leste (X)	Coordenada Norte (Y)	Zona UTM
					.
					.

DETERMINAÇÃO DO TRECHO DO RIO/RIACHO

Largura do canal usada para definir o trecho:	DISTÂNCIA (m) DO X-SITE		Comprimento total do trecho amostrado (m):	Comentário
	Comprimento a jusante	Comprimento a montante		

EQUIPE

NOME	Função: Biologia	Função: Geomorfologia	Função: Protocolo
	☐	☐	☐
	☐	☐	☐
	☐	☐	☐
	☐	☐	☐
	☐	☐	☐

COMENTÁRIOS GERAIS:

INSTRUÇÕES PARA CHEGAR AO LOCAL DO RIACHO/RIO:

Registre as informações utilizadas para definir o comprimento do trecho. Esboce as características gerais do trecho no verso desta folha.

Revisado por (iniciais): ________

Habitat Físico: SEÇÃO TRANSVERSAL DO CANAL/ZONA RIPÁRIA - RIACHOS

IDENTIFICAÇÃO DO PONTO (ID): ____________ DATA: ____ / ____ / ______ TRANSECTO: ☐A ☐B ☐C ☐D ☐E ☐F ☐G ☐H ☐I ☐J ☐K Canal Lateral ☐

INFORMAÇÕES DO SUBSTRATO DA SEÇÃO TRANSVERSAL

	Dist. M. Esq. XX.XX m	Prof. XXX cm	Código Tam. clas.	Imersão 0-100%	Tipo B / F	Obs.
ESQ						
C.ESQ						
CENT						
C.DIR						
DIR						

CÓDIGOS DE CLASSES - TAMANHO DO SUBSTRATO

	Código	Imersão (%)
(F) FÍSICO	RL = Rocha (Lisa) - (Mais larga que um carro)	0
	RR = Rocha (Rugosa) - (Mais larga que um carro)	0
	CO = Concreto/Asfalto	
	ML = Matacão Largo (1000 até 4000 mm) - (Caixa d'água até um carro)	
	MT = Matacão (250 até 1000 mm) - (Bola de basquete até caixa d'água)	
	BL = Bloco (64 até 250 mm) - (Bola de tênis até bola de basquete)	
	CG = Cascalho Grosso (16 até 64 mm) - (Jabuticaba até bola de tênis)	
	CF = Cascalho Fino (2 até 16 mm) - (Joaninha até jabuticada)	
	AR = Areia (0.06 até 2 mm) - (Arenosa - até o tamanho de Joaninha)	100
	FN = Finos (Silte / Argila / Lama - Não arenosa)	100
	AC = Argila consolidada (Hardpan) - Substrato Fino consolidado, firme	0
(B) BIOL.	BF = Banco de Folhas (e Galhos Pequenos)	
	SF = Serrapilheira Fina (Materia organica particulada)	
	MA = Macrófitas	
	AL = Algas	
	RT = Raizes Finas da Mata Ciliar	
	MD = Madeira - (qualquer tamanho)	
	OT = Outro (escreva comentário abaixo)	

ABRIGO PARA PEIXES/ OUTROS

0 = Ausente (0%)
1 = Esparso (<10%)
2 = Médio (10-40%)
3 = Denso (40-75%)
4 = Muito denso (>75%)
(circule uma opção)

	Cobertura no canal					Obs.
Algas Filamentosas	0	1	2	3	4	
Plantas Aquáticas	0	1	2	3	4	
Pedaços de Madeira >0.3 m (GRANDE)	0	1	2	3	4	
Pedaços de Madeira/Arbustos <0.3 m (PEQ.)	0	1	2	3	4	
Árvores vivas ou raízes	0	1	2	3	4	
Banco de Folhas	0	1	2	3	4	
Vegetação pendurada =<1 m da Superfície	0	1	2	3	4	
Margem Escavada	0	1	2	3	4	
Matacão	0	1	2	3	4	
Estruturas Artificiais	0	1	2	3	4	

ESTIMATIVAS VISUAIS DA ZONA RIPÁRIA

0 = Ausente (0%)
1 = Esparso (<10%)
2 = Médio (10-40%)
3 = Denso (40-75%)
4 = Muito Denso (>75%)

COBERTURA VEG. DA ZONA RIPÁRIA	Margem Esquerda					Margem Direita					Obs.
Dossel (>5 m altura)											
Árvores GRANDES (DAP >0.3 m)	0	1	2	3	4	0	1	2	3	4	
Árvores PEQUENAS (DAP <0.3 m)	0	1	2	3	4	0	1	2	3	4	
Sub-bosque (0.5 até 5 m altura)											
Arbustos lenhosos & mudas	0	1	2	3	4	0	1	2	3	4	
Ervas sem tronco lenhoso & gramíneas	0	1	2	3	4	0	1	2	3	4	
Vegetação Rasteira (<0.5 m altura)											
Arbustos lenhosos & mudas	0	1	2	3	4	0	1	2	3	4	
Ervas sem tronco lenhoso & gramíneas	0	1	2	3	4	0	1	2	3	4	
Solo sem cobertura vegetal ou serrapilheira	0	1	2	3	4	0	1	2	3	4	

INFLUÊNCIA HUMANA

0 = Ausente P = >10 m C = < 10 m B = Na margem

	Margem Esquerda				Margem Direita				Obs.
Muro/dique/Canalização gabião/barramento	0	P	C	B	0	P	C	B	
Construções	0	P	C	B	0	P	C	B	
Estrada calçada ou cascalhada	0	P	C	B	0	P	C	B	
Rodovia/Ferrovia	0	P	C	B	0	P	C	B	
Canos (Captação/descarga)	0	P	C	B	0	P	C	B	
Entulho/Lixo	0	P	C	B	0	P	C	B	
Parque/Gramado	0	P	C	B	0	P	C	B	
Plantações de Grãos	0	P	C	B	0	P	C	B	
Pastagem/ campo de feno	0	P	C	B	0	P	C	B	
Silvicultura/ desmatamento	0	P	C	B	0	P	C	B	
Mineração	0	P	C	B	0	P	C	B	

MEDIDAS DA MARGEM

	Ângulo da margem 0 - 360	Margem escavada Dist. (m)	Obs.
Esquerda			
Direita			

Largura molhada XXX.X m		
Largura das barras de canal XX.X m		
Largura do leito sazonal XXX.X m		
Altura do leito sazonal XX.X m		
Altura da incisão XX.X m		

Cód. Tam. Class F (Marcar apenas se o transecto for 100% biológico)

MEDIDAS DA COBERTURA DO DOSSEL

DENSIÔMETRO (0-17Max)

		Obs.			Obs.
Centro a montante			**Centro a direita**		
Centro a esquerda			**Esquerda**		
Centro a jusante			**Direita**		

Obs.	Comentário

Códigos Obs: K = Amostra não coletada; U = Amostra suspeita F1, F2, etc. = obs. feita pela equipe de campo. Explique todas as observações na seção de comentários.

Habitat Físico: PERFIL LONGITUDINAL & PEDAÇOS DE MADEIRA DO RIACHO

Revisado por (iniciais): ______

IDENTIFICAÇÃO DO PONTO (ID): ____________ DATA: ____ / ____ / ________ TRANSECTO: ☐ A-B ☐ B-C ☐ C-D ☐ D-E ☐ E-F ☐ F-G ☐ G-H ☐ H-I ☐ I-J ☐ J-K

PERFIL LONGITUDINAL — SOMENTE p/ os transectos A e B: Incremento (m) X.X: ____ Comprimento total do trecho (m): ____

TRAN-SECTO	PROFUNDIDADE DO TALVEGUE (cm) (XXX)	LARGURA MOLHADA (m) (XXX.X)	LARGURA DAS BARRAS DE CANAL [1] Presente	LARGURA DAS BARRAS DE CANAL [1] XX.X	SEDIMENTOS PEQUENOS < CASCALHO	CÓDIGO DA UNIDADE DO CANAL	CÓDIGO DA FORMA DA PISCINA	CANAL LATERAL	BACK-WATER	OBS.	COMENTÁRIOS
0			S N		S N			S N	S N		
1			S N		S N			S N	S N		
2			S N		S N			S N	S N		
3			S N		S N			S N	S N		
4			S N		S N			S N	S N		
5			S N		S N			S N	S N		
6			S N		S N			S N	S N		
*7			S N		S N			S N	S N		
8			S N		S N			S N	S N		
9			S N		S N			S N	S N		
10			S N		S N			S N	S N		
11			S N		S N			S N	S N		
12			S N		S N			S N	S N		
13			S N		S N			S N	S N		
14			S N		S N			S N	S N		

SUBSTRATO	Transecto	ESQ	C.ESQ	CENT	C.DIR	DIR	OBS.
	7						

OBS.	COMENTÁRIOS (para SUBSTRATO e PGM)

CÓDIGOS DAS CLASSES DO TAMANHO DO SUBSTRATO

RL = Rocha (lisa) - (mais larga que um carro)
RR = Rocha (rugosa) - (mais larga que um carro)
CO = Concreto/ Asfalto
ML = Matacão largo (1000 até 4000 mm) - (Caixa d'água até um carro)
MT = Matacão (250 até 1000 mm) - (Bola de basquete até caixa d' água)
BL = Bloco (64 TO 250 mm) - (Bola de tênis até bola de basquete)
CG = Cascalho grosso (16 até 64 mm) - (Jabuticaba até bola de tênis)
CF = Cascalho fino (2 até 16 mm) - (Joaninha até jabuticaba)
AR = Areia (0.06 até 2 mm) - (Arenosa - até o tamanho da joaninha)
FN = Silte/Argila/Lama - (não arenosa)
AC = Argila consolidade (Hardpan) - Substrato Fino, consolidado
BF = Banco de Folhas e Galhos Pequenos
SF = Serrapulheira Fina (Materia Organica Particulada)
AL = Algas
MA = Macrófitas
RT = Raízes Finas da Mata Ciliar
MD = Madeira -(qualquer tamanho)
OT = Outro (escreva comentário no verso)

CÓD. DA PISCINA

N = Não é uma piscina
W = Pedaços grandes de madeira
R = Raiz
B = Matacão ou rocha
F = Desconhecido, fluvial
COMBINAÇÕES
ex. WR, BR, WRB

COD. DAS UNIDADES DO CANAL

PP = Piscina após queda d'água
PT = Piscina entricheirada no meio do canal
PL = Piscina formada pela margem
PB = Piscina formada por remanso
PD = Piscina formada por represamento
GL = Fluxo suave
RI = Corredeira
RA = Rápido
CA = Cascata
FA = Queda
DR = Canal seco

PEDAÇOS GRANDES DE MADEIRA (diam. extremidade menor >10 cm ; comp. > 1.5 m) OBS. ____

DIÂMETRO DA EXTRE-MIDADE MAIOR	PEÇAS OU PEDAÇOS DENTRO DO LEITO SAZONAL — Comprimento 1.5-5m	5-15m	>15m	PEÇAS DEPENDURADAS ACIMA DO LEITO SAZONAL — Comprimento 1.5-5m	5-15m	>15m
0.1-<0.3 m						
0.3-0.6 m						
0.6-0.8 m						
>0.8 m						

Códigos das OBS.: K = medição não realizada; U = medições suspeitas; F1, F2, etc. = obs. feitas pela equipe de campo; G1, G2, etc. para bandeiras não específicas para um transecto. Explique todas as OBS. nos Comentários
1 = Medida do comprimento da barra na estação 0 e meia estação (5 ou 7)

Revisado por (iniciais): ______

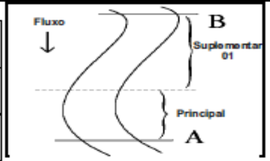
Habitat Físico: DECLIVIDADE & DIREÇÃO - RIACHOS

IDENTIFICAÇÃO DO PONTO (ID): ____________ DATA: ___ / ___ / ______

PRINCIPAL (sempre usado)				SUPLEMENTAR - 01			SUPLEMENTAR - 02			
TRANSECTO & MÉTODO Marque o método para cada Transecto	Decliv.(%) ou Elev. Diferencial. (cm) Marque as unidades para cada Transecto	ANGULO 0 - 359	PROPOR-ÇÃO %	Decliv.(%) ou Elev. Diferencial. (cm)	ANGULO 0 - 359	PROPOR-ÇÃO %	Decliv.(%) ou Elev. Diferencial. (cm)	ANGULO 0 - 359	PROPOR-ÇÃO %	OBS.
A < B ☐ CL ☐ TR ☐ HL ☐ WT ☐ LA ☐ Other	. ☐ % ☐ cm			.			.			
B < C ☐ CL ☐ TR ☐ HL ☐ WT ☐ LA ☐ Other	. ☐ % ☐ cm			.			.			
C < D ☐ CL ☐ TR ☐ HL ☐ WT ☐ LA ☐ Other	. ☐ % ☐ cm			.			.			
D < E ☐ CL ☐ TR ☐ HL ☐ WT ☐ LA ☐ Other	. ☐ % ☐ cm			.			.			
E < F ☐ CL ☐ TR ☐ HL ☐ WT ☐ LA ☐ Other	. ☐ % ☐ cm			.			.			
F < G ☐ CL ☐ TR ☐ HL ☐ WT ☐ LA ☐ Other	. ☐ % ☐ cm			.			.			
G < H ☐ CL ☐ TR ☐ HL ☐ WT ☐ LA ☐ Other	. ☐ % ☐ cm			.			.			
H < I ☐ CL ☐ TR ☐ HL ☐ WT ☐ LA ☐ Other	. ☐ % ☐ cm			.			.			
I < J ☐ CL ☐ TR ☐ HL ☐ WT ☐ LA ☐ Other	. ☐ % ☐ cm			.			.			
J < K ☐ CL ☐ TR ☐ HL ☐ WT ☐ LA ☐ Other	. ☐ % ☐ cm			.			.			

COMENTÁRIOS

OBS.	



Código das OBS.: K = Amostra não coletada; U = Amostra suspeita; F1, F2, M (M = Método - usar somente para métodos comentados) = obs. feita pela equipe de campo. Explique todas as OBS. na seção de comentários CL=Clinômetro; HL=nível de água feito a mão; LA=Medidor laser com clinômetro; TR=passagem; WT=Água canalizada.

ENCAIXAMENTO DO CANAL - RIACHOS E RIOS

IDENTIDICAÇÃO DO PONTO (ID): ________________ DATA: ____ / ____ / ______

ENCAIXAMENTO DO CANAL

PADRÃO DO CANAL (Marque uma opção)

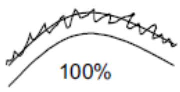
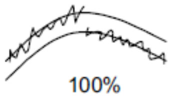
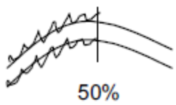
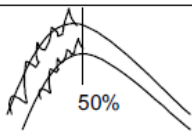
- ☐ Canal único
- ☐ Canal anastomosado (complexo) - (Separação e junção de um canal mais longo em canais menores, separados por ilhas fixas e vegetadas)
- ☐ Canal entrelaçado - (Separação e junção de vários canais estreitos - existe apenas um único canal que é cortado por numerosas barras móveis e desprovidas de vegetação no seu leito)

ENCAIXAMENTO DO CANAL (Marque uma opção)

- ☐ Vale em «V» raso 
- ☐ Vale em «V» profundo 
- ☐ Garganta 
- ☐ Concavo/abaulado 
- ☐ Vale assimétrico 
- ☐ Vale em «U» 
- ☐ Vale não perceptível

CARACTERÍSTICAS DO ENCAIXAMENTO (Marque uma opção)

- ☐ Rocha (o canal formado predominantemente pela rocha; formato de garganta)
- ☐ Vale (canal encaixado em um vale estreito em formato de V)
- ☐ Terraço (canal encaixado devido a sua incisão nos depósitos aluviais)
- ☐ Alterações antrópicas nas margens (encaixamento em gabião, aterros, diques, estradas, etc)
- ☐ Não há feições de encaixamento

Porcentagem do comp. do canal com a margem em contato com a feição de encaixamento ___ % (0-100%) --->	**Exemplos de porcentagem das margens do canal**
Largura do leito sazonal ___ (m)	 100%  100%
Largura do vale (Média de estimativa visual): ___ (m) Se você não pode ver as bordas do vale, registre a distância que você pode ver e marque a opçao ao lado. ☐	 50%  50%

Comentários

PROTOCOLO - DESCARGA DO RIACHO

Revisado por (iniciais): ________

IDENTIDICAÇÃO DO PONTO (ID): ________________ DATA: ___ / ___ / _____

☐ Área de velocidade

Unidades de distância: cm | Unidade de velocidade: m/s
Unidade de comprimento: cm

(A última medida deve ser da margem esquerda).

	Dist. da margem	Profundidade	Velocidade	Obs.
1	0			
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				
16				
17				
18				
19				
20				

☐ Tempo de preenchimento

Medição	Volume (L)	Tempo (s)	Obs.
1	___.__	___.__	
2	___.__	___.__	
3	___.__	___.__	
4	___.__	___.__	
5	___.__	___.__	

☐ Objeto Flutuante Neutro

	Flutuação 1	Flutuação 2	Flutuação 3
Dist. flut. (m)			
Tempo flut. (s)			
Obs.			

Seções Transversais nos trechos de flutuação

	Seção a mont.	Seção interm.	Seção a jusante
Largura (m)	___.__	___.__	___.__
Profundidade 1 (cm)			
Profundidade 2			
Profundidade 3			
Profundidade 4			
Profundidade 5			

☐ Q (Vazão)

Se a descarga for determinada diretamente em campo, anote o valor aqui: Q = ____________ m^3/s OBS ____

Obs.	Comentários

PROTOCOLO DE AVALIAÇÃO DO CANAL- RIACHOS/RIOS

Revisado por (Iniciais): ____

IDENTIDICAÇÃO DO PONTO (ID): ____________ DATA: ___/___/_____

USO E OCUPAÇÃO DO SOLO NA BACIA HIDROGRÁFICA E DISTÚRBIOS OBSERVADOS (Intensidade : Em branco = não observado, L=baixo , M=moderado, H= alto)

Residencial	Recreativo	Agrícola	Industrial	Intervenções nos riachos
L M H Residências	L M H Trilhas para caminhadas	L M H Plantação	L M H Fábricas	L M H Calagem
L M H Gramados	L M H Parque	L M H Pastagem	L M H Mineração/Pedreiras	L M H Tratamento Químico
L M H Construções	L M H Acampamento	L M H Pecuária	L M H Poço de gás/petróleo	L M H Pressão de pesca
L M H Dutos; tubulação	L M H Lixo	L M H Pomares	L M H Hidrelétricas	L M H Dragagem
L M H Depósito de lixo	L M H Filme na superfície	L M H Aves domésticas	L M H Silvicultura/desmatamento	L M H Canalização
L M H Rodovias		L M H Equip. Irrigação	L M H Evidências de queimadas	L M H Flutuações do nível d'água
L M H Pontes/bueiros		L M H Captação de água	L M H Odores	L M H Piscicultura
L M H Tratamento de esgoto			L M H Comercial	L M H Barragens

CARACTERÍSTiCAS DO LUGAR (raio de 200 m)

Características do Corpo d'água	Natural	☐ 5	☐ 4	☐ 3	☐ 2	☐ 1	Altamente perturbado
	Agradável	☐ 5	☐ 4	☐ 3	☐ 2	☐ 1	Desagradável
Uso do solo predominante	Uso do solo predominante Assinale com um X	☐ Florestal	☐ Agrícola	☐ Pastagem	☐ Urbano	☐ Peri-urbano	
	Se floresta, classe de idade dominante	☐ 0 - 25 anos	☐ 25 - 75 anos	☐ > 75 anos			

CONDIÇÕES ATMOSFÉRICAS

AVALIAÇÃO GERAL (Integridade biótica, diversidade da vegetação, algum outro comentário relevante)

PROTOCOLO DE AMOSTRAS COLETADAS

Revisado por (Iniciais): ______

IDENTIDICAÇÃO DO PONTO (ID): ______________	DATA: ____/____/______

AMOSTRAS DE BENTOS - MÚLTIPLOS HABITATS																							
TRANSECTO		A		B		C		D		E		F		G		H		I		J		K	
No ETIQUETA																							
SUBSTRATO	CANAL	Sub.	Canal	Sub.	Canal	Sub.	Canal	Sub.	Canal	Sub.	Canal	Sub.	Canal	Sub.	Canal	Sub.	Canal	Sub.	Canal	Sub.	Canal	Sub.	Canal
Silte, argila ou lama	Piscina	☐ L	☐ PI	☐ L	☐ PI	☐ L	☐ PI	☐ L	☐ PI	☐ L	☐ PI	☐ L	☐ PI	☐ L	☐ PI	☐ L	☐ PI	☐ L	☐ PI	☐ L	☐ PI	☐ L	☐ PI
Areia	Fluxo suave lento	☐ A	☐ SL	☐ A	☐ SL	☐ A	☐ SL	☐ A	☐ SL	☐ A	☐ SL	☐ A	☐ SL	☐ A	☐ SL	☐ A	☐ SL	☐ A	☐ SL	☐ A	☐ SL	☐ A	☐ SL
Cascalho	Fluxo suave rápido	☐ C	☐ SR	☐ C	☐ SR	☐ C	☐ SR	☐ C	☐ SR	☐ C	☐ SR	☐ C	☐ SR	☐ C	☐ SR	☐ C	☐ SR	☐ C	☐ SR	☐ C	☐ SR	☐ C	☐ SR
Seixo	Corredeira	☐ S	☐ CO	☐ S	☐ CO	☐ S	☐ CO	☐ S	☐ CO	☐ S	☐ CO	☐ S	☐ CO	☐ S	☐ CO	☐ S	☐ CO	☐ S	☐ CO	☐ S	☐ CO	☐ S	☐ CO
Bloco	Rápido	☐ B	☐ RA	☐ B	☐ RA	☐ B	☐ RA	☐ B	☐ RA	☐ B	☐ RA	☐ B	☐ RA	☐ B	☐ RA	☐ B	☐ RA	☐ B	☐ RA	☐ B	☐ RA	☐ B	☐ RA
Banco de folhas		☐ F		☐ F		☐ F		☐ F		☐ F		☐ F		☐ F		☐ F		☐ F		☐ F		☐ F	
Velocidade (m/s)		|_|_|_|		|_|_|_|		|_|_|_|		|_|_|_|		|_|_|_|		|_|_|_|		|_|_|_|		|_|_|_|		|_|_|_|		|_|_|_|		|_|_|_|	
Profundidade (cm)		|_|_|_|		|_|_|_|		|_|_|_|		|_|_|_|		|_|_|_|		|_|_|_|		|_|_|_|		|_|_|_|		|_|_|_|		|_|_|_|		|_|_|_|	

AMOSTRA DE BENTOS - FOLHIÇO									
TRANSECTO	____	____	____	____	____	____	____	____	Comentários
No ETIQUETA									
Piscina	☐ PI	☐ PI	☐ PI	☐ PI	☐ PI	☐ PI	☐ PI	☐ PI	
Fluxo Suave Lento	☐ SL	☐ SL	☐ SL	☐ SL	☐ SL	☐ SL	☐ SL	☐ SL	
Fluxo Suave Rápido	☐ SR	☐ SR	☐ SR	☐ SR	☐ SR	☐ SR	☐ SR	☐ SR	
Corredeira	☐ CO	☐ CO	☐ CO	☐ CO	☐ CO	☐ CO	☐ CO	☐ CO	
Rápido	☐ RA	☐ RA	☐ RA	☐ RA	☐ RA	☐ RA	☐ RA	☐ RA	

AMOSTRAS DE PEIXES											
TRANSECTO	A	B	C	D	E	F	G	H	I	J	K
No ETIQUETA											
Comentários											

Revisado por (Iniciais): ______

QUÍMICA DA ÁGUA - RIACHOS E RIOS

IDENTIDICAÇÃO DO PONTO (ID): ________	**DATA:** ___/___/_____

QUÍMICA DA ÁGUA

Hora : __:__	**pH:** ___.__	**OD :** Vol (1) ml: ___.__
Temperatura (C): ___.__	**STD mg/l:** ____.__	Vol (2) ml: ___.__
Condutividade µS/cm : ____.__	**Turbidez NTU :** ____.__	Normalidade: ______ Concentração final mg/l: ___.__
Nitrogênio Total mg/l: ___.__	**Fósforo Total mg/l :** ___.__	

Alcalinidade :	**Vol (1) ml:** ___.__	**pH (1) :** ___.__	**Normalidade:** ______
	Vol (2) ml: ___.__	**pH (2) :** ___.__	**Concentração final µEq/l:** ____.__
	Vol (3) ml: ___.__	**pH (3) :** ___.__	

Comentários