UNIVERSIDADE FEDERAL DO RIO GRANDE DO SUL

INSTITUTO DE BIOCIÊNCIAS

PROGRAMA DE PÓS-GRADUAÇÃO EM ECOLOGIA

Dissertação de Mestrado

Influências da pressão pesqueira e áreas de proteção ambiental na comunidade de peixes em dois rios tropicais

PEDRO PEIXOTO NITSCHKE

Porto Alegre, maio de 2018

Influências da pressão pesqueira e áreas de proteção ambiental na comunidade de peixes em dois rios tropicais

Pedro Peixoto Nitschke

Dissertação apresentada ao Programa de Pós-Graduação em Ecologia, do Instituto de Biociências da Universidade Federal do Rio Grande do Sul, como parte dos requisitos para obtenção do título de Mestre em Ecologia.

Orientador: Prof. Dr. Renato Azevedo Matias Silvano

Comissão Examinadora:
Profa. Dra. Sandra Maria Hartz (UFRGS/RS)
Profa. Dra. Ana Cristina Petry (UFRJ/RJ)
Dr. Marcelo Costa Andrade (UFPA/PA)

Porto Alegre, maio de 2018

CIP - Catalogação na Publicação

Peixoto Nitschke, Pedro
Influências da pressão pesqueira e áreas de proteção ambiental na comunidade de peixes em dois rios tropicais / Pedro Peixoto Nitschke. -- 2018.
59 f.
Orientador: Renato Azevedo Matias Silvano.

Dissertação (Mestrado) -- Universidade Federal do Rio Grande do Sul, Instituto de Biociências, Programa de Pós-Graduação em Ecologia, Porto Alegre, BR-RS, 2018.

1. Manejo pesqueiro. 2. Conservação. 3. Amazônia. 4. Diversidade. 5. Ecologia. I. Azevedo Matias Silvano, Renato, orient. II. Título.

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

Agradecimentos

Agradeço a todos os pescadores e moradores das comunidades amazônicos que participaram direta ou indiretamente desta pesquisa, que compartilharam seus conhecimentos e tempo para me ensinar sobre a diversidade e a vida na região amazônica. Sem todas essas pessoas este e muitos outros trabalhos que virão não teriam sido possíveis.

Agradeço ao meu orientador Renato Silvano por sua paciência e ensinamentos que me acompanham dês da graduação. Com certeza é um exemplo de pesquisador e professor, dividindo seu conhecimento e dando oportunidades a todos que te cercam.

Aos meus pais Angelita e José Paulo que sempre foram o suporte e incentivo ao longo da minha vida. A minha irmã Bianca que sempre foi minha melhor amiga e companheira. Essa dissertação também é fruto do teu trabalho mana que leu, releu e corrigiu várias vezes meu texto e sofreu com minhas explicações ecológicas e discussões sobre estatística ser empregada em outras áreas do conhecimento. Te garanto, sem ti isso não seria possível.

A todos os colegas do LECHUPE Daiana, Anaís, Paula (Pinguim), Paula (dra), Kaluan, Henrique, Tati, Carol e Luís por todos os momentos vividos em laboratório e em campo. Aos membros honorários do laboratório, Gustavo Hallwass e Fred pelas conversas e conselhos para desenvolver o mestrado. A Carol P. e Bagé que entraram comigo nesse mestrado, os três decidindo em cima da hora se inscrever e enfrentar isso (arrependidos?). Ao Murilo e Maico, membros honorários do LECHUPE e que- definitivamente- ajudaram para que essa dissertação de mestrado se alongasse o máximo possível, mas que também tornaram os momentos vividos juntos inesquecíveis. A os amigos do colégio, Mátheus, Lima, Gui e Ramiro que serviram de ponte para o mundo fora da academia, mostrando que outros assuntos sem ser métodos estatísticos, metodologia de campo e discussões sobre teorias ecológicas também são interessantes e dignos de conversa. A todos os amigos que participaram de momentos nesses dois anos e em especial a Luciana, Ricardo Naja, Rike, Helena, Isa, Kaka e Alina.

Agradeço ao PPG-Ecologia da UFRGS por todo o suporte oferecido ao longo desses dois anos, a CAPES pela bolsa que possibilitou que essa dissertação fosse possível e a United States Agency for International Development (USAID) que financiou o projeto de pesquisa “Linking sustainability of small-scale fisheries, fishers’ knowledge, conservation and co-management of biodiversity in large rivers of the Brazilian Amazon” do qual minha dissertação faz parte.

Por fim agradeço imensamente as professoras Dra. Sandra Hartz e Dra. Ana Cristina Petry e ao Dr. Marcelo Andrade por aceitarem revisar essa dissertação. Meus sinceros agradecimentos.

Resumo

A pressão pesqueira tem aumentado nas ultimas décadas, ameaçando comunidades de peixes de água doce ao redor do mundo. A Amazônia é o bioma brasileiro mais protegido com mais de 17% do se território dentro de unidades de conservação (UC), mas essas UCs foram implementadas visando a proteção de ecossistemas terrestres e os benefícios aos ambientes aquáticos ainda não estão claros. Nosso estudo investiga as influências de reservas extrativistas de uso sustentável (RESEX), diferentes escalas de pesca (artesanal e comercial) e parâmetros ambientais na diversidade de peixes dos rios Tapajós e Negro, Amazônia brasileira. Foram analisados aspectos da diversidade (funcional e taxonômica) assim como descritores das comunidades de peixes (β diversidade). Oito comunidades de pescadores foram estudadas em cada rio, quatro dentro e quatro fora da RESEX. As reservas se diferenciavam no quesito de permissão da atividade comercial de pescadores artesanais no Tapajós e a proibição dessa atividade comercial no Negro. A pressão pesqueira artesanal foi medida a partir do registro de desembarque pesqueiros em cada comunidade e a pressão pesqueira comercial medida a partir da distancia dos maiores centros urbanos de cada rio. Foi possível verificar que a diversidade funcional e taxonômica foram negativamente relacionadas com a pesca artesanal e comercial no rio Tapajós. No rio Negro, a pesca artesanal esteve positivamente relacionada com a diversidade funcional em lagos. Os padrões espaciais da composição das espécies (β diversidade) foram relacionados com a pesca comercial em ambos os rios. A RESEX foi relacionada a um aumento de diversidade taxonômica no rio Tapajós e a mudanças na assembleia de peixes no rio Negro, indicando de forma geral um efeito positivo nas comunidades de peixes em ambos os rios. Esses resultados indicam que áreas de proteção ambiental com enfoque em sistemas terrestres podem ser benéficas para comunidade de peixes. Salienta-se que atividades de pesca comercial estão relacionadas com resultados negativos na diversidade de peixes e áreas de proteção ambiental que permitam essas

atividades devem desenvolver regras de manejo adicionais para regular e controlar a pesca local, preferencialmente em colaboração com os pescadores.

Palavras-chave: pesca de pequena escala; manejo pesqueiro; conservação; beta diversidade; comunidade de peixes.

Abstract

Fishing pressure increased in the last decades, threatening freshwater fish communities around the world. Amazonia is the most protected biome in Brazil with more than 17% of its territory inside protected areas, but most of them were designed to protect terrestrial ecosystems and their benefits to freshwater ecosystems are not well known. Our study investigated the influences of protected areas in the form of Extractive Reserves (RESEX), two scales of fishing pressure and environmental parameters on fish diversity in the Tapajós and Negro rivers, Brazilian Amazon. We analyzed aspects of biodiversity (taxonomic and functional diversity) and assemblage structures descriptors (β diversity). Eight riverine communities were studied in each river, four inside and four outside a RESEX. The RESEX differentiate by allowing artisanal commercial fishing in Tapajós and prohibiting this activities in Negro River. Local fishing pressure for each riverine community was estimated through the record of fish landings, while commercial fishing was estimated through the distance of each community from the main city in each river. Fish were sampled in river and lake sites near the studied communities. Overall, functional, taxonomic of fish diversity were negatively related with artisanal and commercial fishing pressure In the Tapajós river, and artisanal fishing was positively related functional diversity in Negro River. Spatial patterns of fish diversity were related to commercial fishing in both rivers. The RESEX was related with an increase of diversity in the Tapajós River and to spatial patterns of diversity in Negro River indicating an overall positive effect on the fish community. This results indicate that protected areas designed to preserve terrestrial systems can deliver benefits for fish community. However commercial fishing activities are related to negative outcomes in the fish community and protected areas that allow this activities need additional management rules to regulate local fishing.

Keywords: Beta diversity; small scale fisheries; conservation; fish assemblage, Brazilian Amazon, Tapajós River, Negro River

Sumário

Introdução

Atividades humanas têm causado diversos impactos aos ecossistemas, sendo a principal causa da atual extinção de espécies e perda de serviços ecossistêmicos (Barnosky et al. 2011; Cardinale et al. 2012; IUCN 2018). Ao que tudo indica, os impactos antrópicos estão nos direcionando a uma extinção em massa como nunca visto antes (Barnosky et al. 2011). Com o intuito de mitigar os efeitos negativos, políticas de estabelecimento de áreas de proteção ambiental têm aumentado exponencialmente (Andrade & Rhodes 2012). Apesar do aumento das áreas protegidas, ainda se discute se estas áreas são selecionadas visando incluir ambientes que realmente necessitam ser protegidos ou incluem somente áreas de baixa produtividade e pouca rentabilidade econômica. Ainda que haja um aumento significativo na proteção dos ambientes, existe uma tendência em proteger os ecossistemas terrestres, deixando os ambientes aquáticos marginalmente abrangidos (Rodríguez-Olarte et al. 2011; Castello et al. 2013). Ambientes aquáticos, em especial os de água doce, encontram-se entre os mais ameaçados do mundo (Abell et al. 2008) com taxas de extinção até cinco vezes maiores do que as encontradas em ambientes terrestres (Ricciardi & Rasmussen 1999).

O Brasil, empenhado em combater a diminuição da diversidade e seguindo o padrão mundial, tem aumentado as áreas de conservação em áreas definidas como “Áreas Prioritárias para a Conservação” (MMA 2007). Cada bioma brasileiro deveria ser protegido estando dentro de uma unidade de conservação, podendo ser de Proteção integral ou de Uso Sustentável (MMA,2011). As principais diferenças entre as duas categorias de proteção consistem em que as de proteção Integral impedem atividades humanas dentro da área delimitada e, por outro lado, as de uso sustentável permitem, em diferentes níveis, a incorporação de ações humanas seguindo certas regras de manejo. Dos 7 biomas brasileiros, a Amazônia destaca-se com mais de 74 mil hectares de área protegida por algum tipo de unidade de conservação (MMA 2007), totalizando 17% do seu território legal. Em segundo lugar, o bioma mais protegido é o Cerrado com 11 mil hectares (5,77%) dentro de algum tipo de unidade de conservação. Essa disparidade de área protegida se deve, entre outros fatores, pela pressão dos meios científicos, público e político durante os anos de 1980 a 1990, que impulsionaram a criação de grandes áreas de proteção (Castello et al. 2013). Apesar de relativamente bem protegida, a Amazônia possui um déficit de proteção para os seus sistemas aquáticos, que permanecem protegidos apenas quando inclusos pelas áreas de proteção terrestres (Castello et al. 2013). Ainda não está estabelecido se áreas de proteção terrestres possuem um efeito positivo na proteção da diversidade aquática. Entretanto, estudos recentes mostraram efeitos, mesmo que pouco evidentes, de proteção em lagos canadenses (Chu et al. 2017). Já em ambientes amazônicos, esses estudos ainda são poucos e mostram resultados parciais das áreas protegidas para a proteção da diversidade aquática (Keppeler et al. 2017).

Apesar de sua importância biológica e dos esforços conservacionistas, a Amazônia tem sofrido com o aumento dos impactos antrópicos como o desmatamento, a poluição, a construção de canais portuários e as hidroelétricas (Castello et al. 2013; Winemiller et al. 2016). Ainda que a perda de habitat terrestre tenha sido lentamente diminuída com diversos programas e incentivos governamentais, a construção de hidroelétricas tem sido incentivada pelo governo brasileiro, com cerca de 43 novas barragens planejadas para conclusão até o ano de 2022 no Rio Tapajós (Fearnside 2015). Por serem muito conectados, os sistemas aquáticos repercutem mudanças locais a longas distâncias, o que os torna muito suscetíveis a impactos antrópicos. Os efeitos das barragens em rios variam de perdas de espécies, alterações das características ambientais e físicas (Kingsford 2000) até o impacto nas comunidades ribeirinhas que dependem de espécies de peixes como principal forma de alimento (Hallwass et al. 2013).

A pesca no contexto amazônico não é apenas um modo de subsistência, mas sim uma característica cultural que está associada aos costumes e modo de vida das comunidades ribeirinhas. Essas comunidades locais utilizam os peixes tanto para consumo próprio quanto para complementar sua renda, vendendo-os para os mercados locais. Apesar de pouco regulada, a pesca artesanal de peixes é responsável por até 60% de toda a biomassa capturada na região (Bayley & Petrere,1989). Além disso, o aumento da necessidade de recursos pesqueiros na região amazônica tem feito com que barcos pesqueiros intensifiquem a pressão pesqueira nos rios adjacentes às grandes cidades, causando um impacto nas comunidades de peixes. Estudos recentes mostram que, apesar de ser multiespecífica, a pesca amazônica se concentra em algumas espécies, sendo que os pescadores capturam principalmente 11 espécies de peixes, sendo 9 migradoras (Hallwass & Silvano 2016). A pesca comercial na Amazônia tem levado a diminuição de populações de peixes em algumas regiões, mostrando sinais de superexploração (Barthem & Goulding 2007; Castello et al. 2011). Assim como em outras regiões de água doce do mundo, populações de peixes mais pescadas estão mostrando sinais de sobrepesca, com a diminuição do tamanho médio do corpo, processo conhecido como *fishing-down process* (Welcomme 1999; Castello et al. 2011), padrão que tem sido observado em algumas regiões da Amazônia (Castello et al. 2011, 2013).

Ainda que não se tenham muitos estudos quanto ao efeito da pesca nas comunidades de peixes na Amazônia (Castello et al. 2013; Correa et al. 2015; Keppeler et al. 2017), em áreas marinhas de recifes a pesca artesanal tem sido responsável pela diminuição do tamanho corporal das espécies (Dulvy et al. 2004), pela perda de serviços ecossistêmicos (Bellwood et al. 2003) e pela diminuição da densidade de espécies comercialmente visadas (Silvano et al. 2017). Em áreas marinhas, a pesca comercial de larga escala causou um efeito tão devastador nas populações de peixes que o foco comercial passou de grandes predadores para espécies de menores níveis tróficos (Pauly et al. 1998). Para diminuir esses efeitos, áreas de proteção marinha têm sido propostas com resultados eficientes na proteção e manutenção de recursos pesqueiros (Bohnsack 1998; Halpern 2003; Pelletier et al. 2005). Áreas de proteção marinha que tiveram participação da comunidade local tiveram um sucesso de implementação maior (Pollnac et al. 2001; Pelletier et al. 2005), como o aumento da população de invertebrados marinhos

(Gelcich et al. 2008) e de peixes (Aswani & Sabetian 2010). Além disso, áreas próximas dessas unidades de conservação tiveram um aumento de até 90% na captura de peixes (Roberts et al. 2001), mostrando a sua efetividade. Assim como nos ambientes marinhos, áreas de proteção ambiental amazônicas mostraram aumento na captura de peixes por pescadores em áreas próximas às unidades de conservação (Silvano et al. 2014; Keppeler et al. 2017).

Grande parte dos estudos na área de pesca e de conservação são focados em mudanças locais de diversidade (α) e biomassa (Bellwood et al. 2003; Dulvy et al. 2004; Keppeler et al. 2017; Silvano et al. 2017) e essas diferenças na riqueza podem ser traduzidas como mudanças na composição de espécies, também conhecida como beta diversidade (Gutiérrez-Cánovas et al. 2013). Impactos antrópicos são conhecidos fatores de alteração das comunidades, criando um gradiente de aumento da diversidade beta (Kessler et al. 2009; Gutiérrez-Cánovas et al. 2013; Socolar et al. 2016) e o entendimento desses padrões de perda de diversidade são essenciais para a conservação (Socolar et al. 2016). Ao invés de focar os esforços na preservação de áreas com alto número de espécies, a adoção de métodos como a beta diversidade podem ajudar a identificar e preservar hábitats com maior heterogeneidade espacial e de espécies. Com esta visão, podemos proteger uma variedade de espécies e de comunidades possibilitando uma maior preservação dos diferentes nichos (Anderson et al. 2013).

A presente dissertação tem por objetivos principais: 1) estudar os efeitos da pesca artesanal e comercial nas comunidades de peixes em dois rios amazônicos: Tapajós (Pará) e Negro (Amazonas). 2) investigar os efeitos das Reservas Extrativistas de Uso Sustentável (RESEX) com diferentes regras de manejo da pesca, verificando potenciais benefícios dessas RESEX para as comunidades de peixes. Foram selecionados variáveis que conhecidamente são influenciadas por pressão pesqueira e ação antrópicas (Aswani & Sabetian 2010; Vallès & Oxenford 2015), esses indicadores foram diversidade funcional de Rao (Rao 1982), índice de diversidade de Simpson e Redundância funcional. Além disso foram analisados os padrões na diferença da composição das espécies (*i.e.* beta diversidade) para entender os principais agentes causadores de mudanças na composição das comunidades. Foram testadas três hipóteses: 1) A diversidade funcional (Rao), redundância funcional e índice de diversidade de Simpson vão ser negativamente relacionados com a pesca comercial e artesanal; 2) a variação na beta diversidade entre os ambientes vai estar relacionada a mudanças na composição das espécies ou flutuações na abundância das espécies, ambas influenciadas pela pesca comercial e artesanal; 3) A RESEX, por ser uma reserva voltada para o ambiente terrestre, não vai influenciar nenhum dos parâmetros de diversidade de peixes analisados. Além disso, outros fatores que podem influenciar a comunidade de peixes (variáveis físico-químicas e cobertura florestal) serão analisadas (Tejerina-Garro et al. 1998; Lobón-Cerviá et al. 2015; Arantes et al. 2017).

Referências Bibliográficas Introdução

Abell, R., Thieme, M.L., Revenga, C., Bryer, M., Kottelat, M., Bogutskaya, N., Coad, B., Mandrak, N., Balderas, S.C., Bussing, W., Stiassny, M.L.J., Skelton, P., Allen, G.R., Unmack, P., Naseka, A., Ng, R., Sindorf, N., Robertson, J., Armijo, E., Higgins, J. V., Heibel, T.J., Wikramanayake, E., Olson, D., López, H.L., Reis, R.E., Lundberg, J.G., Sabaj Pérez, M.H. & Petry, P. (2008). Freshwater Ecoregions of the World: A New Map of Biogeographic Units for Freshwater Biodiversity Conservation. *Bioscience*, 58, 403.

Anderson, M.J., Tolimieri, N. & Millar, R.B. (2013). Beta Diversity of Demersal Fish Assemblages in the North-Eastern Pacific: Interactions of Latitude and Depth. *PLoS One*, 8, 1–15.

Andrade, G.S.M. & Rhodes, J.R. (2012). Protected areas and local communities: An inevitable partnership toward successful conservation strategies? *Ecol. Soc.*, 17.

Aswani, S. & Sabetian, A. (2010). Implications of Urbanization for Artisanal Parrotfish Fisheries in the Western Solomon Islands. *Conserv. Biol.*, 24, 520–530.

Barnosky, A.D., Matzke, N., Tomiya, S., Wogan, G.O.U., Swartz, B., Quental, T.B., Marshall, C., McGuire, J.L., Lindsey, E.L., Maguire, K.C., Mersey, B. & Ferrer, E.A. (2011). Has the Earth's sixth mass extinction already arrived? *Nature*, 471, 51–57.

Barthem, R. & Goulding, M. (2007). *An unexpected ecosystem: the Amazon as revealed by fisheries. An unexpected Ecosyst. Amaz. as Reveal. by Fish.* Association Press, Lima.

Bellwood, D.R., Hoey, A.S. & Howard Choat, J. (2003). Limited functional redundancy in high diversity systems: resilience and ecosystem function of coral reefs. *Ecol. Lett.*, 6, 281–285.

Bohnsack, J.A. (1998). Application of marine reserves to reef fisheries management. *Austral Ecol.*, 23, 298–304.

Cardinale, B.J., Duffy, J.E., Gonzalez, A., Hooper, D.U., Perrings, C., Venail, P., Narwani, A., Mace, G.M., Tilman, D., A.Wardle, D., Kinzig, A.P., Daily, G.C., Loreau, M., Grace, J.B., Larigauderie, A., Srivastava, D.S. & Naeem, S. (2012). Biodiversity loss and its impact on humanity. *Nature*, 489, 326–326.

Castello, L., McGrath, D.G. & Beck, P.S.A. (2011). Resource sustainability in small-scale fisheries in the Lower Amazon floodplains. *Fish. Res.*, 110, 356–364.

Castello, L., Mcgrath, D.G., Hess, L.L., Coe, M.T., Lefebvre, P. a., Petry, P., Macedo, M.N., Renó, V.F. & Arantes, C.C. (2013). The vulnerability of Amazon freshwater ecosystems. *Conserv. Lett.*, 6, 217–229.

Chu, C., Ellis, L. & de Kerckhove, D.T. (2017). The effectiveness of terrestrial protected areas for lake fish community conservation. *Conserv. Biol.*, 1–36.

Correa, S.B., Araujo, J.K., Penha, J.M.F., da Cunha, C.N., Stevenson, P.R. & Anderson, J.T. (2015). Overfishing disrupts an ancient mutualism between frugivorous fishes and plants in Neotropical wetlands. *Biol. Conserv.*, 191, 159–167.

Dulvy, N.K., Polunin, N.V., Mill, A.C. & Graham, N.A. (2004). Size structural change in lightly exploited coral reef fish communities: evidence for weak indirect effects. *Can. J. Fish. Aquat. Sci.*, 61, 466–475.

Fearnside, P.M. (2015). Amazon dams and waterways: Brazil's Tapajós Basin plans. *Ambio*, 44, 426–439.

Gelcich, S., Godoy, N., Prado, L. & Castilla, J.C. (2008). Add-on Conservation Benefits of Marine Territorial User Rights Fishery Policies in Central Chile. *Ecol. Appl.*, 18, 273–281.

Gutiérrez-Cánovas, C., Millán, A., Velasco, J., Vaughan, I.P. & Ormerod, S.J. (2013). Contrasting effects of natural and anthropogenic stressors on beta diversity in river organisms. *Glob. Ecol. Biogeogr.*, 22, 796–805.

Hallwass, G., Lopes, P.F., Juras, A. a. & Silvano, R. a M. (2013). Fishers' knowledge identifies environmental changes and fish abundance trends in impounded tropical rivers. *Ecol. Appl.*, 23, 392–407.

Hallwass, G. & Silvano, R. (2016). Patterns of selectiveness in the Amazonian freshwater fisheries: implications for management. *J. Environ. Plan. Manag.*, 59, 1537–1559.

Halpern, B.S. (2003). The Impact of Marine Reserves : Do Reserves Work and Does Reserve Size Matter? *Ecol. Appl.*, 13.

IUCN. (2018). The IUCN Red List of Threatened Species [WWW Document]. URL http://www.iucnredlist.org

Keppeler, F.W., Hallwass, G. & Silvano, R.A.M. (2017). Influence of protected areas on fish assemblages and fisheries in a large tropical river. *Oryx*, 51, 1–12.

Kessler, M., Abrahamczyk, S., Bos, M., Buchori, D., Putra, D.D., Gradstein, S.R., Höhn, P., Kluge, J., Orend, F., Pitopang, R., Saleh, S., Schulze, C.H., Sporn, S.G., Steffan-Dewenter, I., Tjitrosoedirdjo, S.S. & Tscharntke, T. (2009). Alpha and beta diversity of plants and animals along a tropical land-use gradient. *Ecol. Appl.*, 19, 2142–2156.

Kingsford, R.T. (2000). Ecological impacts of dams, water diversions and river management on floodplain wetlands in Australia. *Austral Ecol.*, 25, 109–127.

MMA. (2007). *Informe Nacional sobre Áreas Protegidas no Brasil*. Brasília.

Pauly, D., Christensen, V., Dalsgaard, J., Froese, R. & Jr, F.T. (1998). Fishing Down Marine Food Webs. *Science (80-.).*, 860.

Pelletier, D., Garcia-Charton, J.A., Ferraris, J., David, G., Thebaud, O., Letourneur, Y., Claudet, J., Amand, M., Kulbicki, M. & Galzin, R. (2005). Designing indicators for assessing the effects of marine protected areas on coral reef ecosystems: A multidisciplinary standpoint. *Aquat. Living Resour.*, 18, 15–33.

Pollnac, R.B., Crawford, B.R. & Gorospe, M.L.G. (2001). Discovering Factors that Influenced the Success of Community-Based Marine Protected Areas in the Visayas, Philiphines. *Ocean Coast. Manag.*, 44, 683–710.

Rao, R.C. (1982). Diversity and dissimilarity coefficients: a unified approach. *Theor. Popul. Biol.*, 43, 24–43.

Ricciardi, A. & Rasmussen, J.B. (1999). Extinction rates of North American freshwater fauna.

Conserv. Biol., 13, 1220–1222.

Roberts, C.M., Bohnsack, J.A., Gell, F.R., Hawkings, J.P. & Goodridge, R. (2001). Effects of Marine Reserves on Adjacent Fisheries. *Science (80-.).*, 294, 1920.

Rodríguez-Olarte, D., Taphorn, D.C. & Lobón-Cerviá, J. (2011). Do protected areas conserve neotropical freshwater fishes? A case study of a biogeographic province in Venezuela. *Anim. Biodivers. Conserv.*, 2, 273–285.

Silvano, R.A.M., Nora, V., Andreoli, T.B., Lopes, P.F.M. & Begossi, A. (2017). The ghost of past fishing: Small-scale fisheries and conservation of threatened groupers in subtropical islands. *Mar. Policy*, 75, 125–132.

Silvano, R. a M., Hallwass, G., Lopes, P.F., Ribeiro, A.R., Lima, R.P., Hasenack, H., Juras, A. a. & Begossi, A. (2014). Co-management and Spatial Features Contribute to Secure Fish Abundance and Fishing Yields in Tropical Floodplain Lakes. *Ecosystems*, 17, 271–285.

Socolar, J.B., Gilroy, J.J., Kunin, W.E. & Edwards, D.P. (2016). How Should Beta-Diversity Inform Biodiversity Conservation? Conservation Targets at Multiple Spatial Scales. *Trends Ecol. Evol.*, 31, 67–80.

Vallès, H. & Oxenford, H.A. (2015). The utility of simple fish community metrics for evaluating the relative influence of fishing vs. other environmental drivers on Caribbean reef fish communities. *Fish Fish.*, 16, 649–667.

Welcomme, R.L. (1999). A review of a model for qualitative evaluation ofexploitation levels in multi-species fisheries. *Fish. Manag. Ecol.*, 6, 1–9.

Winemiller, K.O., McIntyre, P.B., Castello, L., Fluet-Chounard, E., Giarrizzo, T., Nam, S., Baird, I.G., Darwall, W., Lujan, N.K., Harrison, I., Stiassny, M.L.J., Silvano, R.A.M., Fitzgerald, D.B., Pelicice, F.M., Agostinho, A.A., Gomes, L.C., Albert, J.S., Baran, E., Jr, M.P., Zarfl, C., Mulligan, M., Sullivan, J.P., Arantes, C.C., Sousa, L.M., Koning, A.A., Hoeinghaus, D.J., Sabaj, M., Lundberg, J.G., Armbruster, J., Thieme, M.L., Petry, P., Zuanon, J., Vilara, G.T., Snoeks, J., Ou, C., Rainboth, W., Pavanelli, C.S., Akama, A., Soesbergen, A. Van & Sáenz, L. (2016). Balancing hydropower and biodiversity in the Amazon, Congo, and Mekong. *Science (80-.).*, 351, 128–129.

Artigo[1]

Influences of fishing pressure and protected areas on fish diversity patterns in two tropical rivers

Pedro Peixoto Nitschke, Renato Azevedo Matias Silvano[2]

Abstract

Fishing pressure increased in the last decades, threatening freshwater fish communities around the world. Amazon is the most protected biome in Brazil with more than 17% of its territory inside protected areas, but most of these were designed to protect terrestrial ecosystems and their benefits to freshwater ecosystems are not well known. Our study investigated the influences of protected areas in the form of Extractive Reserves (RESEX), two scales of fishing pressure and environmental parameters on fish diversity in the Tapajós and Negro rivers, Brazilian Amazon. We analyzed aspects of biodiversity (taxonomic and functional diversity) and assemblage structures descriptors (β diversity). Eight riverine communities were studied in each river, four inside and four outside a RESEX. The two studied RESEX differed by allowing artisanal commercial fishing in Tapajós and prohibiting this activity in Negro River. Local fishing pressure for each riverine community was estimated through the record of fish landings, while commercial fishing was estimated through the distance of each community from the main city in each river. Fish were sampled in river and lake sites near the studied communities. Overall, functional and taxonomic fish diversities were negatively related with artisanal and commercial fishing pressure In the Tapajós River, and artisanal fishing was positively related to functional diversity in Negro River. Spatial patterns of fish diversity (Beta diversity) were related to commercial fishing in both rivers. The RESEX was related to an increase of diversity in the

[1] O artigo segue as regras de formatação do periódico Conservation Letters, da editora Wiley. Informações: https://onlinelibrary.wiley.com/journal/1755263x

[2] Department of Ecology, Federal University of Rio Grande do Sul, PO Box 15007–91501-970, Porto Alegre, Brazil

Tapajós River and to spatial patterns of diversity in Negro River, indicating an overall positive effect on the fish community. These results indicated that freshwater protected areas can benefit fish communities in tropical rivers. However, commercial fishing activities adversely affected the diversity of the fish community and protected areas that allow commercial fishing may need additional management rules to regulate local fishing.

Keywords: Beta diversity; small scale fisheries; conservation; fish assemblage, Brazilian Amazon, Tapajós River, Negro River

1. Introduction

Fishing has affected marine and freshwater systems across the world, in spite of the efforts to control fishing pressure (Pauly et al. 2002). In both marine reefs (Brewer et al. 2009; Aswani & Sabetian 2010) and freshwaters (Brooks et al. 2016; Keppeler et al. 2018) the proximity to large market centers are indicators of fish community changes, in which the increase of fish demand creates a gradient of fishing pressure in areas near the market centers. Commercial fishing usually focuses on large-bodied species with higher trophic levels in marine ecosystems (Myers & Worm 2003; Olden et al. 2007; Genner et al. 2010). The fishing pressure in those large bodied and slow-growing species are so intense that commercial fishing in marine systems are targeting lower trophic level species instead of the large predators (Pauly et al. 1998). In freshwater systems, we can observe a similar effect among target species showing trends of decreasing fish size and changing the overall composition of target species from larger to smaller ones, a process known as fishing down (Welcomme 1999).

Although most of the attention has been directed to commercial or industrial fisheries, small-scale fisheries are considered to produce half of the total catch in the world and remain poorly studied or regulated (Mahon 1997; Pauly 1997; Berkes et al. 2001; Chuenpagdee and Pauly 2008; Castello et al. 2011). In marine reefs the exploitation by artisanal fisheries has caused reduction of fish size (Dulvy et al. 2004), loss of ecosystem services (Bellwood et al. 2003) and population declines of target species near fishing communities (Silvano et al. 2017). In tropical regions, such as the Amazon Basin, fisheries are considered to be multi-specific and artisanal fishers produce as nearly as 60% of the total catch, which may concentrate on few target fish species (Bayley & Petrere 1989; Hallwass & Silvano 2016). As has been observed in other freshwater ecosystems around the world (Welcomme 1999), the overfishing in the Amazon is already showing signs of fishing-down process with decrease in the mean body size of the main species caught (Castello et al. 2011). The three main species caught in the amazon in the 1900's are now considered endangered by the IUCN and the main reason is overexploitation (Barthem & Goulding 2007; Castello et al. 2011; IUCN 2018).

To reduce the impact of overharvesting, marine protected areas (MPA) have been proposed as an efficient way to control fishing pressure and maintain the biodiversity (Gell & Roberts 2003). The establishment of these areas have expected effects on biomass gain of fishes, increase of recruitment and, consequently, increment of population size and spillover to nearby areas (Bohnsack 1998; Halpern 2003; Pelletier et al. 2005). Capture by artisanal fishing can increase up to 90% in adjacent areas to a MPA after a short time since its establishment (Roberts et al. 2001). MPA's are usually a top-down government approach, which sometimes leads to social problems and conflicts due to lack of dialogue with fishing communities and prohibition of fishing activities (Silvano et al. 2017). To avoid these problems and ensure the expected outcomes, community participation in the decision making and management of the MPA is proposed as a key solution to its successful implementation (Pollnac et al. 2001; Pelletier et al. 2005). MPAs involving local community participation in management has increased the abundance of commercial invertebrates in the marine ecosystem (Gelcich et al. 2008) and improved the abundance of target fish species in reef systems (Aswani & Sabetian 2010). Freshwater protected areas (FPA) are recent and still rare but share similar challenges and expected results from the MPAs, and key lessons from MPA studies should be used for implementation and management of the FPA (Loury et al. 2018).

Due to conservation pressure in the 1980's and 90's (Castello et al. 2013), more than 17% of Amazon territory is protected by different types of conservation units nowadays, making it the most protected biome in Brazil (MMA 2007). However, most protected areas in the Amazon are designed to protect terrestrial ecosystems (Rodríguez-Olarte et al. 2011; Castello et al. 2013). Therefore, freshwater ecosystems lack attention and are protected only in conjunction with terrestrial systems (Castello et al. 2013). It is still not well know if terrestrial protected areas can attenuate the effects of fishing pressure or affect the fish community in broader scales (Nel et al. 2007; Suski & Cooke 2007; Rodríguez-Olarte et al. 2011). Studies showing directs benefits of terrestrial areas are scarce, including examples from the Canadian lakes (Chu et al. 2017). In the Brazilian Amazon, recent studies do not identify a clear effect of protected areas on fish assemblages, but areas influenced by or within conversation units demonstrate an increase in the amount of fish caught by fishermen when compared to unprotected regions (Silvano et al. 2014; Keppeler et al. 2017). This indicates that protected areas in the Brazilian Amazon, especially those that include local people, can regulate human activities, thus allowing fish populations to reestablish and recover to some degree from fishing pressure (Silvano et al. 2014).

The vast majority of studies in fisheries and influence of conservation areas are focused in local changes of diversity (α) and biomass (Bellwood et al. 2003; Dulvy et al. 2004; Keppeler et al. 2017; Silvano et al. 2017). The dissimilarities on species richness are translated into differences in assemblage composition measured by the beta diversity (Gutiérrez-Cánovas et al. 2013). Human impacts are likely to increase beta diversity at a landscape scale (Kessler et al. 2009; Gutiérrez-Cánovas et al. 2013; Socolar et al. 2016) and understanding the spatial scaling of diversity loss and changes are essential to conservation science (Socolar et al. 2016). Rather than focusing conservation strategies in simply preserving species richness (total amount of species in a given area), the adoption of beta diversity can be used to identify and preserve heterogeneous habitats that can host a variety of species and community types (Anderson et al. 2013). Beta diversity can identify factors that are driving the changes in community composition (Legendre & De Cáceres 2013), therefore being an important tool in the conservation and fisheries science.

Previous studies identified that physical and chemical variables are related to fish diversity (Tejerina-Garro et al. 1998) and forest cover was positively related with fish diversity and to spatial patterns of diversification (β diversity) in other Amazonian rivers (Lobón-Cerviá et al. 2015; Arantes et al. 2017). Few studies have jointly analyzed the fishing pressure and these environmental factors for tropical rivers (Keppeler et al. 2018). Our study has the main goal to investigate the influences of commercial fishing (measured as distance to the main port), artisanal fishing (fish landed by local fishing communities) and protected areas on fish diversity in two rivers of the Brazilian Amazon. To test these influences we selected three indicators that are recognized as being affected by fishing and anthropic factors (Aswani & Sabetian 2010; Vallès & Oxenford 2015): Rao's quadratic entropy, Simpson's diversity index, and Functional Redundancy. We also analyzed β diversity patterns to more clearly understand the main drivers of changes in fish community composition. We tested three hypotheses: 1) Rao's quadratic entropy, Simpson's diversity index, and Functional Redundancy will be negatively related to commercial and artisanal fishing. 2) variation in β diversity among habitats is due to changes in species composition (β total) or fluctuations in total fish abundance in local assemblages (β abundance difference), both of which should be associated with commercial and artisanal fishing pressure. 3) protected areas designed to protect terrestrial ecosystems will not influence any of the predictors analyzed related to fish diversity, nor Beta diversity. We also investigated the influences of other ecological characteristics (forest cover and physical and chemical variables) of fish communities on diversity patterns to identify potential confounding factors.

2. Material and Methods

2.1. Study site

The study addressed two rivers in the Amazon basin, Tapajós River and Negro and Unini Rivers in the Negro River Basin. These areas are subjected to seasonal variations in precipitation, resulting in the presence of seasonally inundated flood-plain forests along the margins of each river. Both rivers have protective areas of sustainable use in the form of Extractive Reserve (RESEX) that allows local communities to live inside the area following some specific management rules (Lopes et al. 2011). The RESEX in the two studied rivers differs in some rules, as the RESEX Unini is more restrictive, being closed to outsiders and to commercial fishing vessels and not allowing the sale of fish from artisanal fisheries (ICMBIO 2014). The RESEX of Tapajós is less restrictive, allowing commercial artisanal activities (fishing, collection of nuts and forest products) and due to the Tapajós being a wider river, commercial fishing boats are not controlled. For the purposes of this study, we selected eight riverine communities in each river, four inside and four outside the RESEX (Figure 1 Figure 2). Each community selected had a distance of 10km from each other, had similar social-economic characteristics (dedicated mainly to fishing, besides small-scale agriculture) and were willing to participate in this study. More information about the studied communities are in a previous study (Nagl 2017).

2.1.1. Tapajós River

The study area is located in the lower part of the Tapajós river in the Pará state, Brazil. This river is considered to be of clear water with low levels of sediments and nutrient concentration (Goulding et al. 2003). The lower section of the river is wide with opposite banks having more than 15 km apart in the widest part. This area contains two Conservation units: The National Forest of Tapajós (FLONA) and the RESEXof Tapajós–Arapiuns, which was the subject of our study (Figure 1). This RESEX was established in 1998 following a local initiative against illegal logging (ICMBIO 2008). The local riverine population is allowed to live inside the RESEX and to perform subsistence-related activities, such as small-scale agriculture, livestock farming, fishing, hunting and extraction of forest products (ICMBIO 2008). Although the RESEX excludes large-scale commercial fishing vessels, many interviewed fishers there said that fishing boats from the largest city in the region (Santarém) are common inside the RESEX (Hallwass 2015). Besides this problem of the presence of commercial boats, areas surrounding the RESEX have human densities 10 times higher and both commercial and artisanal fisheries are common (Keppeler et al. 2017).

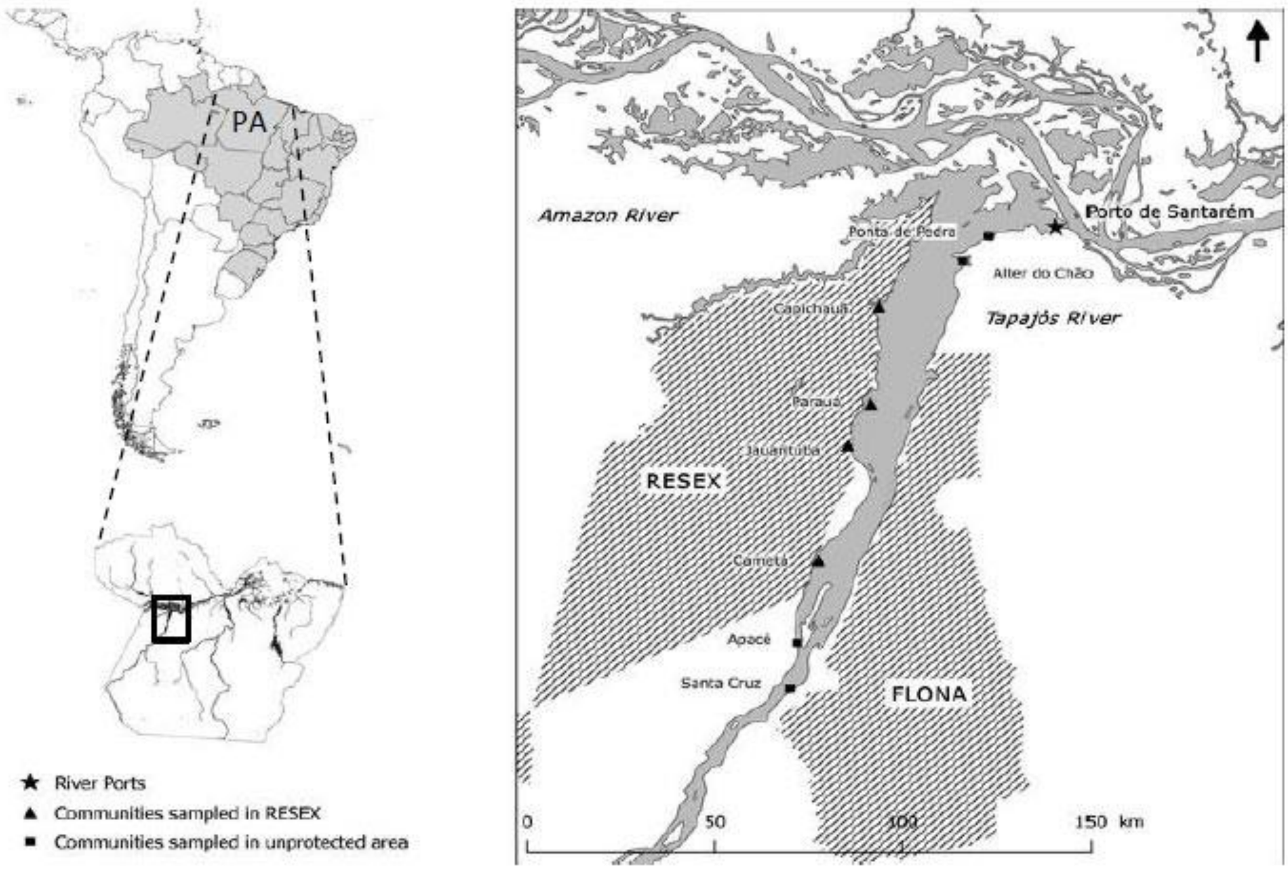


Figure 1: Location of the studied communities in the Tapajós River, Pará state. Shaded areas designate conservation units, the Sustainable Reserve Tapajós National Forest (FLONA) and Extractive Reserve Tapajós-Arapiuns (RESEX) object of our study. Communities sampled are marked as triangles (inside RESEX) and squares (outside), Santarém the major city of the region is marked as a star. Modified from Nagl (2017).

2.1.2. Negro River

The Negro river is a black water river characterized by low concentrations of nutrients being one of the biggest tributaries of the Amazon River. The water has tannins and organic components from the forest, which are responsible for the typical reddish-black color of the water. The study area is located in the Unini River, one of the major tributaries of the Negro River and in the middle stretch of the Negro River. The RESEX of Unini River (RESEX Unini) was created in 2006, following a demand of local communities to avoid the impacts of commercial and sport fisheries in the area. The local population has to follow some local management rules, including the prohibition of commercial fisheries inside the reserve (ICMBIO 2014).

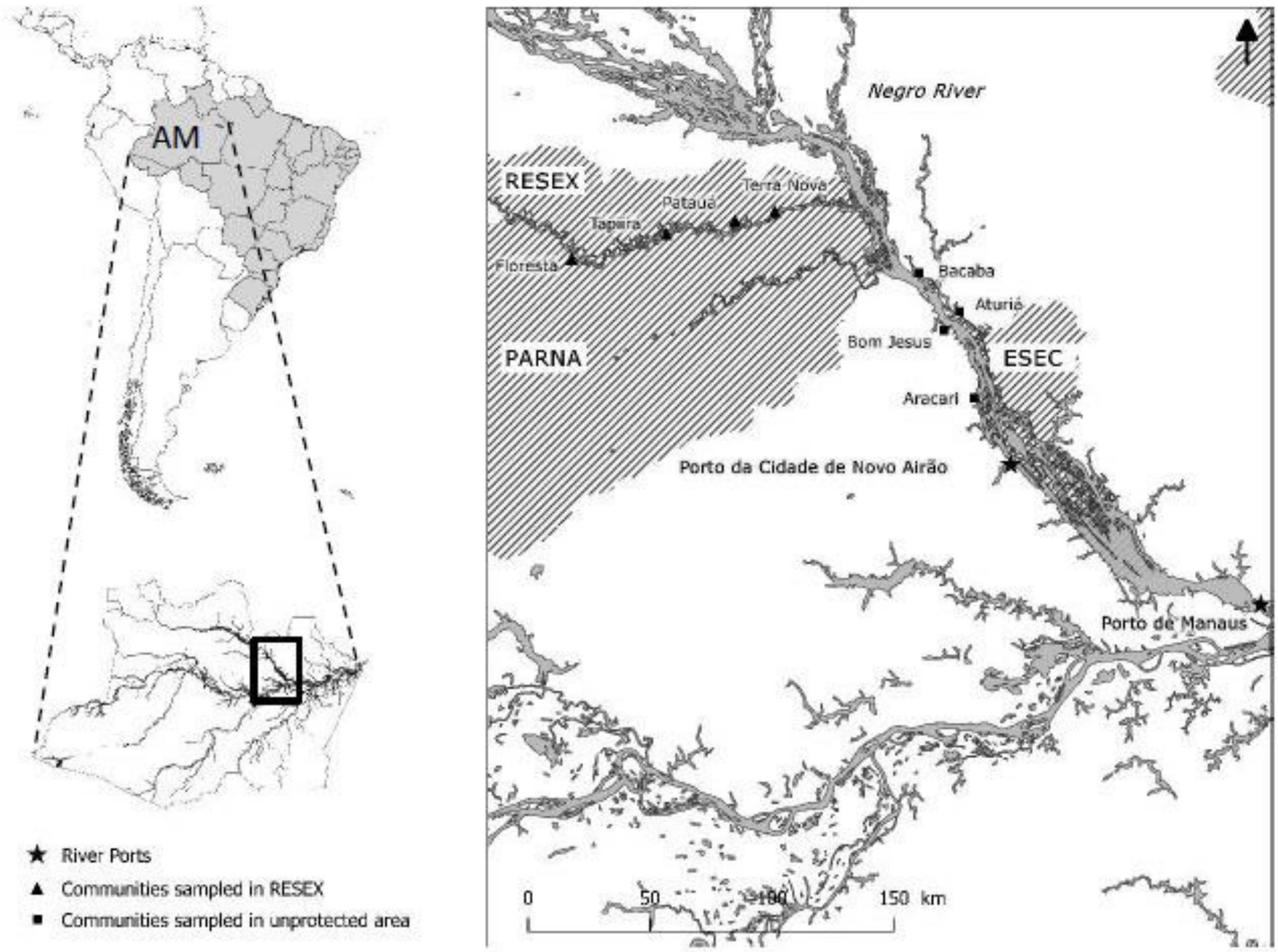


Figure 2: Location of the studied communities in Unini and Negro River, Amazonas state. Shaded areas designate conservation units, National Park of Jaú (PARNA) and Extractive Reserve Unini (RESEX) object of our study. Communities sampled are marked as triangles (inside RESEX) and squares (outside), Manus the major city of the region is marked as a star. Modified from Nagl (2017).

2.2. Data collection

2.2.1. Fish sampling

Two fish samplings were made in each studied community, 16 samplings in each studied river, one sample in lakes or lentic environments and the other in a river stretch or in more lotic environment. The fish samplings were conducted during the dry season in November (Tapajós) and December (Negro/Unini). Local people indicated areas of the river and floodplain lakes where they usually perform their fishing activities and which were suitable for fish sampling. Fishes were collected using two sets of gillnets with different mesh sizes (15-80mm between opposite knots), one set was placed along the shoreline and the other in the center of the river (or lake), for 24 hours. Gillnets were checked every 4 hours and each individual fish captured was measured to standard length (cm) and weighed (g). Some fish were collected and taken to the lab for species identification.

We analyzed two datasets, one including sampling sites in both river and lake and another one with data from lake sites only. This approach was used to provide a more detailed evaluation of different effects of fishing pressure (commercial and artisanal), as commercial fisheries exploit mostly the main river, while artisanal fisheries use both river and lakes.

2.2.2. Artisanal fishing

Artisanal fishing pressure was defined as the fisheries productivity of each studied community, which was measured through participatory monitoring of fish landings by fishers, a reliable method to collect fishing data that can indicate relative fishing intensity (Hallwass et al. 2011; Keppeler et al. 2017). In each community, fishers were asked and trained to record their first five fishing trips on each month during one year (July 2016 to June 2017 in Tapajos, August 2016 to July 2017 in Negro). Initially 155 fishers agreed with monitoring their fish landings (86 in Tapajós and 69 in Negro/Unini), resulting in 3391 fishing landings recorded over 12 months

(Table S1 and 2). Since regions had different numbers of participants recording fishing landings we pondered the total fish landed (Kg) by the numbers of recorded fishing landings, resulting in the estimated Artisanal Fishing Pressure for each community. For more information about the methodology of recording fish landings see Nagl (2017).

2.2.3. Physical and Chemical variables

We measured four physical and chemical variables that are likely to influence the fish community (Tejerina-Garro et al. 1998; Petry et al. 2003): depth, PH, water temperature and dissolved oxygen. Since the last three variables may vary along the day, we measured these each time we checked the nets resulting in five measurements for each environment. The average of all these measures were used in the analysis.

2.2.4. Satellite imagery: land cover and commercial fishing

To test whether the commercial fishing had an effect on fish assemblage we used distance from the main city as a proxy for commercial fishing impact. The use of the distance to major cities or markets is an approach that has been used to indicate overall fishing pressure when other variables, such as fish landings, are not easily obtained (Silvano et al. 2017; Keppeler et al. 2018). Distance to the main city reflects the access to larger fish markets and the relative cost of fishing activities, which increases as boats harvest in more distant areas (Brewer et al. 2009; Aswani & Sabetian 2010; Silvano et al. 2017; Keppeler et al. 2018). We used Google Earth Pro software to measure the distance of each community to the main city (Santarém in Tapajós and Manaus in Negro River).

We defined a buffer with 4km radius centered in the place where fishing gillnets were set in each sampled site in each community. Floodplain land cover was defined following

Mapbiomas (2018) classification, selecting open water, forest, and herbaceous vegetation cover classifications, as these landscape factors are related with changes in fish assemblages (Lobón-Cerviá et al. 2015; Arantes et al. 2017). Each pixel (30 x 30m resolution) inside the buffer zone was selected and the percentage of each land cover was calculated using Idrisi software. Since the distance between the sample habitats (lentic and lotic) were small, only one buffer was measured for the two sampled sites in each fishing community, resulting in 8 buffers in each studied river.

2.3. Data analysis

2.3.1. Explanatory variables

Land cover variables, commercial (*i.e.* distance to the main city) and artisanal fishing pressure indicators were log transformed and submitted to Person correlation test to evaluate collinearity among variables. To avoid multicollinearity between our Physical and Chemical variables we performed a principal component analysis based on the correlation matrix (PCA). We then selected the first component axe and used its values in the subsequent analyses (Figure S1 and S2). We also checked the influence of the protected area (RESEX) in the fish assemblage descriptors, including the location inside or outside the RESEX as a categorical variable in the analyses.

2.3.2. Response variables: Fish assemblage and Functional Traits classification

Fish abundances were standardized as catch-per-unit of effort (CPUE), measures as the biomass of fish sampled divided by hours of each net in the water, in each sampling site. This measure of CPUE was used in all analysis. We measured the Simpson index of species diversity for each community sampled, based on CPUE values for each sampled fish species.

We selected five functional traits that are likely to influence how fish species respond to environmental variation and fishing activities that were obtained from the literature (Froese & Pauly 2018). When the information was not available or it was not possible to identify the individual to species level, we used information for species from the same genus. These traits were: (1) maximum size, when the collected individuals were smaller than records from the literature; (2) diet, which was classified in broad categories as herbivore, detritivore, omnivore, invertivore, planktivores and piscivore; (3) migratory habit, classified as migratory or not; (4) position in the water column, classified as Benthopelagic, Pelagic or Demersal ; and (5) trophic level.

Since our traits have different scales of measure we used Gower's similarity index in order to have a dissimilarity matrix with Euclidean metric proprieties (Podani 1999). Functional diversity was measured as Rao's quadratic entropy (Rao 1982) and, following de Bello et al. (2007), we measured functional redundancy (FR) as the difference between species diversity (D) and functional diversity (FD):

$$FR = D - FD$$

In this, D is the Simpson index and FD is Rao's quadratic entropy index. FR ranges from 0 (when species are different for the traits) to 1 (when species are identical for the traits). Functional Redundancy is defined as how much the community is saturated with species with similar traits (de Bello et al. 2007).

To investigate the determinants of the observed diversity patterns of studied fish assemblages we generated multiple regression models. The response variables in these models were functional redundancy (FR), functional diversity (Rao's quadratic entropy) and Simpson's diversity index and the five explanatory variables (physicochemical variables, forest cover, commercial and artisanal fishing pressure- - and RESEX). The model was assessed with respect to normally distributed errors and variation inflation factor (VIF) to test multicollinearity. In the

Negro River, due to the inflation of variance (VIF), we excluded the variable RESEX from the analysis (Figure S3).

2.3.3. Betadiversity

We investigated the variation on β diversity of studied fishing communities using an approach proposed by Legendre (2014) to explain the variation in diversity along environmental gradients. Due to the fact that our sample units had maximum distance of 100km from each other, we used abundance indices that are preferable within small spatial ranges. The selected index was percentage difference (Odum 1950) known as Bray-Curtis index. We then decompose the total amount of β diversity (β total) for all pair sites in spatial turnover (β turnover) and abundance difference (β abundance difference, considering CPUE of each species) following Podani et al. (2013) and Legendre (2014). Turnover is the change of community composition (i.e. gain and loss of species) from one sampling unit to another along an ecological gradient (Whittaker 1972; Anderson et al. 2011). Abundance difference refers to the fact that one community may include a larger abundance of species than another, which may reflect the diversity of niches or ecological processes (Legendre 2014).

In order to investigate the associations between the components of β diversity and the five explanatory variables (physicochemical variables, forest cover, commercial and artisanal fishing pressure and RESEX) we used a Partial Constrained Analysis of Principal Coordinates (CAP), an ordination method that allows non-Euclidian dissimilarity indices. A permutation test (999 permutations) was used to test the significance of each variable.

To test whether the RESEX was an important factor influencing the variance of β diversity we used a multivariate analysis of variance (PERMANOVA), where the total sum-of-squares of the species data can be divided among the group of sites (Legendre & De Cáceres 2013). This procedure indicates whether the sites located inside and outside the RESEX have different species compositions in their respective fish communities.

All analyses were performed in the R version 3.3.3 (R Development Core Team 2016). Rao's Quadratic Entropy, Gini-Simpson and Functional Redundancy were computed using *SYNCSA* package (Debastiani & Pillar 2012). CAP (function *capscale)* and permutation test (function *anova.cca*) were computed using *vegan* package (Oksanen et al. 2017). β diversity, turnover and abundance difference were decompose with the function *beta.div.comp* using *adespatial* package (Dray et al. 2017).

3. Results

We collected 3647 individuals of 117 species in the Tapajós River, resulting in more than 239.9 kg of fish sampled. *Plagioscion squamosissimus* was the most sampled fish (total biomass: 33.9 kg; 27.3 kg outside and 6kg inside RESEX), followed by *Pygocentrus nattereri* (total biomass: 27.1 kg; 24.9 kg outside and 2 kg inside RESEX) and *Loricariichthys acutus* (total biomass: 15.8 kg; 8.4 outside and 7.3 inside RESEX). *P. squamosissimus* is a target species for the fisheries market (Hallwass et al. 2011; Hallwass & Silvano 2016) and most of its biomass was caught outside the RESEX areas.

In the Negro River, we collected 5963 individuals of 143 species, resulting in 376 kg of fish sampled. *P. squamosissimus* was the most caught fish in Negro river too (total biomass: 44.3 kg; 39.9 kg outside and 4.3 kg inside RESEX), followed by *Hemiodus immaculatus* (total biomass: 34.4 kg; 21.4 kg and 13 kg inside RESEX) and *Ageneiosus inermis* (total biomass: 17.7 kg; 14 kg outside and 3.1 kg inside RESEX). The same pattern was observed with *P. squamosissimus* in Negro River, with most of its biomass caught outside RESEX.

3.1. Functional diversity

Tapajós River

We observed a negative effect of the commercial fishing in the Rao's quadratic entropy (Figure 3.A) and in Simpsons diversity (Figure 3.C) in the analysis with the complete dataset, indicating that areas more distant from the main port tended to have higher levels of functional diversity and an increase in Simpsons diversity. The same pattern was observed with the RESEX variable, meaning that communities inside the RESEX tended to have a higher Simpsons diversity when compared to communities outside (Figure 3.C). Simpsons diversity index was negatively related to Artisanal fishing, showing that areas that had higher local fishing pressure (more biomass of fish landed) had less diversity (Figure 3.C). The same pattern was observed for the forest cover (Figure 3.C), in which higher levels of forest cover were related to low levels of species diversity. Functional redundancy was not related to any of our explanatory variables (Figure 3.B).

The analyses using the lake dataset showed a different pattern: Simpson's diversity was not related to any of the explanatory variables (Figure 3.G). Functional Redundancy was positively affected by Forest Cover (Figure 3.F), indicating that areas with higher forest cover tended to have species that are more similar regarding functional traits (*I.e.* redundant). The Rao index exhibited a positive relationship with the distance (*i.e.* negative relation with commercial fishing) and the physical and chemical components (PC1 axe, Figure 3.D). This indicates that areas more distant from the main port tended to have higher levels of functional diversity, and that the physical and chemical variables are a limiting factor in the functional diversity. A negative relation was observed between the Rao's index and the explanatory variable Artisanal fishing (Figure 3.D), indicating that areas with higher fishing pressure tended to have fish communities with less functional diversity. The same result was observed with forest cover, where areas with more forest cover tended to have communities less functionally diverse (Figure 3.D).

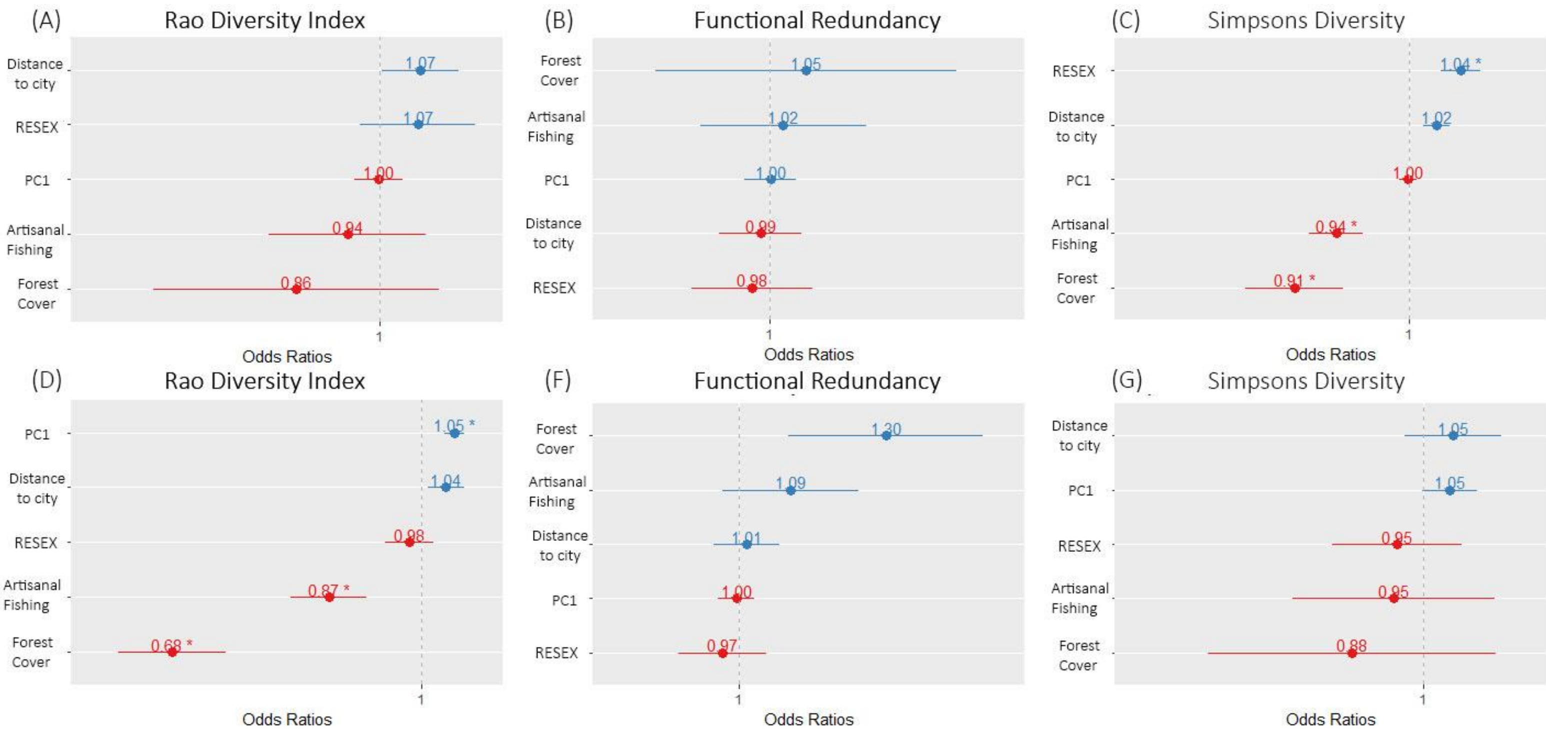


Figure 3: Odds Ratios and 95% of Confidence interval of the predictors for Rao Quadratic Entropy, Functional Redundancy and Simpson diversity in the **Tapajós** River. A-C Indicates results from the complete data set and D-G indicates data from lakes only. Variables were considered to have a significant effect when 95% Confidence Intervals did not cross the value 1 of Odds Ratios.

Negro River

The explanatory variables did not influence the response variables (Rao index, Functional Redundancy, and Simpson diversity index) for the complete dataset (Figure 4.A-C). For the lake dataset Artisanal fishing had a positive relationship with Rao's index, indicating that areas with higher local fishing pressure tended to have fish communities with higher functional diversity (Figure 4.D). The other response variables were not related to the respective explanatory variables (Figure 4.F-G).

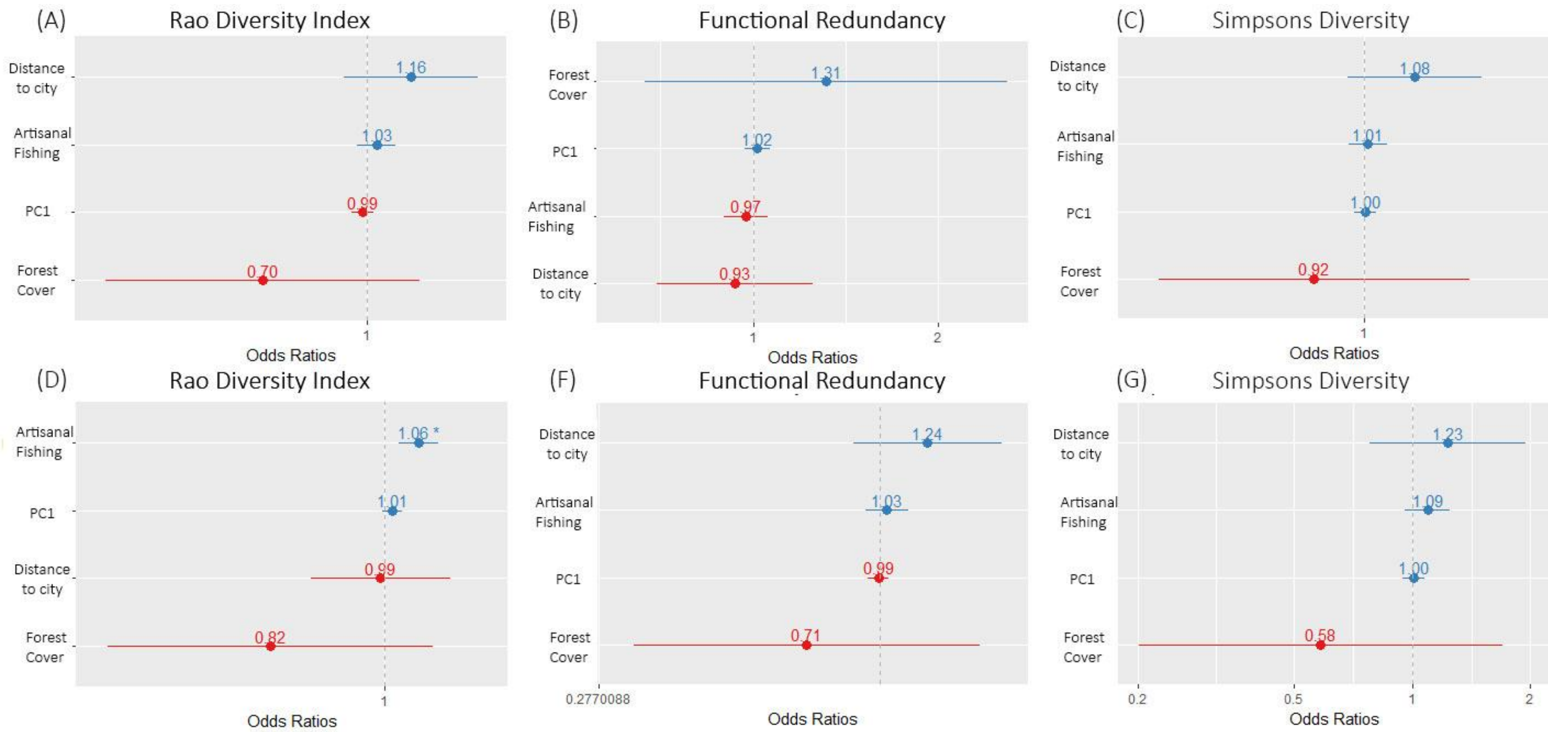


Figure 4: Odds Ratios and 95% of Confidence interval of the predictors for Rao Quadratic Entropy, Functional Redundancy and Simpson diversity in the **Negro River**. (A-C Indicates results from the complete data set and D-G indicates data from lakes only. Variables were considered to have a significant effect when 95% Confidence Intervals did not overlap the one mark.

3.2. Beta Diversity

Tapajós River

Beta diversity of fishes in the Tapajós river was associated only with distance (commercial fishing) to the main port for both Total Beta diversity (βTotal; **Table 1**; Figure S4; p=0.01) and for Abundance difference (βAbundance; **Table 1**; Figure S4; p=0.02). This indicated that areas that are more distant to the main city showed greater variation in composition and abundances of species. The turnover (βTurnover) of species was not related to any of the explanatory variables analyzed (Table 1). Areas inside the RESEX do not differ from outside areas regarding the beta diversity and its components (βTotal p=0.678; βTurnover p= 0.378; βAbundance p=0.664).

The lake dataset revealed a different pattern, as the βTotal was influenced by the forest cover (**Table 2**; Figure S5; p=0.02) and βAbundance was again related with distance, an indicator of commercial fishing (**Table 2**; Figure S5; p=0.02). The βTurnover was not related to the explanatory variables (Table 2). As observed for the complete dataset, sites inside RESEX did not differ from outside areas regarding Beta diversity patterns (βTotal p=0.226; βTurnover p= 0.122; βAbundance p=0.113).

Table 1: Results of the Partial Constrained Analysis of Principal Coordinates with **complete dataset** for fish Beta diversity in the **Tapajós** River (lakes and river sampling for each community) and the selected variables. F relates to the Fisher's distribution and Pr(>F) relates to the probability of observing that F-test in a normal distribution of F values.

	BTotal			βTurnover			βAbundance		
Variable	*Sum of Squares*	*F*	*Pr(>F)*	*Sum of Squares*	*F*	*Pr(>F)*	*Sum of Squares*	*F*	*Pr(>F)*
Forest (%)	0.406	1.294	0.226	0.168	3.023	0.185	0.126	0.877	0.502
Distance	0.675	2.152	**0.018****	-0.09	-1.642	0.870	0.721	5.019	**0.024****
Landing	0.165	0.527	0.973	0.064	1.151	0.403	0.027	0.189	0.929
PC1 axe	0.250	0.813	0.673	0.087	1.573	0.329	0.057	0.398	0.789
Residual	0.940			0.167			0.431		

Table 2*:* Results of the Partial Constrained Analysis of Principal Coordinates with **lake dataset** for fish Beta diversity in the **Tapajós** River and the selected variables. F relates to the Fisher's distribution and Pr(>F) relates to the probability of observing that F-test in a normal distribution of F values.

	βTotal			βTurnover			βAbundance		
Variable	*Sum of Squares*	*F*	*Pr(>F)*	*Sum of Squares*	*F*	*Pr(>F)*	*Sum of Squares*	*F*	*Pr(>F)*
Forest (%)	0.697	2.006	**0.028****	0.094	0.869	0.533	0.302	2.865	0.125
Distance	0.536	1.543	0.114	-0.120	-1.105	0.868	0.671	6.363	**0.025****
Landing	0.201	0.578	0.936	0.064	0.594	0.568	0.067	0.643	0.569
PC1 axe	0.355	1.023	0.445	0.019	0.176	0.687	0.208	1.977	0.201
Residual	1.042			0.327			0.316		

Negro River

In the Negro River we observed an influence of distance (commercial fishing) in βTotal (Table 3; p=0.03; Figure S6) and in βTurnover (Table 3; Figure S6; p=0.02). β Abundance difference was not affected by any of the explanatory variables (Table 3). RESEX was a factor driving the variation in community composition for the βTotal (p=**0.03**), however it was not possible to observe the same effect in βAbundance (p=0.06) and βTurnover (p=0.09).

The lake dataset did not show any relationship among response and explanatory variables (**Table 4**; Figure S7), and RESEX affect slightly the β Total (p=0.05) and the βTurnover (p=0.06) but no clear pattern was observed for the βAbundance (p=0.9).

Table 3: Results of the Partial Constrained Analysis of Principal Coordinates with **complete dataset** for fish diversity in the **Negro** River (lakes and river sampling for each community) and the selected variables. F relates to the Fisher's distribution and Pr(>F) relates to the probability of observing that F-test in a normal distribution of F values.

	βTotal			βTurnover			βAbundance		
Variable	*Sum of Squares*	*F*	*Pr(>F)*	*Sum of Squares*	*F*	*Pr(>F)*	*Sum of Squares*	*F*	*Pr(>F)*
Forest (%)	0.245	1.187	0.313	0.100	0.905	0.555	0.052	4.00	0.125
Distance	0.407	1.973	**0.030****	0.319	2.890	**0.023****	0.001	0.148	0.808
Landing	0.325	1.577	0.092	0.280	2.535	0.085	0.007	0.553	0.507
PC1 axe	0.260	1.262	0.224	0.030	0.810	0.617	0.047	3.660	0.144
Residual	0.619			0.390			0.039		

Table 4: Results of the Partial Constrained Analysis of Principal Coordinates with **lake dataset** for fish diversity in the **Negro** River and the selected variables. F relates to the Fisher's distribution and Pr(>F) relates to the probability of observing that F-test in a normal distribution of F values.

	βTotal			βTurnover			βAbundance		
Variable	*Sum of Squares*	*F*	*Pr(>F)*	*Sum of Squares*	*F*	*Pr(>F)*	*Sum of Squares*	*F*	*Pr(>F)*
Forest (%)	0.313	0.861	0.602	0.172	6.914	0.060	0.010	0.037	0.985
Landing	0.336	0.924	0.575	0.219	8.820	0.161	0.002	0.008	0.979
Distance	0.463	1.272	0.272	0.247	9.967	0.054	0.116	0.428	0.629

PC1 axe	0.202	0.5575	0.914	0.137	5.534	0.077	0.040	0.147	0.857
Residual	1.092			0.074			0.817		

4. Discussion

As we expected according to our hypothesis 1, commercial fishing, here measured as distance to the main city or port, affected fish functional diversity and was related to β diversity patterns in Tapajós River. These findings suggest that fishing pressure caused by large-scale commercial boats coming from larger cities can lead to spatial homogenization of fish communities and to differences in spatial patterns of fish abundance, as fish communities subjected to a more intense fishing pressure would show a more similar species composition. A potential effect of the selectivity of the commercial fisheries (Bayley & Petrere 1989; Myers & Worm 2003; Olden et al. 2007; Genner et al. 2010; Hallwass & Silvano 2015) was reflected in the fish functional diversity, which increased as we go farther from the main port of Tapajós. The tradeoff between the benefit of fishing in less exploited and more distant areas and the cost of a longer fishing trip (time and fuel) may create a spatial gradient of fishing pressure in the Tapajós and possibly also in other rivers in the Brazilian Amazon (Silvano et al. 2014; Keppeler et al. 2018) and elsewhere. Our findings strengthen the assumption that distance to the main city can be used as proxy for fishing pressure in marine and freshwater ecosystems (Silvano et al. 2017; Keppeler et al. 2018). Since the main port in the Tapajós region is near the Amazon River (Figure 3), we could expect that communities near the main city would suffer the influences of this river. Different water characteristics make the Amazon river richer in nutrients and highly diverse (Goulding et al. 2003). Furthermore, the confluences of rivers are associated to the enrichment of the fish diversity providing the encounter of species from both rivers (Knight 1986; Osborne & Wiley 1992; Fernandes et al. 2004), so this association should increase functional and taxonomic diversity. As we go farther from the city, we would expect less influence of the Amazon River and, consequently, high levels of species turnover along the spatial gradient. Since this pattern was not observed, we can assume that the fishing pressure from the main city has a strong effect in the fish community, affecting functional and taxonomic diversity and being a driver of changes in the fish community assemblage. Commercial fishing in the lowest part of the Tapajós River may be acting as a kind of 'anthropic barrier', preventing target fish species coming from the Amazon River to establish populations in the Tapajós River, but future studies may be needed to address this question.

The species composition of fish assemblages (Beta diversity) was related with commercial fishing (*i.e.* distance to the main port) in the Negro River, indicating that commercial fishing can be related to changes in fish assemblages across space. However, due to our sampling design in Negro River we have to be careful with interpretations of the relationships between β diversity and distance (β Total and β Turnover, Table 3; Figures S3-S4). Because some of our sampling areas were in different Rivers (Figure 2), the observed effects in the β diversity might be linked to differences from rivers on fish diversity, especially when species turnover is related to distance indicating that there is a change in species composition along the rivers. The lack of relation between functional and taxonomic diversity related to the distance indicate that these areas have similar diversity (functional and number of fish species) and the change along the river (β Turnover) may be due to differences in the river characteristics or biogeographical patterns not evaluated in this study. Therefore, in this case distance may not be the best proxy for commercial fishing. The same precaution has to be made regarding the effects of RESEX on βTotal, since this protected area is in a different river and this might influence the fish composition observed. We suggest that the differences observed in the fish communities (β diversity) are due to the joint influences of the presence of the RESEX in the Unini River, which would be also more distant from the main port (Manaus). As result of this precaution, our second and third hypotheses are not confirmed in the Negro River.

Despite the negative effect of commercial fishing in Tapajós River, we observed a positive effect of the RESEX in the taxonomic diversity of fishes. Keppeler et al. (2017) did not observe positive effects of the protected areas of Tapajos River on fish diversity, but this contrasting result might be because these authors made less intensive fish samplings, only in lakes. Indeed, we also did not observe a RESEX effect when analyzing lake data only. We speculate that a lack of RESEX effects on fish in lakes was due to local commercial fishing inside the RESEX. In this case, even though the whole area (river and lakes) was positively influenced by the RESEX, local fishing pressure inside lakes by artisanal fisheries might cause a dilution of the RESEX`s influence. Nevertheless, fishing productivity may be increased inside the protected areas, including the RESEX, as has been observed previously in the Tapajos River (Keppeler et al. 2017). This positive effect of protected areas on local fisheries has been also recorded in other rivers in the Brazilian Amazon (Almeida et al. 2009; Silvano et al. 2014) and elsewhere in marine ecosystems (Bohnsack 1998; Pelletier et al. 2005; Gelcich et al. 2008; Aswani & Sabetian 2010). Our third hypothesis was partially confirmed, since the protective effects in the fish diversity are mediated by the environmental scale (lake or river), indicating that conservation policies and actions should be different for each environment.

The artisanal fishing pressure was associated with negative effects on fish diversity (Simpson's and Rao's diversity indexes) in the Tapajós River. This pattern agrees with observed effects of artisanal fisheries in reef systems, causing the loss of fish species and ecosystem services (Bellwood et al. 2003). However, we observed a different pattern in Negro River, where the Rao`s diversity index tended to have a positive relationship with fish landings (artisanal fishing). The artisanal fishing in Negro River might be acting as intermediate disturbance, causing fish communities to be more diverse when compared to communities with less fishing pressure. This suggests that artisanal fisheries with commercial purposes, such as those in Tapajos River, may increase fishing pressure in lakes, thus affecting fish diversity. Artisanal fishing with commercial objectives caused depletion of target species in other Amazonian regions (Barthem

& Goulding 2007; Castello et al. 2011) and we may have observed the same effect in the Tapajos River, even inside the RESEX, which is a protected area. This highlights some precautions since initiatives from local people demand a review of the management rules in the RESEX-Unini to allow sport and commercial fisheries. This demand is coming from the local fisheries communities to improve financial and social benefits that these activities deliver, however the ecological outcome from these activities are not clear. If the same pattern of artisanal fishing in Tapajós River occurred in the Negro/Unini River we would expect a decrease in diversity of taxonomic and functional diversity of fishes in lake and river systems. This highlights the need for additional management measures and careful monitoring in protected areas that allow commercial fishing.

Physical and Chemical variables were positively related with the functional diversity of fishes in the lakes of the Tapajós River, aligning with the results previously observed for species richness in the Tapajos (Keppeler et al. 2017) and other areas in the Amazon (Tejerina-Garro et al. 1998). The influence on the fish functional diversity indicated that these variables are acting as a filter in the community, selecting a broad variety of species that have different adaptations to live in these lake systems (Almeida-Val et al. 1993). This highlights the relevance of environmental heterogeneity in the maintenance of highly diverse habitats.

Forest cover was related to changes in fish assemblage (β diversity) in lake communities in the Tapajós River, as observed in the Lower Amazon River (Arantes et al. 2017). There was a negative influence of forest cover on the Simpson's diversity when considering the complete dataset and on the Rao's entropy when considering lake data in the Tapajos River. This negative influence of forest cover on fish diversity did not match previous findings from other studies that showed the opposite effect: richness, functional diversity and uniqueness of species composition are positively affected by the forest cover (Casatti et al. 2015; Lobón-Cerviá et al. 2015; Arantes et al. 2017). Nevertheless, forest cover showed a positive relation to Functional

Redundancy in the Tapajos River, which could be related to a greater resilience capacity or to a higher homogenization of the fish community, which would be correlated to the observed low levels of Rao's index in areas with higher levels of forest cover. We thus propose two hypotheses to explain these observed patterns in the Tapajós River. Our first hypothesis is that the previous studies were performed in rivers that have different physical and chemical characteristics, such as white water rivers. Fish species in these areas might be more linked to allochthonous resources from the forest, which make them more strongly influenced by the forest cover. Our second hypothesis relates to the fishing activities in the Tapajos River. Castello et al. (2017) observed that forest cover was positively related with fisheries yields and Lobón-Cerviá et al. (2015) identify a positive relationship with the forest cover and the biomass of commercially important fish species, both studies in the Amazon River. Therefore, forest cover may provide nutrients and shelter to fish species and might increase their abundance (Goulding et al. 2003; Lobón-Cerviá et al. 2015). Higher quantities of forest might indicate that the riverine community is using more resources from the river and lake and dedicating less time to agricultural activities. This is aligned with positive effects of the forest cover in Functional redundancy since fishing activities are focused in a few species and functional groups (Hallwass & Silvano 2016). Therefore, the exploitation of these few functional groups may reduce the overall functional diversity, increasing the redundancy of the community. These hypotheses could and should be further investigated with studies dedicated to this trade-off between fisheries and agriculture, including interviews with fishers. No relation between forest cover and fish diversity was observed in the Negro River, but this lack of relation are probably due to the high amount of forest cover in all the analyzed communities.

The environmental variables showed low relation with our response variables for fish community diversity (Simpson, Rao and Functional redundancy) and assemblage patterns (β diversity). This results indicates that fish communities in the analyzed rivers are more influenced by anthropic variables (related to fishing pressure or management) than by environmental variables, which was a different outcome from other studies in the Amazon basin (Tejerina-Garro et al. 1998; Keppeler et al. 2017). Fishing pressure, therefore, is a driver related to the loss of diversity and changes in fish composition that should be taken into account when managing and creating new protected areas. We highlight that response variables related to fish diversity used in our study respond differently in each river in respect to our explanatory variables. This strengthens the need for studies considering different types of variables.

5. Conservation and management implications

Our results indicated some benefits of protected areas (RESEXs) to protect fish communities from fishing pressure, even considering that these protected areas are concentrate in terrestrial ecosystems (Rodríguez-Olarte et al. 2011; Castello et al. 2013). The demand for protected areas is increasing, as well as the demand for food resources and financial security by local riverine communities, which will increase the social and biodiversity conflicts of interests. Our results indicated that commercial fishing activities may lead to impacts on the spatial patterns of fish diversity and on the structure of fish communities. Such anthropic factors were drivers in the changes of community composition of fishes and should be taken into account when creating or managing protected areas. Therefore, we suggest that social demands must be taken into account when managing conservation areas, by implementing fishing regulations, such as quotas, closed seasons or no-take areas, besides government incentives to evade commercial fishing from larger boats from outside these areas. Since protective areas managed with local participation are highly effective (Pollnac et al. 2001; Pelletier et al. 2005; Almeida et al. 2009; Silvano et al. 2014), we encourage that local rules be negotiated with riverine communities to avoid or reduce potential impacts from commercial fishing on fish diversity.

6. Bibliography

Almeida, O.T., Lorenzen, K. & McGrath, D.G. (2009). Fishing agreements in the lower Amazon: For gain and restraint. *Fish. Manag. Ecol.*, 16, 61–67.

Almeida-Val, V. M. F., A. L. Val, and P. W. Hochachka. "Hypoxia tolerance in Amazon fishes: status of an under-explored biological "goldmine"." Surviving Hypoxia: Mechanisms of Control and Adaptation (1993): 435-445.

Anderson, M.J., Crist, T.O., Chase, J.M., Vellend, M., Inouye, B.D., Freestone, A.L., Sanders, N.J., Cornell, H. V., Comita, L.S., Davies, K.F., Harrison, S.P., Kraft, N.J.B., Stegen, J.C. & Swenson, N.G. (2011). Navigating the multiple meanings of B diversity: A roadmap for the practicing ecologist. *Ecol. Lett.*, 14, 19–28.

Anderson, M.J., Tolimieri, N. & Millar, R.B. (2013). Beta Diversity of Demersal Fish Assemblages in the North-Eastern Pacific: Interactions of Latitude and Depth. *PLoS One*, 8, 1–15.

Arantes, C.C., Winemiller, K.O., Petrere, M., Castello, L., Freitas, C.E.C. & Hess, L.L. (2017). Relationships between forest cover and fish diversity in the Amazon River floodplain. *J. Appl. Ecol.*, 1–10.

Aswani, S. & Sabetian, A. (2010). Implications of Urbanization for Artisanal Parrotfish Fisheries in the Western Solomon Islands. *Conserv. Biol.*, 24, 520–530.

Barthem, R. & Goulding, M. (2007). *An unexpected ecosystem: the Amazon as revealed by fisheries. An unexpected Ecosyst. Amaz. as Reveal. by Fish.* Association Press, Lima.

Bayley, P.B., and M. Jr. Petrere. 1989. "Amazon Fisheries: Assessment Methods, Current Status and Management Points." In Proceedings of the International Large River Symposium, edited by D.P. Dodge, 385?398. Ontario, Canada: Canadian Special Publication of Fisheries and Aquatic Sciences, 106

de Bello, F., Lepš, J., Lavorel, S. & Moretti, M. (2007). Importance of species abundance for assessment of trait composition: an example based on pollinator communities. *Community Ecol.*, 8, 163–170.

Bellwood, D.R., Hoey, A.S. & Howard Choat, J. (2003). Limited functional redundancy in high diversity systems: resilience and ecosystem function of coral reefs. *Ecol. Lett.*, 6, 281–285.

Bohnsack, J.A. (1998). Application of marine reserves to reef fisheries management. *Austral Ecol.*, 23, 298–304.

Berkes, F., Mahon, R., McConney, P., Pollnac, R.C., Pomeroy, R.S., 2001. Managing Small-scale Fisheries: Alternative Directions and Methods. International Development Research Centre, Ottawa.

Brewer, T.D., Cinner, J.E., Green, A. & Pandolfi, J.M. (2009). Thresholds and multiple scale interaction of environment, resource use, and market proximity on reef fishery resources in the Solomon Islands. *Biol. Conserv.*, 142, 1797–1807.

Brooks, E.G.E., Holland, R.A., Darwall, W.R.T. & Eigenbrod, F. (2016). Global evidence of positive impacts of freshwater biodiversity on fishery yields. *Glob. Ecol. Biogeogr.*, 25, 553–562.

Casatti, L., Teresa, F.B., Zeni, J. de O., Ribeiro, M.D., Brejão, G.L. & Ceneviva-Bastos, M. (2015). More of the Same: High Functional Redundancy in Stream Fish Assemblages from Tropical Agroecosystems. *Environ. Manage.*, 55, 1300–1314.

Castello, L., Hess, L.L., Thapa, R., McGrath, D.G., Arantes, C.C., Renó, V.F. & Isaac, V.J. (2017). Fishery yields vary with land cover on the Amazon River floodplain. *Fish Fish.*, 1–10.

Castello, L., McGrath, D.G. & Beck, P.S.A. (2011). Resource sustainability in small-scale fisheries in the Lower Amazon floodplains. *Fish. Res.*, 110, 356–364.

Castello, L., Mcgrath, D.G., Hess, L.L., Coe, M.T., Lefebvre, P. a., Petry, P., Macedo, M.N., Renó, V.F. & Arantes, C.C. (2013). The vulnerability of Amazon freshwater ecosystems. *Conserv. Lett.*, 6, 217–229.

Chu, C., Ellis, L. & de Kerckhove, D.T. (2017). The effectiveness of terrestrial protected areas for lake fish community conservation. *Conserv. Biol.*, 1–36.

Debastiani, V.J. & Pillar, V.D. (2012). SYNCSA — R tool for analysis of metacommunities based on functional traits and phylogeny of the community components. *Bioinformatics*, 28, 2067–2068.

Dray, A.S., Blanchet, G., Borcard, D., Clappe, S., Guenard, G., Jombart, T., Larocque, G., Legendre, P., Madi, N. & Wagner, H.H. (2017). Package " adespatial ."

Dulvy, N.K., Polunin, N.V., Mill, A.C. & Graham, N.A. (2004). Size structural change in lightly exploited coral reef fish communities: evidence for weak indirect effects. *Can. J. Fish. Aquat. Sci.*, 61, 466–475.

Fernandes, C.C., Podos, J. & Lundberg, J.G. (2004). Amazonian ecology: Tributaries enhance the diversity of electric fishes. Science (80-.)., 305, 1960–1962

Froese, R. and D. Pauly. Editors. 2018. FishBase. World Wide Web electronic publication. www.fishbase.org, version (02/2018).

Gelcich, S., Godoy, N., Prado, L. & Castilla, J.C. (2008). Add-on Conservation Benefits of Marine Territorial User Rights Fishery Policies in Central Chile. *Ecol. Appl.*, 18, 273–281.

Gell, F.R. & Roberts, C.M. (2003). Benefits beyond boundaries: The fishery effects of marine reserves. *Trends Ecol. Evol.*, 18, 448–455.

Genner, M.J., Sims, D.W., Southward, A.J., Budd, G.C., Masterson, P., Mchugh, M., Rendle, P., Southall, E.J., Wearmouth, V.J. & Hawkins, S.J. (2010). Body size-dependent responses of a marine fish assemblage to climate change and fishing over a century-long scale. *Glob. Chang. Biol.*, 16, 517–527.

Goulding, M., Barthem, R. & Ferreira, E. (2003). *The Smithsonian Atlas of the Amazon*. Smithsonian Books, Washington, DC, USA.

Gutiérrez-Cánovas, C., Millán, A., Velasco, J., Vaughan, I.P. & Ormerod, S.J. (2013). Contrasting effects of natural and anthropogenic stressors on beta diversity in river organisms. *Glob. Ecol. Biogeogr.*, 22, 796–805.

Hallwass, G. (2015). *Etnoecologia e Pesca: influência de Unidades de Conservação e aplicação do Conhecimento Ecológico Local de pescadores no manejo e conservação dos recursos pesqueiros no Baixo Rio Tapajós, Amazônia Brasileira*.

Hallwass, G., Lopes, P.F., Juras, A.A. & Silvano, R.A.M. (2011). Fishing effort and catch composition of urban market and rural villages in Brazilian Amazon. *Environ. Manage.*, 47, 188–200.

Hallwass, G. & Silvano, R. (2016). Patterns of selectiveness in the Amazonian freshwater fisheries: implications for management. *J. Environ. Plan. Manag.*, 59, 1537–1559.

Halpern, B.S. (2003). The Impact of Marine Reserves : Do Reserves Work and Does Reserve Size Matter? *Ecol. Appl.*, 13.

ICMBIO. (2008). Plano de Manejo Reserva Extrativista Tapajós-Arapiuns.

ICMBIO. (2014). *Plano de manejo participativo da Reserva Extrativista do Rio Unini*. Novo Airão.

IUCN. (2018). The IUCN Red List of Threatened Species [WWW Document]. URL http://www.iucnredlist.org

Keppeler, F.W., Hallwass, G. & Silvano, R.A.M. (2017). Influence of protected areas on fish assemblages and fisheries in a large tropical river. *Oryx*, 51, 1–12.

Keppeler, F.W., Souza, A., Hallwass, G., Almeida, M., Isaac, V.J. & Silvano, R.A.M. (2018). *Ecological influences of human population size and distance to urban centers on fish communities in tropical lakes*. *Aquat. Conserv. Mar. Freshw. Ecosyst.*, in prep.

Kessler, M., Abrahamczyk, S., Bos, M., Buchori, D., Putra, D.D., Gradstein, S.R., Höhn, P., Kluge, J., Orend, F., Pitopang, R., Saleh, S., Schulze, C.H., Sporn, S.G., Steffan-Dewenter, I., Tjitrosoedirdjo, S.S. & Tscharntke, T. (2009). Alpha and beta diversity of plants and animals along a tropical land-use gradient. *Ecol. Appl.*, 19, 2142–2156.

Knight, H. (1986). Assemblage organization of stream fishes: The effect of rivers on adventitious stream. Am. Nat., 127, 484–494.

Legendre, P. (2014). Interpreting the replacement and richness difference components of beta diversity. *Glob. Ecol. Biogeogr.*, 23, 1324–1334.

Legendre, P. & De Cáceres, M. (2013). Beta diversity as the variance of community data: Dissimilarity coefficients and partitioning. *Ecol. Lett.*, 16, 951–963.

Lobón-Cerviá, J., Hess, L.L., Melack, J.M. & Araujo-Lima, C.A.R.M. (2015). The importance of forest cover for fish richness and abundance on the Amazon floodplain. *Hydrobiologia*, 750, 245–255.

Loury, E.K., Ainsley, S.M., Bower, S.D., Chuenpagdee, R., Farrell, T., Guthrie, A.G., Heng, S., Lunn, Z., Mamun, A. Al, Oyanedel, R., Rocliffe, S., Satumanatpan, S. & Cooke, S.J. (2018). Salty stories, fresh spaces: Lessons for aquatic protected areas from marine and freshwater experiences. Aquat. Conserv. Mar. Freshw. Ecosyst., 28, 485–500.

Mahon, R., 1997. Does fisheries science serve the needs of managers of small stocks in developing countries? Can. J. Fish. Aquat. Sci. 54, 2207–2213.

MMA. (2007). *Informe Nacional sobre Áreas Protegidas no Brasil*. Brasília.

Myers, R.A. & Worm, B. (2003). Rapid worldwide depletion of predatory fish communities. *Nature*, 423, 280–283.

Nagl, P. (2017). *Small-Scale Fisheries Of Frugivorous Fish In Clear And Black Water Rivers Of The Brazilian Amazon*.

Nel, J.L., Roux, D.J., Maree, G., Kleynhans, C.J., Moolman, J., Reyers, B., Rouget, M. & Cowling, R.M. (2007). Rivers in peril inside and outside protected areas: A systematic approach to conservation assessment of river ecosystems. *Divers. Distrib.*, 13, 341–352.

Odum, E.P. (1950). Bird Populations of the Highlands (North Carolina) Plateau in Relation to Plant Succession and Avian Invasion. *Ecology*, 31, 587–605.

Oksanen, J., Guillaume Blanchet, F., Friendly, M., Kindt, R., Legendre, P., McGlinn, D., Minchin, P.R., O'Hara, R.B., Simpson, G.L., Solymus, P., Stevens, M.H.H., Szoecs, E. & Wagner, H. (2017). Community Ecology Package, Package " vegan ."

Olden, J.D., Hogan, Z.S. & Zanden, M.J. Vander. (2007). Small fish, big fish, red fish, blue fish: Size-biased extinction risk of the world's freshwater and marine fishes. *Glob. Ecol. Biogeogr.*, 16, 694–701.

Osborne, L.L. & Wiley, M.J. (1992). Influence of Tributary Spatial Position on the Structure of Warmwater Fish Communities. Can. J. Fish. Aquat. Sci., 49, 671–681.

Pauly, D., 1997. Small-scale fisheries in the tropics: marginality, marginalization and some implication for fisheries management. In: Pikitch, E.K., Huppert, D.D., Sissenwine, M.P.s (Eds.), Global Trends: Fisheries Management. American Fisheries Society Symposium. Bethesda, Maryland, pp. 40–49.

Pauly, D., Christensen, V., Dalsgaard, J., Froese, R. & Jr, F.T. (1998). Fishing Down Marine Food Webs. *Science (80-.).*, 860.

Pauly, D., Christensen, V., Guénette, S., Pitcher, T.J., Sumaila, U.R., Walters, C.J., Watson, R. & Zeller, D. (2002). Towards sustainability in World Fisheries. *Nature*, 418, 689–695.

Pelletier, D., Garcia-Charton, J.A., Ferraris, J., David, G., Thebaud, O., Letourneur, Y., Claudet, J., Amand, M., Kulbicki, M. & Galzin, R. (2005). Designing indicators for assessing the effects of marine protected areas on coral reef ecosystems: A multidisciplinary standpoint. *Aquat. Living Resour.*, 18, 15–33.

Petry, P., Bayley, P.B. & Markle, D.F. (2003). Relationships between fish assemblages, macrophytes and environmental gradients in the Amazon River floodplain. *J. Fish Biol.*, 63, 547–579.

Podani, J. (1999). Extending Gower's general coefficient of similarity to ordinal characters. *Taxon*, 48, 331–340.

Podani, J., Ricotta, C. & Schmera, D. (2013). A general framework for analyzing beta diversity, nestedness and related community-level phenomena based on abundance data. *Ecol. Complex.*, 15, 52–61.

Pollnac, R.B., Crawford, B.R. & Gorospe, M.L.G. (2001). Discovering Factors that Influenced the Success of Community-Based Marine Protected Areas in the Visayas, Philiphines. *Ocean Coast. Manag.*, 44, 683–710.

R Development Core Team. (2016). A Language and Environment for Statistical Computing.

Rao, R.C. (1982). Diversity and dissimilarity coefficients: a unified approach. *Theor. Popul. Biol.*, 43, 24–43.

Roberts, C.M., Bohnsack, J.A., Gell, F.R., Hawkings, J.P. & Goodridge, R. (2001). Effects of Marine Reserves on Adjacent Fisheries. *Science (80-.).*, 294, 1920.

Rodríguez-Olarte, D., Taphorn, D.C. & Lobón-Cerviá, J. (2011). Do protected areas conserve neotropical freshwater fishes? A case study of a biogeographic province in Venezuela. *Anim. Biodivers. Conserv.*, 2, 273–285.

Silvano, R.A.M., Nora, V., Andreoli, T.B., Lopes, P.F.M. & Begossi, A. (2017). The ghost of past fishing: Small-scale fisheries and conservation of threatened groupers in subtropical islands. *Mar. Policy*, 75, 125–132.

Silvano, R. a M., Hallwass, G., Lopes, P.F., Ribeiro, A.R., Lima, R.P., Hasenack, H., Juras, A. a. & Begossi, A. (2014). Co-management and Spatial Features Contribute to Secure Fish Abundance and Fishing Yields in Tropical Floodplain Lakes. *Ecosystems*, 17, 271–285.

Silvano, R.A.M., Ramires, M. & Zuanon, J. (2009). Effects of fisheries management on fish communities in the floodplain lakes of a Brazilian Amazonian Reserve. Ecol. Freshw. Fish, 18, 156–166.

Socolar, J.B., Gilroy, J.J., Kunin, W.E. & Edwards, D.P. (2016). How Should Beta-Diversity Inform Biodiversity Conservation? Conservation Targets at Multiple Spatial Scales. *Trends Ecol. Evol.*, 31, 67–80.

Suski, C.D. & Cooke, S.J. (2007). Conservation of aquatic resources through the use of freshwater protected areas: Opportunities and challenges. *Biodivers. Conserv.*, 16, 2015–2029.

Tejerina-Garro, F.L., Fortin, R. & Rodríguez, M.A. (1998). Fish community structure in relation to environmental variation in floodplain lakes of the Araguaia River, Amazon Basin. *Environ. Biol.*

Fishes, 51, 399–410.

Vallès, H. & Oxenford, H.A. (2015). The utility of simple fish community metrics for evaluating the relative influence of fishing vs. other environmental drivers on Caribbean reef fish communities. *Fish Fish.*, 16, 649–667.

Welcomme, R.L. (1999). A review of a model for qualitative evaluation ofexploitation levels in multi-species fisheries. *Fish. Manag. Ecol.*, 6, 1–9.

Whittaker, R.H. (1972). Evolution and Measurement of Species Diversity. *Diversity*, 21, 213–251.

7. Supplementary Material

Fish Landed

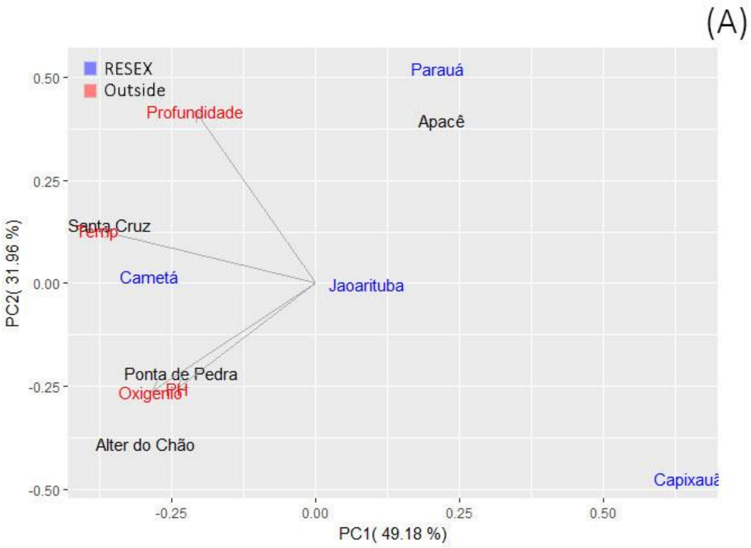
Table S1: Recorded fish landing per community in Tapajós River. * indicates Communities inside the RESEX.

Fishing community	*Recorded landed (n)*	*Total Biomass landed (kg)*	*Total Biomass Consumption (kg)*	*Total Biomass Commercial (kg)*
Alter do chão	197	3.76	0,86	1,58
Apace	361	6.52	1.86	4.08
Ponta de Pedra	209	6.20	1.23	4.29
Santa Cruz	171	1.15	0.65	0.33
Cameta*	391	5.64	2.40	1.48
Capichauã*	79	0.52	0.22	0.19
Jauarituba*	260	2.55	1.05	0.77
Parauá*	356	8.61	1.76	6.37
Total	2024	34.94	10.02	19.07

Table S1: Recorded fish landing per community in Negro River. * indicates Communities inside the RESEX.

Fishing community	*Recorded landed (n)*	*Total Biomass landed (kg)*	*Total Biomass Consumption (kg)*	*Total Biomass Commercial (kg)*
Aracari	52	0.42	0.33	0.07
Aturiá	76	1.46	0.90	0.27
Bacaba	56	2.39	0.25	2.78
Bom Jesus	226	3.85	2.76	0.47
Floresta*	357	2.23	1.68	0.00
Patauá*	51	0.50	0.33	0.00
Tapiira*	316	8.06	7.69	0.00
Terra Nova*	233	2.09	0.97	0.00
Total	1367	21.00	14.91	3.60

Physical and Chemical –PCA plot



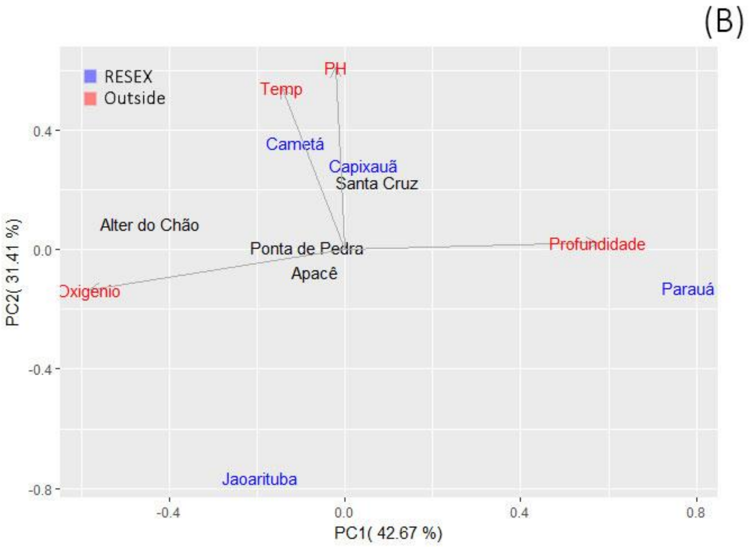


Figure S1: Principal Components Analysis based on correlation matrix (PCA) of physical and chemical variables in the complete data set (A) and lake data set (B) for the Tapajós River. Arrow indicates physical and chemical variables and proportion of variance explained in each axe are showed inside parenthesis.

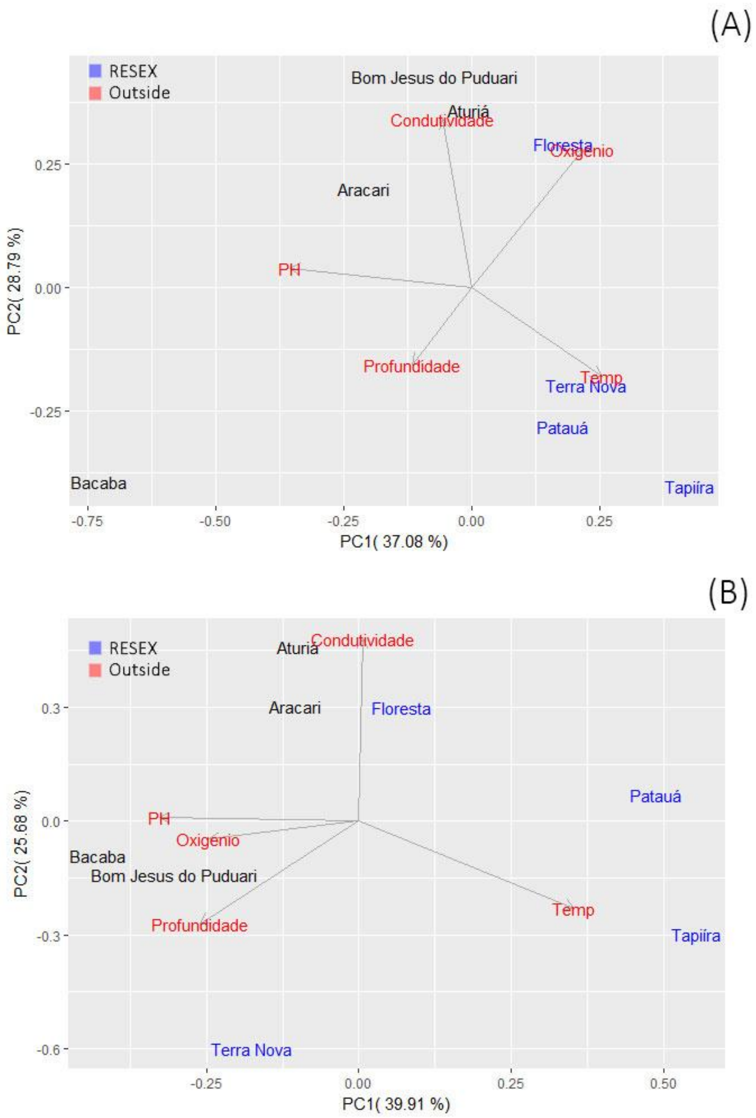
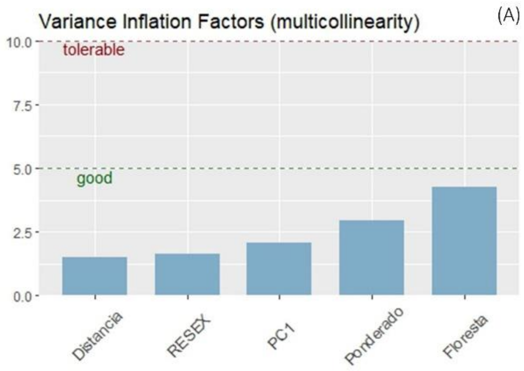


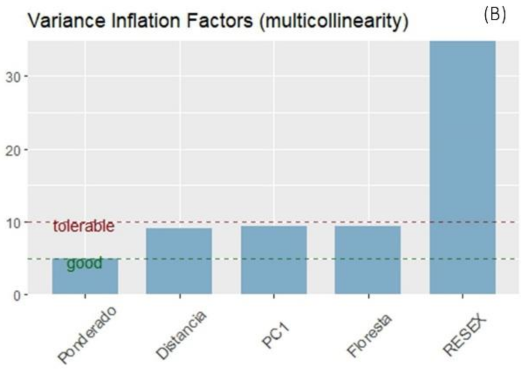
Figure S2: Principal Components Analysis based on correlation matrix (PCA) of physical and chemical variables in the complete data set (A) and lake data set (B) for the Negro River. Arrow indicates physical and chemical variables and proportion of variance explained in each axe showed inside parenthesis.

Variation Inflation (VIF)

Tapajós



Negro



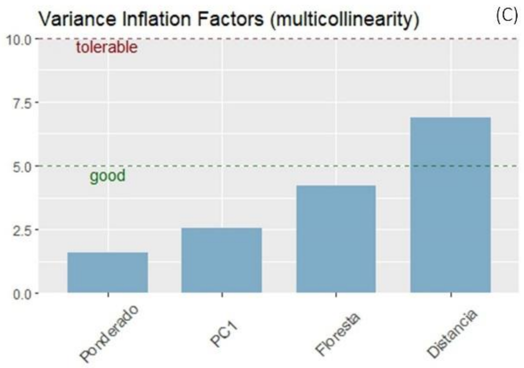


Figure S3: Variation Inflation (VIF) of the explanatory variables used in the multiple linar regressions. Values bellow 5 indicates low multicolianity between variables, above 10 indicates high multicolliniaty. (A) VIF of the explanatory variables used in the Tapajós river. B-C show the VIF of explanatory variables used in the Negro river, due to the high multicolliniaty in (B), the variable RESEX was excluded of the analysis as seen in (C), to avoid the inflaction of the standart errors of the cofficients.

β diversity components

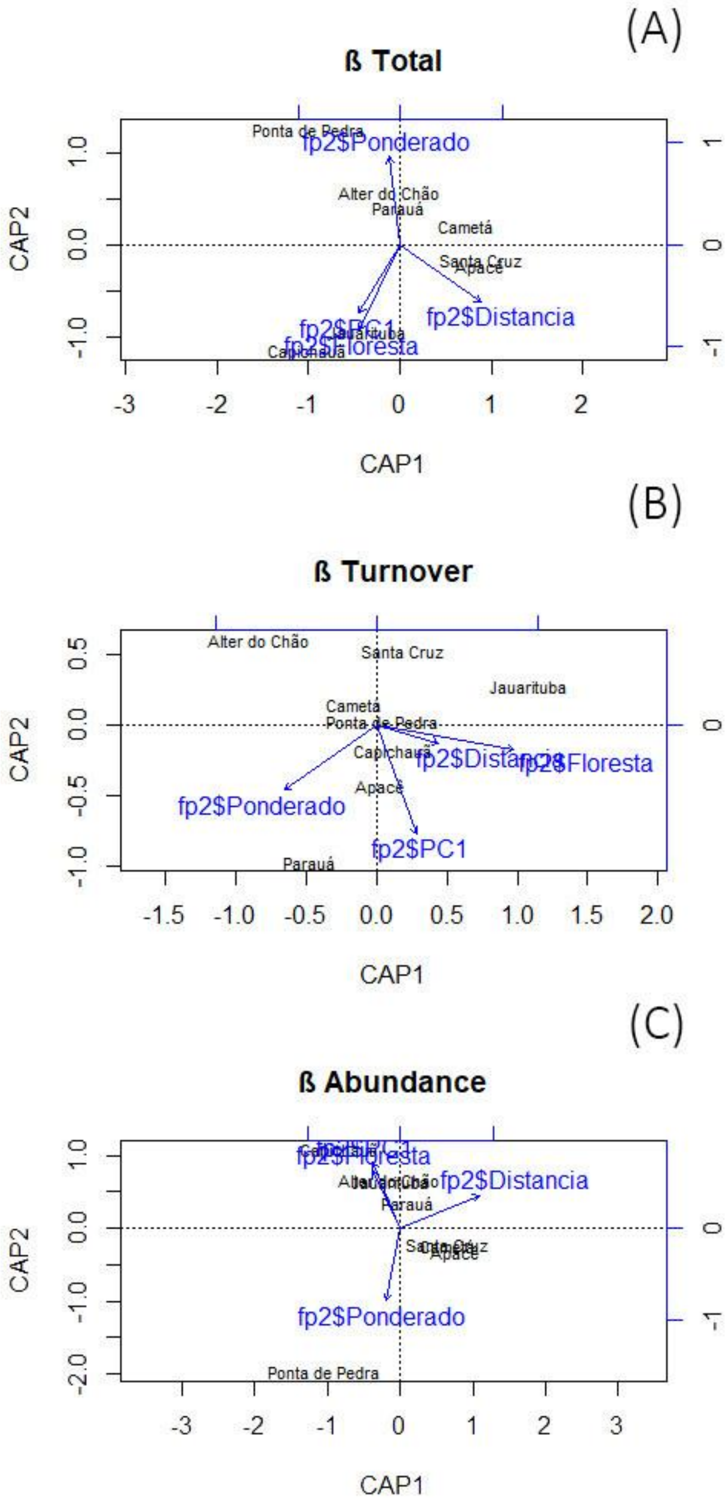


Figure S4: Partial Constrained Analysis of principal Coordinates biplots showing associations between the β diversity components: (A) β Total, (B) β Turnover and (C) β Abundance Difference and the variables (arrows). Tapajós complete dataset.

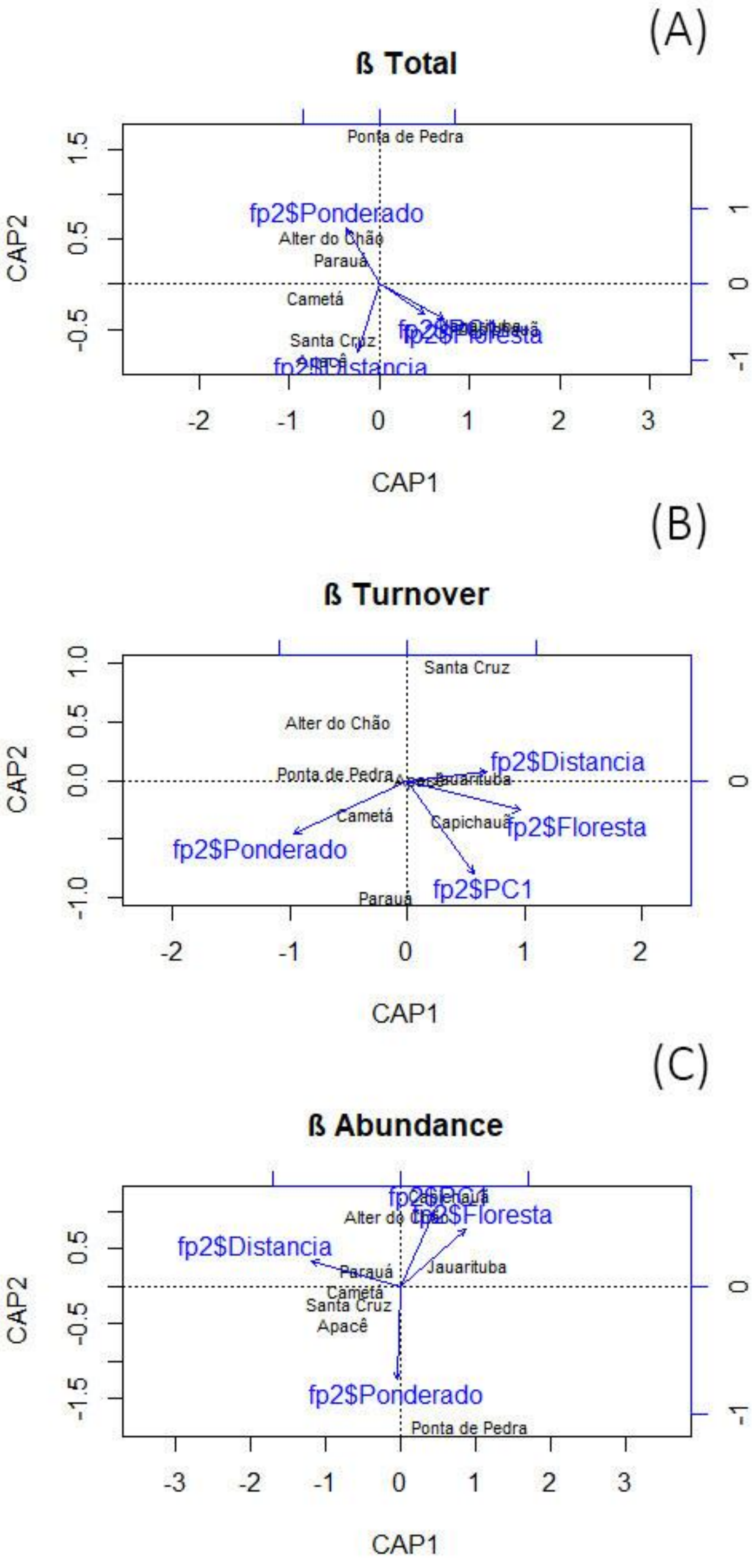


Figure S5: Partial Constrained Analysis of principal Coordinates biplots showing associations between the β diversity components: (A) β Total, (B) β Turnover and (C) β Abundance Difference and the variables (arrows). Tapajós Lake dataset.

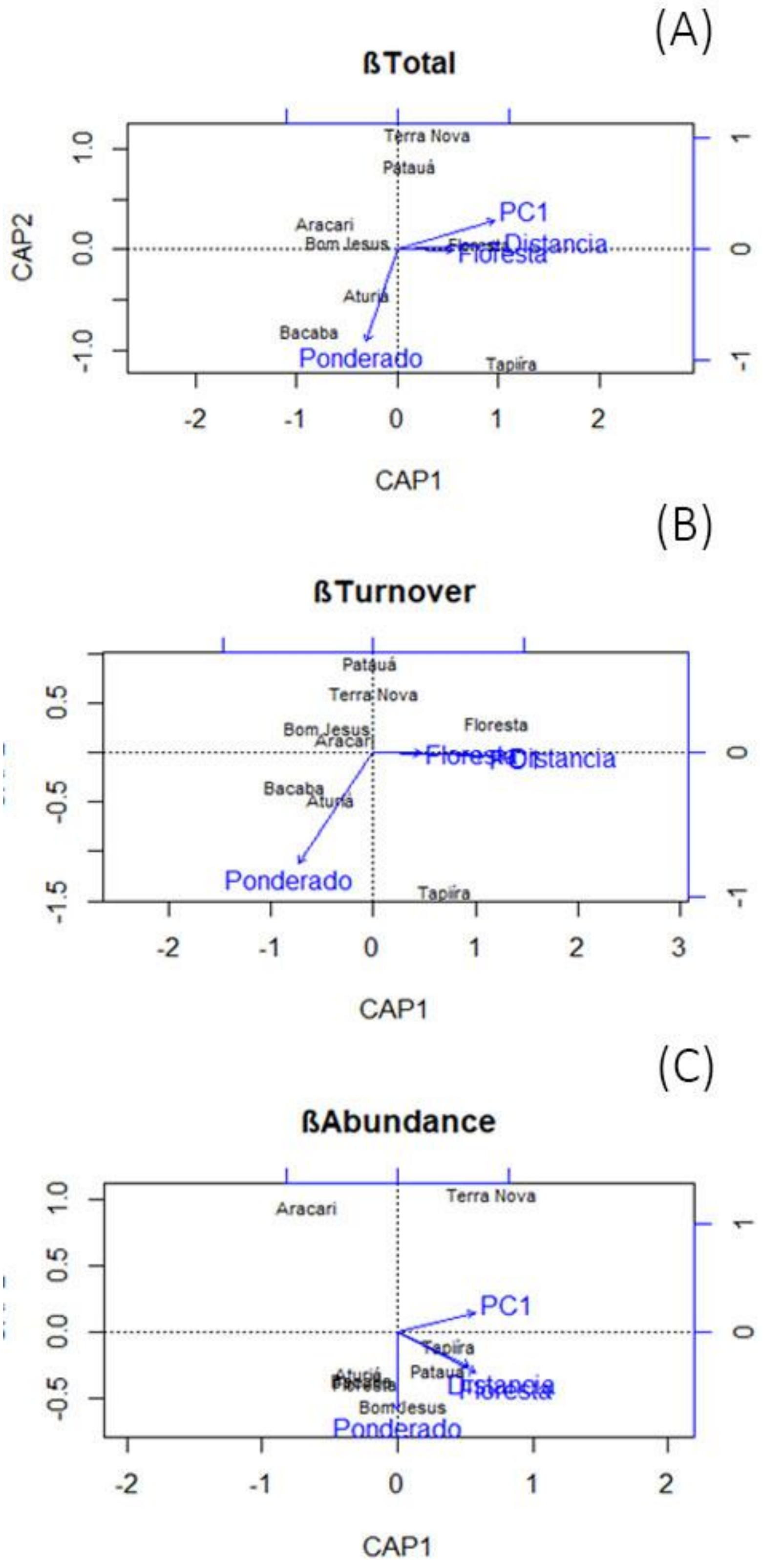


Figure S6: Partial Constrained Analysis of principal Coordinates biplots showing associations between the β diversity components: (A) β Total, (B) β Turnover and (C) β Abundance Difference and the variables (arrows). Negro complete dataset.

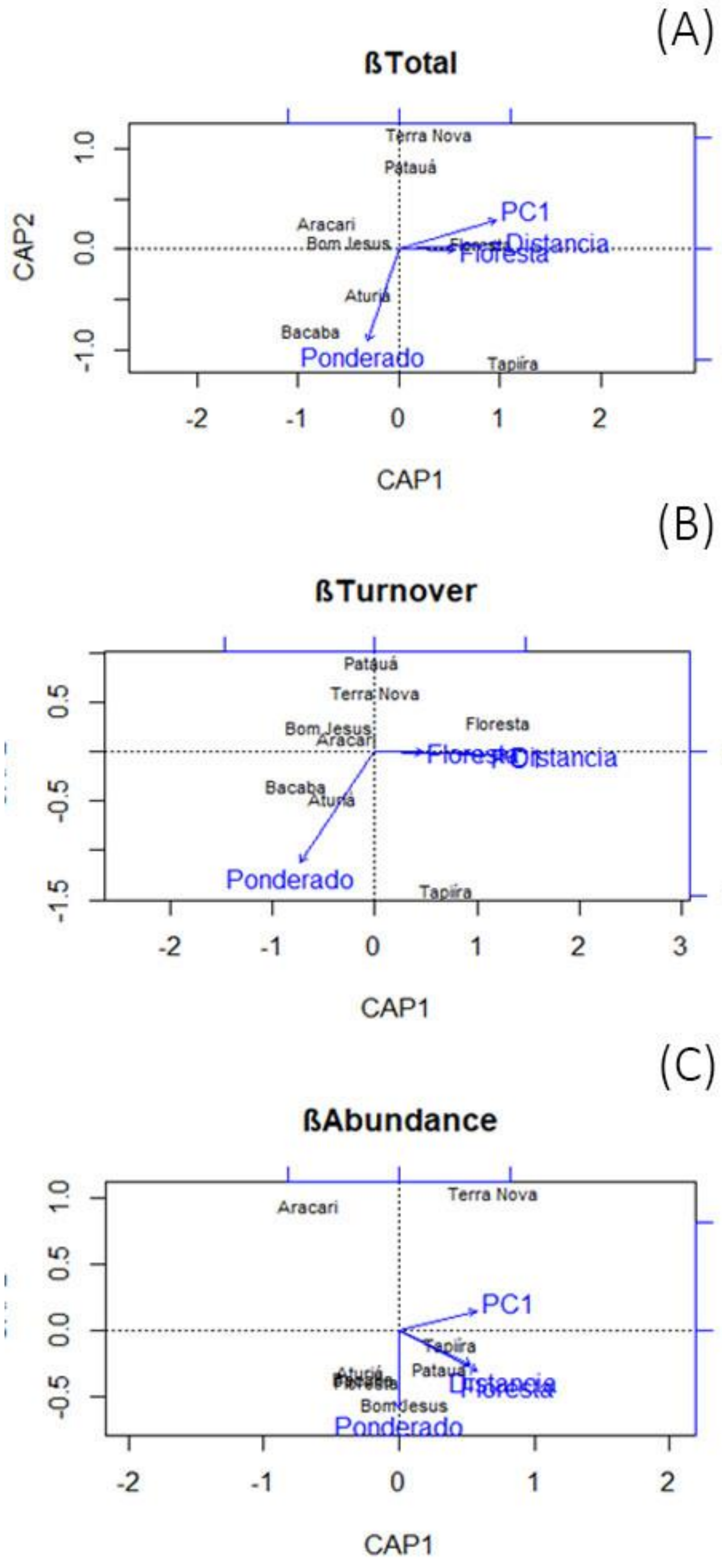


Figure S7: Partial Constrained Analysis of principal Coordinates biplots showing associations between the β diversity components: (A) β Total, (B) β Turnover and (C) β Abundance Difference and the variables (arrows). Negro lake dataset.

Considerações Finais

Os resultados levantados por este estudo indicam que a pesca comercial de larga escala causa impactos nas comunidades de peixes amazônicos, causando uma diminuição na diversidade taxonômica e funcional de peixes, além de ser um dos principais agentes causadores de mudanças na composição de espécies. É possível observar ainda que diferentes tipos de pesca artesanal podem estar associados a diferentes respostas na diversidade. A pesca artesanal com foco comercial na região do Tapajós esteve relacionada a perda de diversidade funcional e taxonômica, assim como visto na pesca comercial de larga escala. Na região do rio Negro, a pesca artesanal esteve relacionada com aumento da diversidade funcional, provavelmente atuando como um distúrbio intermediário para a comunidade de peixes. Os resultados indicam que a pesca com foco comercial está relacionada com redução na diversidade de peixes. Estes resultados corroboram estudos em outras áreas da bacia amazônica (Barthem & Goulding 2007; Castello et al. 2011). Apesar de ser uma fonte de renda importante para as comunidades locais, a venda de peixes derivado da pesca artesanal pode causar efeitos negativos nas comunidades de peixes afetadas por essa atividade. Devido a isso, propomos que áreas que desejam conciliar a preservação ambiental e permitir atividades comerciais humanas devem implementar regras de manejo que diminuam o impacto da pesca nas comunidades. Essas regras podem ser delimitação de áreas onde não há pesca, estabelecimento de quotas e regras de manejo pesqueiro local, seguindo sistemas participativos de manejo que já mostram alguns sucessos na sua implementação (Roberts et al. 2001; Almeida et al. 2009; Silvano et al. 2014).

Foi possível verificar que as unidades de conservação (RESEX), mesmo que pensadas para proteger recursos florestais, estão relacionadas com benefícios para as comunidades de peixes, aumentando a diversidade e estando relacionadas a diferenças na composição de espécies. Este resultado, até onde sabemos, é novo para a região amazônica e traz esperanças para a conservação da ictiofauna e dos ambientes aquáticos da região. Evidências de que as unidades de conservação traziam benefícios para a biomassa de peixes e para a produtividade pesqueira já eram conhecidos (Silvano et al. 2009, 2014; Keppeler et al. 2017), mas até então não se haviam indícios de que essas áreas protegidas com enfoque terrestre poderiam trazer benefícios significativos para a diversidade de peixes (Rodríguez-Olarte et al. 2011; Keppeler et al. 2017). Apesar disso, salienta-se de que áreas de proteção voltadas para ambientes de água doce ainda precisam ser implementadas, visando a proteção dos ambientes aquáticos e toda a sua diversidade.

Ainda que pouco utilizado nos estudos de conservação e pesca a beta diversidade pode ser uma ferramenta importante para entender os processos que desencadeiam alterações nas comunidades (Anderson et al. 2013; Socolar et al. 2016). Como visto neste trabalho, a pesca está afetando a comunidade em nível local (índices de diversidade local) e também está associada as mudanças na composição de espécies. Estes resultados evidenciam que a pesca comercial tem um papel importante na alteração das comunidades ictiológicas e medidas que visem o controle ou diminuição desse impacto devem ser incentivadas, porém é importante que tais medidas sejam discutidas e implementadas em colaboração com as comunidades locais para se obter o sucesso desejado (Pollnac et al. 2001; Pelletier et al. 2005; Almeida et al. 2009; Silvano et al. 2014).

As variáveis ambientais estudadas nesse trabalho mostraram pouca associação com os preditores analisados. Esses resultados indicam que as comunidades nos rios analisados estão sofrendo influências maiores de variáveis antrópicas do que ambientais, o que nos leva a crer que a pressão pesqueira pode ser um *driver* de alteração nas comunidades ictiológicas mais importante do que as variáveis ambientais aqui estudadas.

De modo geral, os resultados desse trabalho apontam que a pesca comercial de qualquer tipo (artesanal ou industrial) é um dos principais *drivers* de alteração nas comunidades de peixes, causando a diminuição taxonômica, funcional e mudanças na composição dos peixes amazônicos. Desse modo vemos que as variáveis antrópicas tem um papel tão ou até mais importante que as variáveis ambientais analisadas em estudos anteriores, o que indica que estes fatores devem ser levados em consideração para ações de conservação e para entendimento dos padrões de diversidade de peixes amazônicos.

Referências Considerações finais

Abell, R., Thieme, M.L., Revenga, C., Bryer, M., Kottelat, M., Bogutskaya, N., Coad, B., Mandrak, N., Balderas, S.C., Bussing, W., Stiassny, M.L.J., Skelton, P., Allen, G.R., Unmack, P., Naseka, A., Ng, R., Sindorf, N., Robertson, J., Armijo, E., Higgins, J. V., Heibel, T.J., Wikramanayake, E., Olson, D., López, H.L., Reis, R.E., Lundberg, J.G., Sabaj Pérez, M.H. & Petry, P. (2008). Freshwater Ecoregions of the World: A New Map of Biogeographic Units for Freshwater Biodiversity Conservation. *Bioscience*, 58, 403.

Almeida, O.T., Lorenzen, K. & McGrath, D.G. (2009). Fishing agreements in the lower Amazon: For gain and restraint. *Fish. Manag. Ecol.*, 16, 61–67.

Anderson, M.J., Tolimieri, N. & Millar, R.B. (2013). Beta Diversity of Demersal Fish Assemblages in the North-Eastern Pacific: Interactions of Latitude and Depth. *PLoS One*, 8, 1–15.

Andrade, G.S.M. & Rhodes, J.R. (2012). Protected areas and local communities: An inevitable partnership toward successful conservation strategies? *Ecol. Soc.*, 17.

Barnosky, A.D., Matzke, N., Tomiya, S., Wogan, G.O.U., Swartz, B., Quental, T.B., Marshall, C., McGuire, J.L., Lindsey, E.L., Maguire, K.C., Mersey, B. & Ferrer, E.A. (2011). Has the Earth's sixth mass extinction already arrived? *Nature*, 471, 51–57.

Barthem, R. & Goulding, M. (2007). *An unexpected ecosystem: the Amazon as revealed by fisheries. An unexpected Ecosyst. Amaz. as Reveal. by Fish.* Association Press, Lima.

Cardinale, B.J., Duffy, J.E., Gonzalez, A., Hooper, D.U., Perrings, C., Venail, P., Narwani, A., Mace, G.M., Tilman, D., A.Wardle, D., Kinzig, A.P., Daily, G.C., Loreau, M., Grace, J.B., Larigauderie, A., Srivastava, D.S. & Naeem, S. (2012). Biodiversity loss and its impact on humanity. *Nature*, 489, 326–326.

Castello, L., McGrath, D.G. & Beck, P.S.A. (2011). Resource sustainability in small-scale fisheries in the Lower Amazon floodplains. *Fish. Res.*, 110, 356–364.

Castello, L., Mcgrath, D.G., Hess, L.L., Coe, M.T., Lefebvre, P. a., Petry, P., Macedo, M.N., Renó, V.F. & Arantes, C.C. (2013). The vulnerability of Amazon freshwater ecosystems. *Conserv. Lett.*, 6, 217–229.

Hallwass, G. & Silvano, R. (2016). Patterns of selectiveness in the Amazonian freshwater fisheries: implications for management. *J. Environ. Plan. Manag.*, 59, 1537–1559.

IUCN. (2018). The IUCN Red List of Threatened Species [WWW Document]. URL http://www.iucnredlist.org

Keppeler, F.W., Hallwass, G. & Silvano, R.A.M. (2017). Influence of protected areas on fish assemblages and fisheries in a large tropical river. *Oryx*, 51, 1–12.

MMA. (2007). *Informe Nacional sobre Áreas Protegidas no Brasil*. Brasília.

Pollnac, R.B., Crawford, B.R. & Gorospe, M.L.G. (2001). Discovering Factors that Influenced the Success of Community-Based Marine Protected Areas in the Visayas, Philiphines. *Ocean Coast. Manag.*, 44, 683–710.

Pelletier, D., Garcia-Charton, J.A., Ferraris, J., David, G., Thebaud, O., Letourneur, Y., Claudet, J., Amand, M., Kulbicki, M. & Galzin, R. (2005). Designing indicators for assessing the effects of marine protected areas on coral reef ecosystems: A multidisciplinary standpoint. *Aquat. Living Resour.*, 18, 15–33.

Roberts, C.M., Bohnsack, J.A., Gell, F.R., Hawkings, J.P. & Goodridge, R. (2001). Effects of Marine Reserves on Adjacent Fisheries. *Science (80-.).*, 294, 1920.

Rodríguez-Olarte, D., Taphorn, D.C. & Lobón-Cerviá, J. (2011). Do protected areas conserve neotropical freshwater fishes? A case study of a biogeographic province in Venezuela. *Anim. Biodivers. Conserv.*, 2, 273–285.

Silvano, R. a M., Hallwass, G., Lopes, P.F., Ribeiro, A.R., Lima, R.P., Hasenack, H., Juras, A. a. & Begossi, A. (2014). Co-management and Spatial Features Contribute to Secure Fish Abundance and Fishing Yields in Tropical Floodplain Lakes. *Ecosystems*, 17, 271–285.

Socolar, J.B., Gilroy, J.J., Kunin, W.E. & Edwards, D.P. (2016). How Should Beta-Diversity Inform Biodiversity Conservation? Conservation Targets at Multiple Spatial Scales. *Trends Ecol. Evol.*, 31, 67–80.