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CAMPUS DE SÃO JOSÉ DO RIO PRETO

Responses of stream fish assemblages to timing and extent of deforestation in Western Amazon

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DOUTORADO

PÓS GRADUAÇÃO
EM BIOLOGIA ANIMAL

UNIVERSIDADE ESTADUAL PAULISTA
"JÚLIO DE MESQUITA FILHO"
Campus de São José do Rio Preto

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Financiadora: FAPESP – Proc. 2012/21916-0
FAPESP – Proc. 2015/05827-6

Orientador: Profª. Drª. Lilian Casatti
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São José do Rio Preto
2018

Brejão, Gabriel Lourenço.
Responses of stream fish assemblages to timing and extent of deforestation in Western Amazon / Gabriel Lourenço Brejão. -- São José do Rio Preto, 2018
140 f. : il., tabs.

Orientador: Lilian Casatti
Coorientador: David J. Hoeinghaus
Coorientador: Silvio F. B. Ferraz
Tese (doutorado) – Universidade Estadual Paulista “Júlio de Mesquita Filho”, Instituto de Biociências, Letras e Ciências Exatas

1. Ecologia animal. 2. Ictiologia. 3. Ictiofauna - Rondônia. 4. Desmatamento. I. Universidade Estadual Paulista "Júlio de Mesquita Filho". Instituto de Biociências, Letras e Ciências Exatas. II. Título.

CDU – 597

Ficha catalográfica elaborada pela Biblioteca do IBILCE
UNESP - Câmpus de São José do Rio Preto

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São José do Rio Preto
04 de Maio de 2018

À minha família, que sempre apoiou as minhas escolhas e me acolheu nos momentos duros desta caminhada

The cave you fear to enter holds the treasure you seek

- Joseph Campbell

Agradecimentos

Gostaria de agradecer os meus pais. Minhã mãe, Maria de Lourdes que como professora, e com sua breve passagem pela vida, apresentou o encantamento pelas ciências. Meu pai, Walmir, que por fazer questão de manter a natureza dentro de casa, com suas plantas e aquários, apresentou um certo fascínio por entender como a vida das "coisas" funcionava. A Avani, que aceitou o desafio de acompanhar meu pai em um momento muito difícil para ser parte fundamental dessa jornada. Agradeço também aos meus irmãos, Pedro Ivo e Guilherme, pelos raros encontros dos últimos anos regados a conversas "filosóficas".

Agradeço à Bruna, esposa e amiga, que compreende os desafios dessa carreira e sempre esteve ao meu lado, incentivando/criticando nos momentos de dasânimo, ouvindo intermináveis conversas sobre as relações entre peixes e o desmatamento, ou simplesmente estando presente.

À Lilian Casatti, que há oito anos me aceitou como membro do seu grupo de pesquisa após um e-mail enviado em dezembro de 2010 (e respondido em 3 minutos...), e que me deu a oportunidade de continuar a trabalhar em uma região que me encantou no Mestrado, e uma segunda oportunidade para seguir no doutorado, mesmo após um deslize na primeira seleção para o doutorado. Uma orientadora não só para as questões acadêmicas e científicas, mas que se preocupa demais em formar pessoas melhores. Que permite aos seus alunos a liberdade de ousar, mas deixa uma cordinha sutilmente amarrada no pé pra puxar de volta pra terra e manter o foco no que foi proposto.

Aos meus co-orientadores, Silvio Ferraz, que sempre me ajudou a descascar os abacaxis que a ecologia da paisagem apresentava e a abrir os olhos para uma visão mais regionalizada dos impactos decorrentes do desmatamento. David Hoeinghaus, que me mostrou uma outra visão da ciência (acadêmica e filosoficamente), a ecologia dos testes de hipóteses que, mesmo se tratando de peixinhos de riachos, deve sempre ter potencial para dialogar com outras áreas do conhecimento. Sou grato pela dedicação dos dois na construção desse trabalho, e pelas amizades e parcerias que se estabeleceram.

À Dana Infante, Jansen Zuanon, Danilo Boscolo and Rafael Leitão, pela disponibilidade e pela leitura crítica desta Tese.

À família Hoeinghaus – David, Ana e Brenda – que me receberam tão calorosamente e proporcionaram, no Texas, o sentimento de estar em casa.

À Angélica, que veio da Colômbia para desbravar os riachos rondonienses e construiu grande parte da base de dados que foi utilizade nesse trabalho. E ao Felipe (B-nito) pela ajuda com o desenho amostral e no trabalho de campo. Obrigado por confiar nos mapas e no GPS, mesmo quando não fazíamos ideia de onde estávamos...

Aos todos membros do Laboratório de Ictiologia, especialmente Mônica, Angélica, Camilo, Jaque, Carol, Molina, Fernandinho, Ângelo e Bruno pelos momentos compartilhados ao longo desses anos, muito aprendizado e muitas risadas com todos vocês!

À Bárbara Callegari (MCP/PUCRS), Ilana Fichberg (MZUSP), Fernanda Martins (IFPR), Flávio Lima (UNICAMP), Francisco Langeani (UNESP), Leandro Sousa (UFPA), Manoela Marinho (MZUSP), Marcelo Britto (MNRJ), Marcelo

Carvalho (IB/USP), and William Ohara (MZUSP) pela ajuda na identificação dos peixes; aos membros dos laboratórios de ictiologia da UNESP e da UNIR fpela ajuda nos trabalhos de campo; ao ICMBio (REBio Jaru) Pelo apoio logístico; à SEDAM-RO e às associações de extrativistas pela permissão para coletar nas áreas das RESEX Rio Preto-Jacundá, RESEX Castanheira and RESEX Aquariquara;

Aos amigos da graduação, sempre presentes em especial àqueles que se tornaram minha segunda família nos anos de convívio na R.R.A. Biosfera.

Agradeço imensamente ao Pedro Gerhard, Anderson Ferreira e Katia Ferraz, orientadores e amigos, por serem parte fundamental da minha formação acadêmica. Pedro e Anderson que me apresentaram a ecologia de riachos e a biologia de peixes a distantes 16 anos, e Katia aos sistemas de informação geográfica, 13 anos atrás, no extinto Laboratório de Ecologia Animal Aplicada.

A todos do CEBB Rio Preto, que é um refúgio para compreender as aflições e impermanências do cotidiano, e nos ajuda a não dar tanto peso às experiências.

À University of North Texas por me receber e fornecer a estrutura necessária para o desenvolvimento do meu estágio no exterior durante seis meses.

Ao Programa de Pós-Graduação em Biologia Animal (IBILCE/UNESP) e ao Departamento de Zoologia e Botânica pelo apoio e;

À Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP), pelas bolsas concedidas ao longo do meu doutorado (2012/21916-0 e 2015/05827-6) e pelo Auxílio à Pesquisa que permitiu a construção do banco de dados (2010/17494-8).

Para encerrar esse espaço de agradecimento, proponho uma reflexão sobre o cenário dos últimos sete anos, tempo em que estive envolvido com esse trabalho, no que diz respeito ao panorama cientifico e de políticas ambientais no Brasil atual. Entre outras coisas, o código florestal foi revisado e consolidado, reduzindo a proteção dos ambientes aquáticos e, concomitantemente, a ciência sofreu sucessivos cortes de recursos financeiros. Talvez esses acontecimentos sejam reflexo do distanciamento entre cientistas e sociedade, uma vez que poucos de nós tem procurado formas de divulgar os frutos das nossas pesquisas de maneira acessível a todos e, em consequência, perdemos o apoio da sociedade. Espero que essa questão seja considerada pelos acadêmicos, que pontes sejam construídas, para que não tenhamos trabalhado em vão.

Acknowlegments

I had like to acknowledge my parents. My mother, Maria de Lourdes that being a teacher, and with her brief passage through life, presented me the enchantment by the sciences. My father, Walmir for keeping nature indoors, with his plants and aquariums, showed me a particular fascination to understand how the life of "things" works. To Avani, who accepted the challenge of accompanying my father in a tough time to be a fundamental part of this journey. Also to my brothers, Pedro Ivo and Guilherme, by the rare meetings of recent years, filled with "philosophical" conversations.

To Bruna, wife and friend, who understands the challenges of this career and has always been by my side, encouraging/criticizing in the moments of deafness, listening to endless conversations about the relationships between fish and deforestation, or simply being present.

To Lilian Casatti, who eight years ago accepted me as a member of his research group after an email sent in December 2010 (and replied in 3 minutes). And offered the opportunity to continue to work in a region which enchanted me in the MSc, and a second opportunity to pursue the doctorate, even after the slide on the first selection process. An adivisor not only for academic and scientific issues but who cares too much about tutoring better people. That allows your students the freedom to dare, but leaves a cord subtly tied in the foot to pull back to earth and stay focused on what was proposed.

To my co-advisors, Silvio Ferraz, who has always helped me to "peel the pineapples" presented by landscape ecology and to open my eyes to a more regionalized view of deforestation impacts. David Hoeinghaus, who showed me another view of science (academically and philosophically), the ecology of hypothesis testing which, even in the case of stream fish, must always have the potential to dialogue with other areas of knowledge. I am glad by their dedication in the construction of this work, and by the friendships and established partnerships.

To Dana Infante, Jansen Zuanon, Danilo Boscolo and Rafael Leitão, by the availability and critical reading of this Thesis.

To Hoeinghaus Family – David, Ana and Brenda – who welcomed me so warmly, and provided, in Texas, the feeling of being at home.

To Angélica, who came from Colombia to clear the rondonian streams and built much of the database that was used in this work. And Felipe (B-nito) for help with sample design and fieldwork. Thanks for relying on maps and GPS, even when we had no idea where we were ...

To all members of the of Ichthyology Lab, especially Mônica, Angélica, Camilo, Jaque, Carol, Molina, Fernandinho, Ângelo e Bruno for the moments shared over those years, much learning and many laughs with all of you!

To Bárbara Callegari (MCP/ PUCRS), Ilana Fichberg (UNIFESP), Fernanda Martins (IFPR), Fernando Carvalho (UFMS), Flávio Lima (UNICAMP), Francisco Langeani (UNESP), Leandro Sousa (UFPA), Manoela

Marinho (MZUSP), Marcelo Britto (MNRJ), Marcelo Carvalho (IB/USP), and William Ohara (MZUSP) for help with fish identifications. To members of the ichthyology laboratories from UNESP and UNIR for help with the field work. To ICMBio (REBio Jaru) for logistical support. To SEDAM and to the extractivists' associations for permission to carry out the surveys in the areas of RESEX Rio Preto-Jacundá, RESEX Castanheira and RESEX Aquariquara.

Undergraduate friends, always present, especially those who became my second family in the years living at R.R.A. Biosfera.

I am very grateful to Pedro Gerhard, Anderson Ferreira and Katia Ferraz, advisors and friends, for being fundamental to my academic education. Pedro and Anderson, who introduced me to the stream fish ecology and biology, 16 years ago, and Katia to the Geographic Information Systems, 13 years ago, at the extinct Laboratory of Applied Animal Ecology.

To all from CEBB Rio Preto, which is a refuge to understand the afflictions and impermanence of daily life, and helps us not give so much weight to experiences.

To the University of North Texas for receiving me and providing the necessary structure for the development of my internship abroad during six months.

To the Graduate Program in Animal Biology (IBILCE / UNESP) and the Department of Zoology and Botany for the support, and;

To São Paulo Research Foundation (FAPESP), for grants awarded during my doctorate (2012/21916-0 and 2015/05827-6), and for Research Support that enabled the construction of the database (2010/17494-8).

To close this session of acknowledgments, I propose a reflection about the scenario of the last seven years, which I was involved with this work, regarding the scientific panorama and environmental policies in actual Brazil. Among other things, the forest code was revised and consolidated, reducing the protection of aquatic environments and, concomitantly, science suffered successive funding cuts. Perhaps these events are a reflection of the gap between scientists and society since few of us have endeavored ways to spread the fruits of our research in a way accessible to all people and, as a result, we lose the support of society. I hope that academics consider this point and build bridges, so that we have not worked in vain.

Resumo

Os riachos da região Neotropical abrigam uma ictiofauna de pequeno porte, que frequentemente apresentam distribuições geográficas restritas e, em geral, são altamente dependentes da vegetação ripária para alimentação, abrigo e reprodução. A remoção da vegetação nativa da bacia hidrográfica está entre as modificações ambientais mais severas que afetam os ambientes aquáticos, de uma forma ainda pouco compreendida. Conhecer o histórico de desmatamento, em conjunto com a estrutura atual da paisagem, aumenta o poder das análises para avaliar os efeitos ecológicos do desmatamento. Além disso, os rumos distintos do processo de desmatamento podem afetar a composição e o funcionamento das comunidades de peixes de riachos. O rio Machado, em Rondônia, um importante tributário da bacia Amazônica, apresenta alta diversidade e endemismo, e um histórico recente de altas taxas de desmatamento e intensificação de uso do solo, que causam profundas alterações nos ambientes aquáticos. Sendo assim, o objetivo geral desta Tese foi compreender como o processo de desmatamento afeta a ictiofauna, usando a bacia do rio Machado como modelo. Para atingir esse objetivo, analizamos a relação entre a abundância das espécies de peixes com gradientes de tempo e extensão do desmatamento, para detectar quais espécies foram fortemente afetadas – positiva ou negativamente – pelo desmatamento (Capítulo 1). Conhecendo as respostas das espécies de peixes, determinamos como a composição e a estrutura da assembleia se relacionam com o tempo e a intensidade do desmatamento (Capítulo 2). E encerramos o estudo apresentando como os componentes ambientais influenciaram as taxas de substituição de espécies/atributos funcionais, considerando a idade do processo –

desmatamento recente ou antigo (Capítulo 3). Em suma, encontramos que (1.) As populações de peixes apresentaram respostas distintas ao tempo e à extensão do desmatamento, considerando as estruturas taxonômica e funcional. As respostas negativas ocorreram em baixos níveis de desmatamento e pouco tempo após o impacto. Os limiares de resposta positivos de algumas espécies ao desmatamento extremo são tardios, não compensam a perda de taxons sensíveis e provavelmente contribuem para a homogeneização biótica. (2.) As perdas de riqueza e abundância das espécies de peixes sensíveis ocorreram sincronicamente com a perda de estrutura de hábitat, mas houve um atraso temporal no aumento dos indicadores de homogeneização de habitat e o aumento da riqueza e abundância das espécies tolerantes segue esse atraso. (3.) A substituição de espécies/atributos funcionais foi diferente do esperado pelo acaso, indicando que processos determinísticos estruturam esta assembleia de peixes. Apesar de encontrarmos alta substituição de espécies, a substituição de atributos funcionais foi menor do que a esperada pela substituição de espécies. Significa que temos comunidades taxonomicamente distintas, mas funcionalmente similares, sugerindo que a substituição de espécies ocorre principalmente entre espécies funcionalmente equivalentes. Em conclusão, ao adicionar a camada temporal para analizar os estágios iniciais das mudanças de uso do solo nesta região da Amazônia, foi possível observar a extrema sensibilidade da assembleia de peixes ao desmatamento. Ainda, é possível considerar peixes de riachos como um grupo bandeira a ser incluído em planejamentos de conservação, com o objetivo de minimizar os efeitos da perda de biodiversidade em escala regional.

Palavras-chave: Código Florestal Brasileiro, Ponto de mudança, Limiares de diversidade, Ecomorfologia, Débito de extinção, Atributos funcionais, Dinâmica da paisagem, Atraso temporal, Bacia Amazônica, Bacia do Machado.

Abstract

The streams of the Neotropical region harbor a small-sized fish fauna, frequently with limited geographical distribution and, generally, highly dependent on riparian vegetation for feeding, shelter, and reproduction. The watershed native vegetation removal is one among several modifications, which effects on aquatic environments are not entirely understood yet. The knowledge of deforestation history along with current landscape structure enhances the power of analysis to evaluate ecological deforestation effects. Moreover, distinct ways of deforestation process might affect the fish community composition and functioning. The Machado river, in Rondônia, an important tributary of Amazon basin, exhibit high diversity and endemism and presents a recent history of high deforestation and land use intensification, which can cause profound changes in aquatic environments. Thus, the general aim of this Thesis is to comprehend how deforestation process influences the ichthyofauna. To reach this aim, we analyzed the relation between fish species abundance to environmental gradients of time and extent of deforestation, to detect which species were strongly affected – positively or negatively – by deforestation (Chapter 1). Knowing the fish species responses, we determined how fish assemblage composition and structure was related to deforestation time and intensity (Chapter 2). We end the study by presenting how the environmental components influenced the taxonomic and functional turnover rates, considering the process age – recent or old deforestation (Chapter 3). In Summary, we found that (1.) Stream fish populations present distinct responses to deforestation time and extent, regarding their taxonomic and functional structures, most negative threshold responses occurred at low levels of deforestation and soon after impact, so even in minimal change is expected to affect biodiversity *negatively. Delayed positive threshold responses to extreme deforestation by a few species do not offset the loss of sensitive taxa and likely contribute to biotic homogenization; (2.) The sensitive fish richness and abundance lost occurred synchronically to the habitat structure loss, but there was a time-lag response for habitat homogenization indicators, and tolerant fish richness and abundance increase followed this time-lag; and (3.) Species/functional traits turnover was different than expected by chance, indicating that deterministic processes are structuring this stream fish community. Although we found a high species turnover, functional traits turnover was lower than the expected by the species turnover. It means that taxonomically dissimilar, but functionally similar, suggesting that the species turnover is occurring mainly among functionally equivalents species. In conclusion, by adding the temporal layer to analyze the initial stage of land use changes in this portion of Amazon, was possible to verify the extreme sensitivity of fish assemblages to deforestation. And there is possible to consider stream fish as a flag group to be included on conservation plannings, aiming to reduce the effects of biodiversity loss on a regional scale.*

Key-words: Brazil Forest Code, Change point, Diversity thresholds, Ecomorphology, Extinction debt, Functional traits, Landscape dynamics, Time lag, Amazon basin, Machado basin.

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General Introduction

The most diverse fish fauna from neotropics are found in Brazilian inland waters (Azevedo et al. 2010). In a recent review, Pelicice et al. (2017) called the attention to the severe threats to Neotropical freshwater fish diversity and pointed out the agribusiness as one of the primary drivers of deforestation, habitat loss and degradation in the region. In 2012, a new Forest Code (Federal Law 12.651) started to rule in Brazil, and, despite some advances in law control and implementation systems (Brancalion et al. 2016), it has reduced the protected area around streams. Before the code alteration, landowners should maintain a minimum riparian buffer of 30 meters measured from the largest seasonal stream bed of from water bodies up to 10 m wide (Brancalion et al. 2016). After code alteration depending on property size the landowners would maintain 5, 8, 15, 20 or 30 meters of riparian buffer from the center of the permanent channel, it implicates in an average reduction in streams protection by riparian buffers of 47.8 ± 33.1% (Brancalion et al. 2016). Rivers and streams in Brazil harbor high rates of endangered fish (Casatti 2010) and are being hardly attacked by agribusiness expansion over pristine regions that were stimulated by the relaxation of the law. This harsh scenario of fast habitat destruction brings a significant challenge to the conservation researchers and decision makers: it is crucial to detect ecological patterns while also identifying and understanding processes and presenting solutions. All these tasks together demand a stellar effort without enough information on fish assemblages and instream variables. Notwithstanding, it is possible to rescue fish dataset on museums and establish preterit baselines that can be indirectly used to compose the original species pool from impacted watercourses. Also, historical landscape analyses can represent the land-use change dynamics including their accumulated effects (Ferraz et al. 2009). For example, actual agripasture landscapes can face distinct historical processes of deforestation, like a fast and aggressive forest clearance, in the human settlement beginning or recently, or a continuous forest removal process along the time. In all situations, the side effects of forest removal on streams – habitat loss and homogenization – does not occur immediately after the deforestation event, and the aquatic community state change will face a time lag response, which sensitive species [to deforestation] could be being lost together with allochthonous structure loss while tolerant species has favored by habitat homogenization.

Past species occurrences and land-use history together are significant, but still limited without information that reveals how the essential instream features were. Complete stream inventories (fish + local variables) that will give snapshots along deforestation gradients can, therefore, reconstruct the history of diversity loss, ecological integrity and, by modeling techniques, predict what could happen inside the water in future scenarios of deforestation.

Dias et al. (2016) have identified important gaps in Brazilian stream studies and recommended the *"... need of focusing on recently developed ecological theories and frameworks and expanding the temporal and spatial scales of studies".* The authors also pointed out about Brazilian founding agencies policies that favor short-term projects (1-3 years) due to long-term projects, which could *"... help to produce long-term monitoring data, sound ecological results* *and more comprehensive conservation plans".* We agree with the authors, but considering the actual crisis surrounding the Brazilian Science, that is facing several budget cuts (Angelo 2016), this sponsoring strategy probably will continue.

Therefore, how can we work around these problems? How can we turn species inventories in ecological integrity assessments? Recently, advances in GIS tools and the availability of high-quality land-use and climatic datasets (i.e., MapBiomas and WorldClim) already allow us to recover temporal and spatial scales information. However, we need to establish standardized protocols to assess instream variables that are even respecting sampling nature (e.g., inventories or ecological diagnostics), allows researchers to expand the scale of analysis and at the same time permit them to understand accurately how the agribusiness advance is imperiling Neotropical freshwater fish.

The Rondônia State, especially the Machado river basin, presents high rates of recent deforestation (Ferraz et al. 2005). This is a consequence of the human occupation, which has begun with the Federal Highway BR-364 construction at the end of the 1960's, strengthened in the early 1980's with the expansion of adjacent roads (Numata et al. 2009). Consequently, the region presents a unique model for studies with the aim of investigating the communities' ecological attributes variation.

Considering this, the general aim of this Thesis is to comprehend how deforestation process influences the ichthyofauna. To reach this aim, we analyzed the relation between fish species abundance to environmental gradients of time and extent of deforestation, to detect which species were strongly affected – positively or negatively – by deforestation (Chapter 1). Knowing the fish species responses, we determined how fish assemblage composition and structure was related to deforestation time and intensity (Chapter 2). We end the study by presenting how the environmental components influenced the taxonomic and functional turnover rates, considering the process age – recent or old deforestation (Chapter 3). All chapters were prepared according to Conservation Biology journal rules.

In 2015, the Division for Sustainable Development of United Nations proposed the 2030 Agenda, a new plan of action for people, planet, and prosperity, with 17 Sustainable Development Goals and 169 associated targets at its core (UN 2017). In this sense, the present Thesis fits on the SDG 15, Life on Land, which preconizes *"Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss."* The first target of this SDG, expect *"... by 2020, ensure the conservation, restoration and sustainable use of terrestrial and inland freshwater ecosystems and their services, in particular forests, wetlands, mountains, and drylands, in line with obligations under international agreements."* Inside this, the proportion of important sites for terrestrial and freshwater biodiversity that are covered by protected areas, by ecosystem type, is one indicator (# 15.1.2) to evaluate this target. Therefore, we expect that this Thesis also can contribute to a framework to quantify this indicator, considering the freshwater biodiversity.

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Synthesis

In Amazon, the deforestation is the primary environmental filter driving habitat loss and fragmentation affecting terrestrial and aquatic ecosystems. However, the effects of this impact on neotropics are commonly assessed through community and landscape snapshots (a single measure in the present time), missing the historical legacy-effects of land use changes on stream fish communities.

The effects of deforestation accumulate over the time since its beginning, affecting fish populations in distinct ways. The time and the direction of each species response to this impact will define the community integrity evaluated on the snapshot. Therefore, the information given only by these snapshots offers a narrow contribution for conservation plannings. By being able to measure the legacy-effects of impact, it may be possible to project if the environment has already reached a new stable state, or if it still is in the adjustment of richness and abundance process. To drive the communities back to a stable state, resembling the pristine conditions, is necessary much time and energy. However, if the disturbance is in progress and the community is unstable, facing the adjustment processes, it may be possible to decelerate the process of state change (i.e., which can be from a diverse and equitable to a homogeneous and dominant community) through ecological restoration.

However, the effects of deforestation, even occurring in low intensity (i.e., reduced impact logging projects), can promote immediate changes in fish communities richness and abundance, and these changes remain by years after the impact. The main deforestation mode in Amazon is the typical slash-and-burn in extensive areas. Therefore, the effects of such deforestation on the fish communities structure are very intense and interfere in the way which deforestation dynamics is structuring the diversity patterns of the fish assemblages.

Including the time scale as a variable in stream ecology research is essential to better comprehend the legacy effects of land use changes on fish assemblages and instream habitat structure. Notwithstanding, it is indispensable to maintain, on a regional scale, forest remnants that may reflect this history. Even if large areas are converted into production systems, these remnants can make it possible to recover the past scenarios. Without this minimum, what is remaining allows us only tell a very poorly understood story.

By adding the temporal layer to analyze the initial stage of land use changes in this portion of Amazon, it was possible to verify the extreme sensitivity of fish assemblage to deforestation. With our results, it is reasonable to consider stream fish as a flag group to be included on conservation plannings aiming to reduce the effects of biodiversity loss on a regional scale.