UNIVERSIDADE FEDERAL DE LAVRAS

SARAH DE OLIVEIRA SARAIVA

WOOD AS ELEMENT OF FLUVIAL ECOSYSTEMS:

ASSESSING THE AMOUNTS, PREDICTORS AND DYNAMICS OF IN-STREAM WOOD IN BRAZILIAN STREAMS

LAVRAS – MG
2021

SARAH DE OLIVEIRA SARAIVA

WOOD AS ELEMENT OF FLUVIAL ECOSYSTEMS: ASSESSING THE AMOUNTS, PREDICTORS AND DYNAMICS OF IN-STREAM WOOD IN BRAZILIAN STREAMS

Tese apresentada à Universidade Federal de Lavras, como parte das exigências do Programa de Pós-Graduação em Ecologia Aplicada, área de concentração em Ecologia e Conservação de Recursos em Paisagens Fragmentadas e Agrossistemas, para obtenção do título de Doutor.

Prof. Dr. Paulo dos Santos Pompeu
Orientador (UFLA)

Prof. Dr. Ian Rutherfurd
Coorientador (The University of Melbourne)

LAVRAS – MG
2021

Ficha catalográfica elaborada pelo Sistema de Geração de Ficha Catalográfica da Biblioteca Universitária da UFLA, com dados informados pelo(a) próprio(a) autor(a).

Saraiva, Sarah de Oliveira.
Wood as element of fluvial ecosystems : Assessing the amounts, predictors and dynamics of in-stream wood in Brazilian streams / Sarah de Oliveira Saraiva. - 2021.
155 p. : il.

Orientador(a): Paulo dos Santos Pompeu.
Coorientador(a): Ian Rutherfurd.
Tese (doutorado) - Universidade Federal de Lavras, 2021.
Bibliografia.

1. Fluvial ecosystems. 2. Riverine ecology. 3. In-stream wood. I. Pompeu, Paulo dos Santos. II. Rutherfurd, Ian. III. Título.

SARAH DE OLIVEIRA SARAIVA

A MADEIRA COMO ELEMENTO DOS ECOSSISTEMAS FLUVIAIS: UMA ANÁLISE DAS QUANTIDADES, PREDITORES E DINÂMICA DA MADEIRA EM RIACHOS BRASILEIROS

WOOD AS ELEMENT OF FLUVIAL ECOSYSTEMS: ASSESSING THE AMOUNTS, PREDICTORS AND DYNAMICS OF IN-STREAM WOOD IN BRAZILIAN STREAMS

Tese apresentada à Universidade Federal de Lavras, como parte das exigências do Programa de Pós-Graduação em Ecologia Aplicada, área de concentração em Ecologia e Conservação de Recursos em Paisagens Fragmentadas e Agrossistemas, para obtenção do título de Doutor

APROVADA em 26 de novembro de 2021
Dr. Felipe Rossetti de Paula, USP
Dr. Gabriel Lourenço Brejão, UFSCAR
Dra. Renata Dias Francoso Brandão, UFLA
Dr. Eduardo Van den Berg, UFLA

Prof. Dr. Paulo dos Santos Pompeu
Orientador (UFLA)

Prof. Dr. Ian Rutherfurd
Coorientador (The University of Melbourne)

LAVRAS – MG
2021

A meus avós por terem aberto a trilha no matagal de dificuldades,
A meus pais por terem pavimentado o caminho a seguir,
À minha irmã pela companhia na caminhada.

DEDICO

AGRADECIMENTOS

Ao planeta Terra, à natureza e à vida, objetos de meu estudo e devoção. Que continuem resistindo bravamente à presença e insensatez humanas e que sobrevivam à nossa efêmera passagem.

À Ciência, por fornecer as ferramentas necessárias para que compreendamos, ainda que parcialmente, os mistérios do universo. Que progressivamente seja acessada por mais e mais pessoas, democratizando o conhecimento e superando a ignorância.

À educação pública gratuita de qualidade, responsável por minha formação desde a pré-escola até o doutorado. Que mais crianças brasileiras tenham acesso a um ensino de qualidade como tive para que assim o Brasil possa içar a âncora da desigualdade social que nos mantém presos no mar tenebroso da pobreza e violência.

À Universidade Federal de Lavras, responsável por toda minha formação de nível superior. Uma universidade em constante evolução, que se transformou e se expandiu trazendo ao interior de Minas Gerais educação do maior nível de qualidade.

À Coordenação de Aperfeiçoamento de Pessoal de Nível Superior Brasil (CAPES) pela concessão da minha bolsa de doutorado (Código de Financiamento 001) e de doutorado sanduíche (88881.361954/2019-01). A manutenção do incentivo à Ciência é mais do que nunca essencial nos tempos difíceis que temos vivido. Por meio do financiamento da CAPES pude me dedicar integralmente ao doutorado por dois anos, o que certamente foi o diferencial para a qualidade da presente tese. Pude ainda ir ao outro lado do mundo, expandindo irremediavelmente meus horizontes.

Ao Serviço Autônomo de Água e Esgoto de Oliveira (SAAE), por permitir meu afastamento das atividades de servidora por dois anos e facilitar a conciliação entre o trabalho e os estudos no restante do tempo. Os conhecimentos por mim adquiridos durante o doutorado já estão sendo aplicados na minha atuação como servidora, contribuindo para a prestação de um serviço público de qualidade e preservação do meio ambiente.

Ao Programa de Pós-Graduação em Ecologia Aplicada e a todos os funcionários e professores, em especial aos membros da minha comissão de acompanhamento acadêmico, Rafael Zenni e Júlio Louzada, que contribuíram significativamente para melhoria da qualidade da tese.

Ao meu orientador Paulo Pompeu, por ocupar este posto há 13 anos na minha vida. Agradeço por embarcar nos meus projetos, sempre fora da curva, e ainda me incentivar a ir mais longe. Liberdade é a palavra para definir a orientação do Paulo, além é claro de disponibilidade, otimismo e compreensão. Sou grata por ter tornado tudo mais leve, mostrando que mesmo quando tudo dá errado, deu certo de alguma forma. E que se tornar doutor(a) é muito mais que publicar artigos. Obrigada por valorizar cada aprendizado, por menor que seja, e me fazer enxergá-los como degraus na longa escada da minha formação acadêmica.

Ao meu coorientador Ian Rutherfurd, primeiramente, por ter me abordado no congresso do Chile e ter se mostrado interessado no meu trabalho desde o começo. Depois, por não ter pensado duas vezes em me receber na Austrália e embarcar no meu projeto. Por ter me levado a enxergar as coisas por um ângulo que eu nem sabia que existia. Por me ter apresentado o universo da geomorfologia de rios e fazer a ponte com a ecologia. Por sua receptividade, amizade e ensinamentos que fizeram a diferença no desafio de viver e estudar em um país estrangeiro.

Aos meus coautores que contribuíram de forma decisiva e indispensável na confecção dos artigos desta tese. Ao Diego Macedo, por ter me socorrido mesmo à distância nos tempos em que eu estava perdida no ArcGIS lá na Austrália e por não ter medido esforços para me ajudar a gerar os dados faltantes das análises espaciais. Ao Rafael Leitão e à Ciça por terem participado das confabulações da minha tese desde o começo, por terem cedido os dados da Amazônia e por terem se empolgado com a estranha ideia de estudar madeira em riachos. Ao Rafael por ter me apresentado o universo da modelagem de equações estruturais que me possibilitou desvendar os mistérios da madeira, antes ocultos no nosso conjunto de dados. À Ciça por todas as contribuições irretocáveis nos meus manuscritos e por ser meu exemplo a ser seguido desde a época da graduação. Ao Phil Kaufmann por ter recebido um e-mail de uma doutoranda brasileira perdida na Austrália e ter embarcado de cabeça na minha tese, mesmo sem me conhecer pessoalmente. Phil contribuiu de maneira absurda para a melhoria da qualidade da presente tese, me instigando e me levando a fazer coisas que nunca me imaginei capaz, tudo isso com uma dose constante de simpatia e leveza.

Aos amigos dos Laboratório de Ecologia de Peixes, por serem os melhores companheiros possíveis, de quem eu mais senti falta durante a pandemia e fase final da tese. Amizade, parceria, escuta, choro conjunto, mão na massa, comilança e festa não faltam! Agradeço especialmente ao Jota e à Aline pela ajuda essencial nos campos, mesmo sendo para coletar madeira e não peixes! Agradeço também à Sílvia, Pat, Andressa, Nina e Lorenna por todas as vezes que escutaram minhas lamúrias e sempre me ajudaram a enxergar as coisas com mais clareza. Sem a intervenção da Lorenna eu nem teria qualificado! À Tatau por ser meu muro das lamentações preferido e por compartilhar das mesmas angústias e sonhos, e a quem eu recorro sempre que na dúvida.

Aos colegas da Ecologia, por terem compartilhado os desafios, frustrações e angústias da pós-graduação. Pelo trabalho conjunto nas intensas disciplinas condensadas. Pelos almoços e lanches e breves momentos de descanso conjunto. Em especial agradeço à Rafa Maciel, por ter me ajudado a trilhar os complexos caminhos da modelagem de equações estruturais, sem a ajuda de quem eu certamente teria me perdido.

Às minhas companheiras de apartamento Denise, Mariana e Michele por terem formado comigo um aconchegante lar em Lavras. Também por compartilhar as alegrias e tristezas da pós-graduação e por fazer das nossas horas de descanso, nossos almoços, finais de tarde e de semana mais agradáveis. A pandemia desmontou nossa casa, mas não nossa amizade que ficará para a vida toda.

Aos amigos que encontrei do outro lado do mundo e que se tornaram um bote salva-vidas ao qual me agarrei cegamente. Aos amigos brasileiros que me mostraram que a nacionalidade é muito mais que o local de nascimento em comum, mas nossa essência como pessoa. E aos amigos estrangeiros que me mostraram outras belas formas de enxergar o mundo. Em especial agradeço à Cássia e à Marina, pois foram elas que me salvaram nos meus vários momentos de desespero na Escola de Geografia da *'University of Melbourne'*. À Hong e ao Alex, meus companheiros de laboratório que me presentearam com amizade, *'help'* e boas risadas. À Alissa que me deu o primeiro teto em Melbourne e me apresentou ao novíssimo mundo Australiano. Ao Alison por compartilhar muitas refeições, angústias, e os perrengues proporcionados por nosso '*landlord'* carcamano. À Carolina e Wendee pelos nossas muitas *'trips'*, até por aquelas frustradas pela pandemia. À Dina, amizade surgida no sufoco, mas que ficará para toda a vida. Aos companheiros Renato, Thaís, Carol, Carolzinha, Ana, Juliana e Gisele do filosófico e inesquecível *'New Year's Eve'* em meio aos *'bushfires'* em Sydney. Aquele fim de semana era tudo que eu precisava. E a todos os demais amigos que ficarão para sempre guardados na memória dos belos tempos vividos na terra dos cangurus.

À minha família em geral por sempre apoiar e se orgulhar da minha trajetória, mesmo sem às vezes entender realmente. À minha irmã pelo fraterno apoio e incentivo. Aos meus pais por tornarem este sonho possível e pela lavagem cerebral que fizeram para que eu e minha irmã estudássemos e nos tornássemos mulheres independentes. Aos meus avós por terem garantido que eu pudesse chegar aqui. Meu avô Marcos, uma rocha e exemplo de honestidade. Minha avó Maria, um doce pedaço de amor. Avô Geraldo, um poço de serenidade e cultura. Deles guardo a saudade e as boas lembranças. Da vó Nice, única que um abraço ainda alcança, herdei as poucas palavras e a firmeza. Pretendo herdar também a longevidade.

Ao Cristiano pela parceria duradoura, constante apoio e compreensão pelos finais de semanas frustrados e ausências recorrentes ou prolongadas. Por ter amadurecido junto comigo, evoluindo, adaptando-se e passando a ver as coisas por um outro ângulo. Por escutar, aconselhar e palpitar, mesmo quando eu não queria ouvir. Por ter sido meu “estagiário” na saga dos toquinhos, assim como minha mãe. Enfim, por estar sempre ao meu lado com amor e carinho.

A todos os demais que contribuíram direta ou indiretamente para que eu chegasse a este momento, afinal não foi fácil, mas é uma honra, entrar para o seleto grupo de 0.2% de brasileiros que chegam ao maior nível de formação acadêmica.

Muito obrigada!

"A mente que se abre a uma nova ideia jamais volta ao seu tamanho original."

(Albert Eistein)

RESUMO

A madeira fornecida na forma de galhos, troncos e raízes aos rios é parte natural dos sistemas aquáticos, integrando-os há milhões de anos. É um elemento-chave tão importante quanto os sedimentos e a vegetação ripária para o funcionamento dos sistemas fluviais. Afeta os aspectos hidráulicos, morfológicos e geomorfológicos do canal, estoca carbono, estrutura o hábitat e beneficia a biota aquática. A distribuição e a quantidade de madeira variam ao longo das bacias hidrográficas, das regiões geográficas e bioclimáticas, dos biomas e do gradiente de preservação das florestas nativas. Variam também dependendo do histórico de atividades antrópicas na bacia e da ocorrência de eventos episódicos. Há grandes lacunas de conhecimento no que se refere à madeira fluvial dos trópicos, uma vez que estudos deste tema historicamente se concentraram em regiões florestadas temperadas. Não há informação suficiente sobre a madeira em cursos d'água da Amazônia, a maior floresta tropical do mundo, nem no Cerrado, segundo maior bioma da América do Sul. O desmatamento atualmente verificado nestes biomas aumenta ainda mais a necessidade de se levantar informações acerca da madeira presente em seus cursos d'água antes que o regime natural deste elemento seja perdido ou significativamente depauperado. Frente a isto, o objetivo da presente tese foi descrever a madeira em riachos da Amazônia e do Cerrado brasileiros, quantificando seus estoques, identificando seus principais preditores e levantando as taxas de recrutamento, retenção e transporte. No primeiro artigo, verificou-se que os estoques de madeira da Amazônia e Cerrado são similares entre si e comparáveis àqueles de biomas temperados. No entanto, o estoque tropical é altamente dominado por galhos menores sendo raro encontrar grandes toras de madeira. No segundo artigo, observou-se que o principal fator que controla a quantidade de madeira num riacho é o tamanho da peça em relação ao canal, acompanhado das variáveis hidráulicas e morfológicas do canal e da vegetação ripária. Basicamente, a madeira presente nos riachos da Amazônia e Cerrado é resultado do que foi fornecido pela mata ciliar local e do quanto ficou retido. No terceiro artigo, detectou-se que a maior parte da madeira em riachos do Cerrado ficou retida de uma estação chuvosa para outra, e o que foi transportado, foi imediatamente resposto. Diferenças hidrológicas e morfológicas e eventos episódicos levaram a variações no estoque de madeira entre riachos. A distância percorrida por uma peça dependeu de seu tamanho, orientação e localização no canal, sendo resultado do balanço entre as forças de arraste e de resistência. A presente tese trouxe informações inéditas ao descrever a madeira existente em riachos da Amazônia e do Cerrado e apontou os fatores críticos para se manter a dinâmica da madeira em riachos tropicais. Concluiu-se que, como as florestas ripárias são a fonte primária de madeira, sua degradação ou remoção das bacias hidrográficas leva ao aumento do transporte e consequente redução dos estoques madeireiros devido à diminuição do tamanho das toras e alterações no regime hidrológico. Portanto, é urgente e indispensável a preservação das matas ciliares também para manter os processos fluviais da madeira.

Palavras-chave: Madeira fluvial. Floresta ripária. Estoque madeireiro. Preditores de madeira. Mobilidade da madeira.

ABSTRACT

Supplied as branches, trunks and roots to rivers and streams, wood is a natural part of aquatic systems, integrating them for million years. It is a key element, as important as sediments and riparian vegetation for the river systems function. It affects the hydraulic, morphological and geomorphological aspects of the channel, stores carbon, structures the habitat and benefits the aquatic biota. The distribution and amounts of wood vary along river basins, geographic and bioclimatic regions, biomes and the gradient of native forests. They also vary depending on the history of human activities in the basin and the occurrence of episodic events. There is a great knowledge gap with regard to in-stream wood in the tropics, since research have historically focused on temperate forest regions. There is little to no information regarding wood in rivers or streams in the Amazon, the largest tropical rainforest in the world, nor in the Cerrado, the Brazilian savanna and the second largest biome in South America. The deforestation pressure currently seen in these biomes further increases the need to gather information about in-stream wood before losing or significantly depleting its natural regime. In face of this, the objective of this thesis was to describe the wood in streams of Amazon and Cerrado, quantifying its stocks, identifying its main predictors, and checking its rates of recruitment, retention and transport. In the first article, we verified that the Amazon and Cerrado wood stocks are similar and comparable to those of temperate biomes. However, the tropical stock is highly dominated by smaller branches, such large logs are rarely found. In the second article, we observed that the main factor controlling the amount of wood is the piece size in relation to the channel, accompanied by the bankfull discharge, the stream power, the channel width and depth and the riparian vegetation. Basically, the wood present in the Amazon and Cerrado streams is the result of what was provided by the local riparian forest and how much of this was retained. In the third article, we found that most of the wood in Cerrado streams is retained from one rainy season to another, and what is transported is immediately replaced by the riparian forest. Hydrological and morphological differences as well as episodic events lead to variations in wood stock between streams. The piece travelled distance depends on its size, orientation and location in the channel, being result of the balance between drag and resisting forces. This thesis provided unprecedented information by describing the wood of Amazon and Cerrado streams and pointed out the critical factors to maintain the dynamics of it in tropical streams. As riparian forests are the primary source of wood to streams, we concluded that their degradation or removal leads to enhanced transport rates and consequent depleted wood stocks due to the decrease in piece size and changes in the hydrological regime. Therefore, it is urgent and essential to preserve riparian forests for the maintenance of fluvial wood processes.

Keywords: Large wood. Riparian forest. Wood stock. Wood Predictors. Wood mobility.

LISTA DE FIGURAS

LISTA DE TABELAS

SUMÁRIO

PRIMEIRA PARTE

1. INTRODUÇÃO GERAL

Estendendo-se ao longo de rios e riachos, as matas ripárias são importante fonte de matéria orgânica e nutrientes para os ecossistemas aquáticos. A madeira, fornecida na forma de galhos, troncos e raízes aos rios e riachos é parte natural dos sistemas aquáticos, integrando-os há milhões de anos e afetando seus aspectos hidráulicos, morfológicos e geomorfológicos (MONTGOMERY, 2003).

Após ter sido ignorada por um longo período, a madeira, finalmente passou a ser objeto de pesquisa de ecólogos e geomorfólogos a partir da década de 1970, que passaram a investigar sua dinâmica e funções em rios e riachos (SWANSON *et al.*, 2020). Os primeiros estudos surgiram na região Noroeste do Pacífico nos Estados Unidos, onde houve a convergência da necessidade de se estudar o tema com a capacidade técnica para fazê-lo. Esta região possui extensas e massivas florestas temperadas úmidas responsáveis por fornecer abundante estoque de madeira aos rios. Em meados de 1970, havia uma necessidade de se regular as práticas florestais nos EUA devido ao avanço do desmatamento e conversão das florestas em áreas agricultáveis e consequente declínio das populações de peixes socialmente importantes, como o salmão (SWANSON *et al.*, 2020). Já havia algumas iniciativas de projetos de restauração com a reintrodução de madeira nos cursos d’água com o objetivo de enriquecer os hábitats para os peixes, no entanto, faltava o embasamento teórico necessário para dar suporte a este tipo de ação (SWANSON *et al.*, 2020). Assim, visando gerar informações confiáveis para basear a legislação florestal, um grupo de pesquisadores da Oregon State University liderados por Frederick Swanson deram início às pesquisas específicas sobre madeira em rios inaugurando este novo ramo da “Ciência Ribeirinha” (do inglês “Riverine Science”) (RUIZ-VILLANUEVA; STOFFEL, 2017), que atualmente conta até com um evento científico internacional realizado a cada quatro anos para tratar exclusivamente deste tema (“The International Conference Wood in World Rivers”). Desde então, a pesquisa sobre madeira em rios se expandiu muito e hoje pode ser separada em três vertentes principais de acordo com SWANSON *et al.* (2020): (i) pesquisa ecossistêmica[1], que abrange pesquisas básicas e descritivas para caracterização de ambientes não previamente estudados e frequentemente relacionada ao papel da madeira nos fluxos de carbono e nitrogênio; (ii) pesquisa aplicada, que inclui projetos de equipes interdisciplinares motivadas por questões relacionadas ao manejo,

---

[1] A presente tese dedica-se à pesquisa ecossistêmica visando descrever a madeira em regiões ainda não estudadas: riachos tropicais da Amazônia e Cerrado brasileiros.

como projetos de revitalização de habitats aquático e riscos ambientais decorrentes de madeira transportada em enchentes em regiões montanhosas; (iii) pesquisas geomorfológicas, que visam documentar como a presença ou ausência de madeira em cursos d’água e em áreas alagáveis pode alterar o processo e a forma do rio, aumentando a rugosidade hidráulica e obstruindo o fluxo e consequentemente afetando a dinâmica dos sedimentos, geometria do canal e conectividade com a planície de inundação.

Após quase 50 anos de pesquisa, hoje conhece-se a importância da madeira em rios, sendo esta considerada um elemento chave (GURNELL *et al.*, 2002; GREGORY; BOYER; GURNELL, 2003; RUIZ-VILLANUEVA *et al.*, 2016; WOHL, 2013, 2017) tão importante quanto os sedimentos e a vegetação ripária para o funcionamento dos sistemas fluviais (RONI; BEECHIE, 2013). O regime natural da madeira é considerado a terceira perna do tripé de processos físicos formado em conjunto com o regime hidrológico e o fluxo de sedimentos (WOHL *et al.*, 2019). Mas não apenas a madeira naturalmente presente nos rios é importante. Até mesmo aquela reintroduzida em projetos de restauração é capaz de produzir efeitos positivos no habitat e nas populações aquáticas (RONI, 2019; RONI *et al.*, 2015). A madeira altera a largura e a profundidade do canal, criando poças e corredeiras (ABBE; MONTGOMERY, 1996; BILBY; BISSON, 1998; ROSENFELD; HUATO, 2003; PAULA *et al.*, 2011), promove o aumento da rugosidade e a retenção de sedimentos (ABBE; MONTGOMERY, 1996; KAUFMANN *et al.*, 2008), a variação nos tamanhos de substrato (FAUSTINI; JONES, 2003; MONTGOMERY *et al.*, 1999), o surgimento de ilhas e estabilização das margens (BROOKS *et al.*, 2001; SHIELDS-JR *et al.*, 2004), favorece a ciclagem de nutrientes e a estocagem de carbono (BECKMAN; WOHL, 2014a; GUYETTE; DEY; STAMBAUGH, 2008; SUTFIN; WOHL; DWIRE, 2016), beneficia a biota aquática estruturando o hábitat (KAUFMANN; HUGHES, 2006; LEAL *et al.*, 2016; MACEDO *et al.*, 2016), fornecendo áreas de desova para peixes (MONTGOMERY *et al.*, 1999; POWER, 2003; NAGAYAMA; NAKAMURA, 2010), abrigo, cobertura e refúgio (BRYANT, 1983; BISSON *et al.*, 1987; BILBY; BISSON, 1998; WRIGHT; FLECKER, 2004) alimento, matéria orgânica e nutrientes (BILBY; BISSON, 1998; FRAINER *et al.*, 2018), e consequentemente melhora os indicadores ecológicos das populações e comunidades aquáticas (ANGERMEIER; KARR, 1984; HERDRICH *et al.*, 2018; LEITÃO *et al.*, 2018; PETTIT *et al.*, 2013; STERLING; WARREN, 2018). No entanto, os benefícios da madeira aos hábitats aquáticos são dependentes da sua distribuição e quantidade nos rios, as quais são variáveis no espaço e no tempo (WOHL, 2017).

No espaço, a madeira varia ao longo das bacias hidrográficas (LIENKAEMPER; SWANSON, 1987; SWANSON, 2003), das regiões geográficas e bioclimáticas (WOHL, 2017; WOHL *et al.*, 2017), dos biomas (LININGER *et al.*, 2017) e do gradiente de preservação das florestas nativas (BECKMAN; WOHL, 2014b; BENDA; BIGELOW; WORSLEY, 2002; IROUMÉ *et al.*, 2014; WOHL *et al.*, 2018). No tempo, varia de acordo com o histórico de atividades antrópicas na bacia (BETTS *et al.*, 2021; MCILROY *et al.*, 2008; PAULA *et al.*, 2013) e pela ocorrência de eventos episódicos (PETTIT *et al.*, 2005; TONON *et al.*, 2017; WOHL *et al.*, 2012; WOHL; OGDEN; GOODE, 2009). Assim sendo, alterações locais, como a construção de uma ponte, ou regionais, como o aumento do desmatamento na bacia, e eventos pontuais, como uma ventania que derruba árvores, ou recorrentes, como a ocorrência de cheias acima da média, todos estes fatores, atuam individual e sinergicamente alterando a disponibilidade da madeira nos rios. Isto porque a quantidade de madeira em um dado trecho de rio é resultado do balanço de massa entre as entradas, saídas e decomposição da madeira num dado intervalo de tempo (BENDA; SIAS, 2003).

A entrada de madeira pode ocorrer lateralmente a partir da queda de árvores inteiras ou de parte delas, seja por mortalidade individual ou em massa, por erosão das margens, enchentes, deslizamentos, ventanias, raios, fogo entre outras causas (BENDA *et al.*, 2003). Pode ocorrer também entrada longitudinal, correspondente ao transporte fluvial da madeira de montante para jusante (BENDA; SIAS, 2003). A saída de madeira se dá a partir de depósitos fora do canal principal do curso d’água pela ação das cheias ou pelo carreamento pela correnteza para jusante do trecho analisado (BENDA; SIAS, 2003). Por fim, tem-se a perda de madeira via decomposição in-situ (BENDA; SIAS, 2003), que se dá por quebra de partes, abrasão ou lixiviação pela água. Seja como for, a decomposição leva à redução do tamanho da peça, da densidade ou da resistência, diminuindo sua estabilidade que, por sua vez, aumenta as perdas via transporte (WOHL, 2017). Portanto, o que define a quantidade de madeira em um curso d’água é o predomínio de uma ou outra força. Se o aporte de madeira é maior que o transporte, então isto resulta em maiores quantidade de madeira estocada. Se, por outro lado, o transporte e a decomposição forem maiores que o recrutamento, então menores quantidades de madeira serão verificadas.

Em regiões de florestas temperadas úmidas, como no Noroeste do Pacífico, há um predomínio das forças de recrutamento e, portanto, grande quantidade de madeira é estocada nestes rios (WOHL, 2017). Já em regiões tropicais, devido a existência de maiores taxas de transporte [o regime hidrológico é caracterizado por cheias frequentes, de curta duração e de grande magnitude (ARENAS, 1983; WOHL, 2005)] e decomposição [a condição climática quente e úmida é ideal para otimizar a ação dos agentes decompositores (ZABEL; MORRELL, 1992)] são esperados uma menor quantidade de madeira e um regime mais transitório, pois as altas taxas de decomposição e transporte são compensadas por taxas de recrutamento também altas (WOHL, 2017). No entanto, ainda não há informação suficiente para fazer qualquer afirmação ou generalização em relação aos rios tropicais, pois estudos nestes ambientes são escassos. As poucas localidades já estudadas não representam a diversidade dos biomas tropicais (WOHL, 2017). Que seja do nosso conhecimento, somente já foram estudados em relação à madeira, riachos de floresta tropical úmida na América Central e no Sudeste Asiático (CADOL *et al.*, 2009; CADOL; WOHL, 2010; GOMI *et al.*, 2006; WOHL *et al.*, 2012), riachos de uma região agrícola tropical semi-úmida no Brasil (PAULA *et al.*, 2011, 2013), grandes rios na região tropical úmida-seca do norte da Austrália (PETTIT *et al.*, 2013) e na savana semi-árida africana (PETTIT *et al.*, 2005; PETTIT; NAIMAN, 2005). Não há registros de estudos com madeiras em rios ou riachos da Amazônia, a maior floresta tropical úmida do mundo, nem no Cerrado, a savana brasileira, segundo maior bioma da América do Sul.

Além da necessidade de preencher a lacuna de conhecimento sobre madeira em rios tropicais, as alterações na paisagem atualmente em curso nestes ambientes aumentam ainda mais a necessidade de estudar este tema. A Amazônia e o Cerrado brasileiros têm experimentado altas taxas de desmatamento nos últimos anos, desencadeado principalmente pela expansão da agricultura e pecuária (PARENTE *et al.*, 2021; PEREIRA *et al.*, 2020; SILVA JUNIOR *et al.*, 2021; TRIGUEIRO; NABOUT; TESSAROLO, 2020). O desmatamento e a degradação das zonas ripárias, agravados pela canalização e perda de conectividade em riachos e rios, interrompem o fornecimento e armazenamento de madeira, resultando em cargas de madeira menores do que seria observado nas condições de referência (WOHL *et al.*, 2019). Estudos de avaliação da condição dos hábitats aquáticos indicam potencial redução da disponibilidade de madeira em riachos tropicais impactados pela agricultura (BETTS *et al.*, 2021; LEAL *et al.*, 2016; POMPEU; YUHARA, 2018). Assim sendo, podemos já ter um regime de madeira perturbado nos riachos tropicais, o regime de madeira contemporâneo alertado por WOHL *et al.* (2019), antes mesmo de se conhecer o regime natural.

Portanto, considerando a importância da madeira para os sistemas aquáticos e as grandes lacunas de conhecimento existentes principalmente em relação aos riachos tropicais, a presente tese de doutorado dedicou-se a descrever a madeira em riachos da Amazônia e Cerrado brasileiros. No primeiro artigo é apresentada a primeira e extensa avaliação de madeira em riachos da Amazônia e do Cerrado, descrevendo os quantitativos e o perfil de tamanho da madeira. Também é realizado um comparativo entre o estoque madeireiro dos riachos dos dois biomas, com dados disponíveis na literatura e com riachos comparáveis de biomas temperados dos EUA. No segundo artigo, os principais preditores da madeira são investigados para os mesmos riachos da Amazônia e do Cerrado, identificando-se os fatores críticos que controlam o recrutamento e o estoque de madeira. Por fim, no terceiro artigo, selecionamos oito riachos do Cerrado e documentamos o recrutamento, retenção e mobilização de madeira durante o período de um ano através da marcação e recaptura das toras.

2. CONCLUSÃO GERAL

No primeiro capítulo verificamos que a madeira está presente em riachos da Amazônia e Cerrado em quantidades e tamanhos similares. O estoque madeireiro destes riachos tropicais é comparável em abundância e volume por unidade de canal àqueles de riachos de biomas temperados correspondentes, diferindo, no entanto, em relação ao perfil de tamanho. O estoque tropical é altamente dominado por galhos de menor tamanho, sendo raro encontrar grandes toras de madeira. A diferenciação das cargas de madeira entre biomas está mais relacionada aos mecanismos de controle do que aos números totais de madeira nos riachos.

No segundo capítulo observamos que o tamanho da madeira em relação ao tamanho do canal é o fator que mais controla o estoque da madeira em riachos. Peças maiores são mais estáveis permanecendo presas no mesmo local por mais tempo. A estabilidade da madeira conjuntamente com a vazão de cheia, o poder de transporte do riacho, a largura e a profundidade do canal e a vegetação ripária, são capazes de predizer razoavelmente bem a quantidade de madeira que um riacho potencialmente pode ter. Basicamente, o estoque de madeira encontrado nos riachos da Amazônia e Cerrado é resultado do que foi fornecido pela mata ciliar local e do quanto ficou retido.

Finalmente no capítulo artigo detectamos que a maior parte da madeira dos riachos do Cerrado ficou retida (~60%) de uma estação chuvosa para outra. O restante (~40%) foi transportado e imediatamente resposto pela mata ciliar, de modo que houve uma constância no estoque madeireiro de um ano para o outro. No entanto, diferenças hidrológicas e morfológicas, bem como a ocorrência de eventos episódicos levaram a variações no estoque de madeira entre riachos. A distância percorrida por uma peça de madeira foi dependente de seu tamanho, orientação e localização no canal, sendo resultado do balanço entre as forças de arraste e as de resistência.

Os três artigos integrantes da presente tese trouxeram informações inéditas ao descrever a madeira presente em riachos da Amazônia e do Cerrado. Frente ao atual e acelerado avanço do desmatamento nestes biomas tropicais, a descrição deste processo ecológico torna-se ainda mais importante, pois é necessário conhecê-lo antes de perdê-lo. As análises preditivas aqui realizadas apontaram os fatores críticos para se manter a dinâmica de madeira em riachos tropicais. A manutenção e conservação das florestas ripárias é de suma importância, porque estas constituem-se na fonte primária da madeira, e também porque sua degradação leva à diminuição do tamanho das toras que é a peça-chave para o transporte da madeira. Além disso, a remoção das florestas nas bacias hidrográficas altera o regime hidrológico favorecendo os picos de cheia, que por sua vez, favorecerão o transporte da madeira reduzindo ainda mais o estoque de madeira em riachos impactados pelo desmatamento. Assim, fica claro que as florestas ripárias são essenciais para a manutenção dos processos fluviais também no que se refere à madeira. Somada à já conhecida importância das matas ciliares nos processos de retenção de sedimentos e como fonte de energia para as comunidades aquáticas, a presente tese fornece ainda mais subsídios para ações de conservação e recuperação das florestas ao longo das redes hidrográficas.

REFERÊNCIAS

ABBE, T. B.; MONTGOMERY, D. R. Large woody debris jams, channel hydraulics and habitat formation in large rivers. **Regulated Rivers Research Management**, v. 12, n. 2–3, p. 201–221, 1996. Disponível em: <http://doi.wiley.com/10.1002/(SICI)1099-1646(199603)12:2/3%3C201::AID-RRR390%3E3.0.CO;2-A>.

ANGERMEIER, P. L.; KARR, R. Relationships between Woody Debris and. **Transactions of the American Fisheries Society**, v. 113, p. 716–726, 1984.

ARENAS, A. D. Tropical storms in Central America and the Caribbean: characteristic rainfall and forecasting of flash floods. In: Keller, R. (Ed.). **Hydrology of Humid Tropical Regions with Particular Reference to the Hydrological Effects of Agriculture and Forestry Practice**. Wallingford: IAHS Publication. 1983. p. 39–51.

BECKMAN, N. D.; WOHL, E. Carbon storage in mountainous headwater streams: The role of old-growth forest and logjams. **Water Resources Research**, v. 50, p. 2376–2393, 2014a.

BECKMAN, N. D.; WOHL, E. Effects of forest stand age on the characteristics of logjams in mountainous forest streams. **Earth Surface Processes and Landforms**, v. 39, n. 11, p. 1421–1431, 2014b.

BENDA, L. E.; BIGELOW, P.; WORSLEY, T. M. Recruitment of wood to streams in old-growth and second-growth redwood forests, northern California, U.S.A. **Canadian Journal of Forest Research**, v. 32, n. 8, p. 1460–1477, 2002.

BENDA, L. E.; SIAS, J. C. A quantitative framework for evaluating the mass balance of in-stream organic debris. **Forest Ecology and Management**, v. 172, n. 1, p. 1–16, 2003.

BENDA, L.; MILLER, D.; SIAS, J.; et al. Wood recruitment processes and wood budgeting. **American Fisheries Society Symposium**, v. 37, p. 49–73, 2003.

BETTS, J. T.; URQUHART, G. R.; ROMÁN-HERACLEO, J.; FLORES MC.REA, J. C. Effects of deforestation from cattle ranching over time on protected rainforest streams in the Rama-Kriol Territory, Nicaragua. **Hydrobiologia**, v. 0123456789, 2021. Disponível em: <https://link.springer.com/10.1007/s10750-021-04684-w>.

BILBY, R. E.; BISSON, P. A. Function and Distibution of Large Woody Debris. In: R. E. Naiman, R. J.; Bilby (Org.); **River ecology and management: lessons from the Pacific Coastal Ecoregion**. p.324–346, 1998. New York: Springer.

BISSON, P. A.; BILBY, R. E.; BRYANT, M. D.; et al. Large Woody Debris in Forested Streams in the Pacific Northwest: Past, Present, and Future. In: E. O. Salo; T. W. Cundy (Orgs.); **Streamside Management: Forestry and Fisheries Interactions**. p.144–190, 1987. Seattle: University of Washington. Disponível em: <https://andrewsforest.oregonstate.edu/sites/default/files/lter/pubs/pdf/pub1316.pdf>.

BROOKS, A. P.; ABBE, T. B.; JANSEN, J. D.; TAYLOR, M.; GIPPEL, C. J. Putting the wood back into our rivers: an experiment in river rehabilitation. In: I. Rutherfurd; F. Sheldon; G. Brierley; C. Kenyon (Orgs.); Proceedings of the 3rd Australian Stream Management Conference. **Anais...** . p.73–80, 2001. Clayton, Australia: Cooperative Research Centre for Catchment Hydrology. Disponível em: <http://www.catchment.crc.org.au/archive/pubs/1000045.html>.

BRYANT, M. D. The Role and Management of Woody Debris in West Coast Salmonid

Nursery Streams. **North American Journal of Fisheries Management**, v. 3, n. 3, p. 322–330, 1983.

CADOL, D.; WOHL, E. Wood retention and transport in tropical, headwater streams, La Selva Biological Station, Costa Rica. **Geomorphology**, v. 123, n. 1–2, p. 61–73, 2010. Elsevier B.V.

CADOL, D.; WOHL, E.; GOODE, J. R.; JAEGER, K. L. Wood distribution in neotropical forested headwater streams of La Selva, Costa Rica. **Earth Surface Processes and Landforms**, v. 34, n. 9, p. 1198–1215, 2009. Disponível em: <http://doi.wiley.com/10.1002/esp.1800>.

FAUSTINI, J. M.; JONES, J. A. Influence of large woody debris on channel morphology and dynamics in steep, boulder-rich mountain streams, western Cascades, Oregon. **Geomorphology**, v. 51, n. 1–3, p. 187–205, 2003.

FRAINER, A.; POLVI, L. E.; JANSSON, R.; MCKIE, B. G. Enhanced ecosystem functioning following stream restoration: The roles of habitat heterogeneity and invertebrate species traits. **Journal of Applied Ecology**, v. 55, n. 1, p. 377–385, 2018.

GOMI, T.; SIDLE, R. C.; NOGUCHI, S.; et al. Sediment and wood accumulations in humid tropical headwater streams: Effects of logging and riparian buffers. **Forest Ecology and Management**, v. 224, n. 1–2, p. 166–175, 2006.

GREGORY, S. V.; BOYER, K.L.; GURNELL, A. M. **The Ecology and Management of Wood in World Rivers**, vol. 37. Bethesda, Maryland: American Fisheries Society, Symposium, 2003.

GURNELL, A. M.; PIÉGAY, H.; SWANSON, F. J.; GREGORY, S. V. Large wood and fluvial processes. **Freshwater Biology**, v. 47, n. 4, p. 601–619, 2002.

GUYETTE, R. P.; DEY, D. C.; STAMBAUGH, M. C. The temporal distribution and carbon storage of large oak wood in streams and floodplain deposits. **Ecosystems**, v. 11, n. 4, p. 643–653, 2008.

HERDRICH, A. T.; WINKELMAN, D. L.; VENARSKY, M. P.; WALTERS, D. M.; WOHL, E. The loss of large wood affects rocky mountain trout populations. **Ecology of Freshwater Fish**, v. 27, n. 4, p. 1023–1036, 2018.

IROUMÉ, A.; MAO, L.; ULLOA, H.; RUZ, C.; ANDREOLI, A. Large Wood Volume and Longitudinal Distribution in Channel Segments Draining Catchments with Different Land Use, Chile. **Open Journal of Modern Hydrology**, v. 04, n. 02, p. 57–66, 2014.

KAUFMANN, P. R.; FAUSTINI, J. M.; LARSEN, D. P.; SHIRAZI, M. A. A roughness-corrected index of relative bed stability for regional stream surveys. **Geomorphology**, v. 99, n. 1–4, p. 150–170, 2008.

KAUFMANN, P. R.; HUGHES, R. M. Geomorphic and anthropogenic influences on fish and amphibians in pacific northwest coastal streams. **American Fisheries Society Symposium**, v. 2006, n. 48, p. 429–455, 2006.

LEAL, C. G.; POMPEU, P. S.; GARDNER, T. A.; et al. Multi-scale assessment of human-induced changes to Amazonian instream habitats. **Landscape Ecology**, v. 31, n. 8, p. 1725–1745, 2016.

LEITÃO, R. P.; ZUANON, J.; MOUILLOT, D.; et al. Disentangling the pathways of land use impacts on the functional structure of fish assemblages in Amazon streams. **Ecography**, v. 41, n. 1, p. 219–232, 2018.

LIENKAEMPER, G. W.; SWANSON, F. J. Dynamics of large woody debris in streams in old-growth Douglas-fir forests. **Canadian Journal of Forest Research**, v. 17, n. 2, p. 150–156, 1987.

LININGER, K. B.; WOHL, E.; SUTFIN, N. A.; ROSE, J. R. Floodplain downed wood volumes: a comparison across three biomes. **Earth Surface Processes and Landforms**, v. 42, n. 8, p. 1248–1261, 2017.

MACEDO, D. R.; HUGHES, R. M.; FERREIRA, W. R.; et al. Development of a benthic macroinvertebrate multimetric index (MMI) for Neotropical Savanna headwater streams. **Ecological Indicators**, v. 64, p. 132–141, 2016.

MCILROY, S. K.; MONTAGNE, C.; JONES, C. A.; MCGLYNN, B. L. Identifying linkages between land use, geomorphology, and aquatic habitat in a mixed-use watershed. **Environmental Management**, v. 42, n. 5, p. 867–876, 2008.

MONTGOMERY, D. R. Geomorphic Effects of Wood in Rivers. **American Fisheries Society Symposium**, v. 37, p. 21–47, 2003. Disponível em: <http://www.fs.fed.us/rm/boise/publications/watershed/rmrs_2003_montomeryr001.pdf>.

MONTGOMERY, D. R.; BEAMER, E. M.; PESS, G. R.; QUINN, T. P. Channel type and salmonid spawning distribution and abundance. **Canadian Journal of Fisheries and Aquatic Sciences**, v. 56, n. 3, p. 377–387, 1999.

NAGAYAMA, S.; NAKAMURA, F. Fish habitat rehabilitation using wood in world. **Landscape and Ecology Engineering**, v. 6, p. 289–305, 2010.

PARENTE, L.; NOGUEIRA, S.; BAUMANN, L.; et al. Quality assessment of the PRODES Cerrado deforestation data. **Remote Sensing Applications: Society and Environment**, v. 21, n. November 2020, 2021.

PAULA, F. R. DE; FERRAZ, S. F. D. B.; GERHARD, P.; VETTORAZZI, C. A.; FERREIRA, A. Large woody debris input and its influence on channel structure in agricultural lands of Southeast Brazil. **Environmental Management**, v. 48, n. 4, p. 750–763, 2011.

PAULA, F. R.; GERHARD, P.; WENGER, S. J.; et al. Influence of forest cover on in-stream large wood in an agricultural landscape of southeastern Brazil: A multi-scale analysis. **Landscape Ecology**, v. 28, n. 1, p. 13–27, 2013.

PEREIRA, E. J. DE A. L.; RIBEIRO, L. C. DE S.; FREITAS, L. F. DA S.; PEREIRA, H. B. DE B. Brazilian policy and agribusiness damage the Amazon rainforest. **Land Use Policy**, v. 92, n. August 2019, p. 104491, 2020. Elsevier. Disponível em: <https://doi.org/10.1016/j.landusepol.2020.104491>.

PETTIT, N. E.; NAIMAN, R. J. Flood-deposited wood debris and its contribution to heterogeneity and regeneration in a semi-arid riparian landscape. **Oecologia**, v. 145, n. 3, p. 434–444, 2005.

PETTIT, N. E.; NAIMAN, R. J.; ROGERS, K. H.; LITTLE, J. E. Post-flooding distribution and characteristics of large woody debris piles along the semi-arid Sabie River, South Africa. **River Research and Applications**, v. 21, n. 1, p. 27–38, 2005.

PETTIT, N. E.; WARFE, D. M.; KENNARD, M. J.; et al. Dynamics of in-stream wood and its importance as fish habitat in a large tropical floodplain river. **River Research and Applications**, v. 29, n. 7, p. 864–875, 2013. Disponível em: <http://doi.wiley.com/10.1002/rra.2580>.

POMPEU, P. S.; YUHARA, T. Y. Impactos de manilhas rodoviárias sobre o ambiente físico de riachos. In A. Bager. (Ed.). **Infraestrutura viária & biodiversidade: métodos e diagnósticos**. Lavras, MG: Universidade Federal de Lavras, vol. 1, p. 147–158, 2018.

RONI, P. Does River Restoration Increase Fish Abundance and Survival or Concentrate Fish? The Effects of Project Scale, Location, and Fish Life History. **Fisheries**, v. 44, n. 1, p. 7–19, 2019.

RONI, P; BEECHIE, T. **Stream and Watershed Restoration: A Guide to Restoring Riverine Processes and Habitats**. Chichester, UK: Wiley-Blackwell, 2013.

RONI, P.; BEECHIE, T.; PESS, G.; HANSON, K. Wood placement in river restoration: Fact, fiction, and future direction. **Canadian Journal of Fisheries and Aquatic Sciences**, v. 72, n. 3, p. 466–478, 2015.

ROSENFELD, J. S.; HUATO, L. Relationship between Large Woody Debris Characteristics and Pool Formation in Small Coastal British Columbia Streams. **North American Journal of Fisheries Management**, v. 23, n. 3, p. 928–938, 2003.

RUIZ-VILLANUEVA, V.; PIÉGAY, H.; GURNELL, A. M.; MARSTON, R. A.; STOFFEL, M. Recent advances quantifying the large wood dynamics in river basins: New methods and remaining challenges. **Reviews of Geophysics**, p. 611–652, 2016.

RUIZ-VILLANUEVA, V.; STOFFEL, M. Frederick J. Swanson's 1976–1979 papers on the effects of instream wood on fluvial processes and instream wood management. **Progress in Physical Geography**, v. 41, n. 1, p. 124–133, 2017.

SHIELDS-JR, F. D.; ASCE, M.; MORIN, N.; COOPER, C. M. Large Woody Debris Structures for Sand-Bed Channels. **Journal of Hydraulic Engineering**, v. 130, n. March, p. 208–217, 2004.

SILVA JUNIOR, C. H. L.; PESSÔA, A. C. M.; CARVALHO, N. S.; et al. The Brazilian Amazon deforestation rate in 2020 is the greatest of the decade. **Nature Ecology and Evolution**, v. 5, n. 2, p. 144–145, 2021. Springer US. Disponível em: <http://dx.doi.org/10.1038/s41559-020-01368-x>.

STERLING, K. A.; WARREN, M. L. Effects of introduced small wood in a degraded stream on fish community and functional diversity. **Southeastern Naturalist**, v. 17, n. 1, p. 74–94, 2018.

SUTFIN, N. A.; WOHL, E. E.; DWIRE, K. A. Banking carbon: A review of organic carbon storage and physical factors influencing retention in floodplains and riparian ecosystems. **Earth Surface Processes and Landforms**, v. 41, n. 1, p. 38–60, 2016.

SWANSON, F. J. Wood in Rivers: A Ladscape Perspective. **American Fisheries Society Symposium**. v. 37, p.299–313, 2003.

SWANSON, F. J.; GREGORY, S. V.; IROUMÉ, A.; RUIZ-VILLANUEVA, V.; WOHL, E. Reflections on the history of research on large wood in rivers. **Earth Surface Processes and Landforms**, p. esp.4814, 2020. Disponível em: <https://onlinelibrary.wiley.com/doi/abs/10.1002/esp.4814>.

TONON, A.; IROUMÉ, A.; PICCO, L.; OSS-CAZZADOR, D.; LENZI, M. A. Temporal variations of large wood abundance and mobility in the Blanco River affected by the Chaitén volcanic eruption, southern Chile. **Catena**, v. 156, n. April, p. 149–160, 2017. Elsevier. Disponível em: <http://dx.doi.org/10.1016/j.catena.2017.03.025>.

TRIGUEIRO, W. R.; NABOUT, J. C.; TESSAROLO, G. Uncovering the spatial variability of recent deforestation drivers in the Brazilian Cerrado. **Journal of Environmental Management**, v. 275, n. August, 2020.

WOHL, E. Downstream hydraulic geometry along a tropical mountain river. In: Harmon R (Ed.). **The Rio Chagres: A Multidisciplinary Profile of a Tropical Watershed**. Dordrecht: Kluwer Academic Publishers. 2005. p. 169–188.

WOHL, E. Floodplains and wood. **Earth-Science Reviews**, ago. 2013. Disponível em: <https://linkinghub.elsevier.com/retrieve/pii/S0012825213000834>. .

WOHL, E. Bridging the gaps: An overview of wood across time and space in diverse rivers. **Geomorphology**, v. 279, p. 3–26, 2017. Disponível em: <https://linkinghub.elsevier.com/retrieve/pii/S0169555X16302082>.

WOHL, E.; BOLTON, S.; CADOL, D.; et al. A two end-member model of wood dynamics in headwater neotropical rivers. **Journal of Hydrology**, v. 462–463, p. 67–76, 2012.

WOHL, E.; CADOL, D.; PFEIFFER, A.; JACKSON, K.; LAUREL, D. Distribution of Large Wood Within River Corridors in Relation to Flow Regime in the Semiarid Western US. **Water Resources Research**, v. 54, n. 3, p. 1890–1904, 2018. Disponível em: <https://onlinelibrary.wiley.com/doi/10.1002/2017WR022009>.

WOHL, E.; KRAMER, N.; RUIZ-VILLANUEVA, V.; et al. The natural wood regime in rivers. **BioScience**, v. 69, n. 4, p. 259–273, 2019.

WOHL, E.; LININGER, K. B.; FOX, M.; BAILLIE, B. R.; ERSKINE, W. D. Instream large wood loads across bioclimatic regions. **Forest Ecology and Management**, v. 404, n. September, p. 370–380, 2017. Elsevier. Disponível em: <http://dx.doi.org/10.1016/j.foreco.2017.09.013>.

WOHL, E.; OGDEN, F. L.; GOODE, J. Episodic wood loading in a mountainous neotropical watershed. **Geomorphology**, v. 111, n. 3–4, p. 149–159, 2009.

WRIGHT, J. P.; FLECKER, A. S. Deforesting the riverscape: The effects of wood on fish diversity in a Venezuelan piedmont stream. **Biological Conservation**, v. 120, n. 3, p. 439–447, 2004.

ZABEL, R. A.; MORRELL, J. J. **Wood Microbiology: Decay and its Prevention**. San Diego: Academic Press, 1992.

SEGUNDA PARTE - ARTIGOS

ARTIGO I - *Wood stock in neotropical streams: quantifying and comparing in-stream wood among biomes and regions*

Sarah de Oliveira Saraiva; Ian Rutherfurd; Philip Robert Kaufmann; Cecília Gontijo Leal;
Diego Rodrigues Macedo; Paulo dos Santos Pompeu

(Manuscrito redigido na língua e formato indicado para revista - número de linhas foi retirado para melhor adequação ao formato da tese)

WOOD STOCK IN NEOTROPICAL STREAMS: QUANTIFYING AND COMPARING IN-STREAM WOOD AMONG BIOMES AND REGIONS

SARAIVA, S. O.[1], RUTHERFURD, I[2]., KAUFMANN[3], P. R., LEAL[4], C. G., MACEDO[5], D. R., POMPEU, P. S[1].*

[1] Departamento de Ecologia e Conservação, Instituto de Ciências Naturais, Universidade Federal de Lavras, Lavras - MG, Brazil, 37.200-900.
[2] School of Geography, Earth, and Atmospheric Sciences, The University of Melbourne, 221 Bouverie St, Carlton, 3010, Melbourne - VIC, Australia.
[3] U.S. Environmental Protection Agency, Office of Research and Development, Center for Public Health and Environmental Assessment, Pacific Ecological Systems Division, 200 SW 35th Street, Corvallis, OR, and Department of Fisheries, Wildlife and Conservation Sciences, Oregon State University, Corvallis, Oregon 97331, USA
[4] Escola Superior de Agricultura Luiz de Queiroz (ESALQ), Universidade de São Paulo, Piracicaba - SP, 13.418-900.
[5] Departamento de Biologia Geral, Universidade Federal de Minas Gerais, Belo Horizonte, Brazil, 31270-901.
** Corresponding author*

Abstract

In-stream wood plays important chemical, physical and ecological functions in aquatic systems, benefiting the biota directly and indirectly. However, human activities along river corridors have disrupted wood recruitment and retention leading to reduced in-stream wood amounts. In the tropics, where wood is assumed to be more transient, the expansion of agriculture and infrastructure might be reducing in-stream wood stock even more than in the better studied temperate streams. However, there is little information about wood in different biomes and ecosystems of neotropical streams, requiring research to comprise. Here we present the first extensive in-stream wood assessment in wet-tropical Amazon and semi-humid-tropical Cerrado (the Brazilian savanna) catchments, describing the in-stream wood loads and size distributions. We also compare neotropical wood stocks with those from temperate streams, first contrasting with literature data and then with a comparable dataset from USA temperate biomes. Contrary to our expectations Amazon and Cerrado streams had similar wood loads, which is lower than the world literature average, but similar to that found in comparable temperate forest and savanna streams in USA. Our results indicate that the field survey methods and the wood metric applied is highly important when comparing different datasets. But when properly proceeding the comparison, we detected that most of the wood in temperate streams is made-up of a small number of large pieces, whereas most wood in neotropical streams is a larger number of small pieces, producing the same total volume. The character of wood loads in biomes is linked more to the mechanisms behind it than to the total numbers. Future studies should further investigate the potential in-stream wood drivers in neotropical catchments in order to better understand the differences and similarities here detected between biomes and bioclimatic regions.

Keywords: wood assessment, riparian forest, Amazon streams, Cerrado streams, temperate streams

1. Introduction

The delivery of wood from forests to streams is a critical material flow between land and water (Wohl, 2013; Swanson *et al.*, 2020). Branches, logs and rootwads which fall from riparian forests affect chemical, physical and biological aspects of streams. The in-stream wood increases the sediment retention (Abbe & Montgomery, 1996; Wohl & Scott, 2017) and carbon storage (Wohl *et al.*, 2012b; Beckman & Wohl, 2014a; Sutfin *et al.*, 2016), changes the channel morphology (Abbe & Montgomery, 1996; Bilby & Bisson, 1998; Rosenfeld & Huato, 2003), provides hydraulic resistance (Montgomery *et al.*, 1999; Faustini & Jones, 2003; Kaufmann *et al.*, 2009) and affects the aquatic biota, directly, by providing food resources and shelter (Bisson *et al.*, 1987; Montgomery *et al.*, 1999; Power, 2003; Wright & Flecker, 2004; Frainer *et al.*, 2018; Leitão *et al.*, 2018) or, indirectly, by altering the physical habitat structure (Kaufmann & Hughes, 2006; Leal *et al.*, 2016; Macedo *et al.*, 2016).

Wohl et al (2019) defined the flux of wood in rivers as a ‘wood regime’. Human activities have transformed the wood regime in streams worldwide. Deforestation and degradation of riparian zones, compounded by channelization and loss of connectivity in streams and rivers, disrupt the supply and storage of wood, with consequences to the conservation of aquatic systems (Wohl *et al.*, 2019). The lower recruitment and retention rates result in an in-stream wood loads lower than those in pristine conditions (Wohl *et al.*, 2019). In the tropics, the expansion of agriculture and infrastructure development have certainly changed the natural wood regime (Betts *et al.*, 2021; Leal *et al.*, 2016; Pompeu & Yuhara, 2018). However, in-stream wood research has received far less attention in tropical than temperate regions, and the few localities studied do not represent the diversity of tropical biomes (Wohl, 2017).

The characteristics of each biome or bioclimatic region do affect the wood regime, since the amount of wood delivered to streams depends on the characteristics and proximity of forest, and the wood storage depends on the transport and decay rates (Lininger *et al.*, 2017; Wohl *et al.*, 2017, 2019). Therefore, it is important to study an extensive range of environments to really understand the natural and contemporary wood regime and its regional variation. Comparisons of in-stream wood between biomes have shown that the bioclimatic region is a critical factor in predicting wood dynamics in rivers (Wohl *et al.*, 2017), with the largest wood volumes occurring in sites with high primary productivity combined with limited decomposition rates and so slow wood turnover time (Lininger *et al.*, 2017). However, the former study is limited by comparing secondary data from different datasets and the second by analysing only temperate biomes.

The few studies that have measured in-stream wood in tropical biomes suggest that these streams have lower wood storage than temperate streams (Wohl, 2017). Higher rates of biological activity, wetter and warmer conditions mean that wood in tropical streams has a higher decay rate (Panshin *et al.*, 1964; Zabel & Morrell, 1992) so that it is more readily degraded and transported downstream (Wohl *et al.*, 2009, 2012a, Wohl, 2017). The higher transport capacity is a consequence of the high peak discharge per unit drainage area in the tropics (Wohl & Jaeger, 2009), but also of increasing decay through higher abrasion and breakage rates (Merten *et al.*, 2013). Nevertheless, wood in tropical streams still performs important physical and ecological functions (Power, 2003; Wright & Flecker, 2004; Paula *et al.*, 2011; Pettit *et al.*, 2013; Leal *et al.*, 2016; Leitão *et al.*, 2018).

The knowledge on wood loads in tropical biomes was built upon a restricted set of environments. These include the humid headwater streams in Central America and Southeast Asia (Gomi *et al.*, 2006; Cadol *et al.*, 2009; Cadol & Wohl, 2010; Wohl *et al.*, 2012a), streams in a semi-humid tropical region in Brazil (Paula *et al.*, 2011, 2013), large rivers in tropical wet-dry region of northern Australia (Pettit *et al.*, 2013) and in the semi-arid African savanna (Pettit & Naiman, 2005; Pettit *et al.*, 2005). To our knowledge, there is no published studies documenting the in-stream wood in the Amazon Forest, despite the fact that it is the largest tropical forest in the world. Neither has in-stream wood been studied in the wadeable streams from the South American savanna, locally known as Cerrado, which in Brazil occupies over two million km^2 (22% of the land area). Further aggravating the lack of information, Amazon and Cerrado have been experiencing high rates of deforestation in recent years, mainly triggered by the expansion of agriculture and livestock (Parente et al., 2021; Pereira et al., 2020; Silva-Jr. et al., 2021; Trigueiro et al., 2020).

Deforestation and degradation of riparian zones, aggravated by channelling and loss of connectivity in streams and rivers, interrupt wood supply and storage, resulting in lower wood loads than would be observed under reference conditions (Wohl et al., 2019). Studies evaluating the condition of aquatic habitats indicate a potential reduction in the availability of wood in tropical streams impacted by agriculture (Betts et al., 2021; Leal et al., 2016; Pompeu & Yuhara, 2018). Therefore, we may already have a disturbed wood regime in tropical streams, the contemporary wood regime warned by Wohl et al. (2019), even before knowing the natural regime.

Aiming to fill this knowledge gap, we present the results of the first extensive assessment of in-stream wood in Amazon and Cerrado biomes. Here we analyse an original dataset that includes 258 streams sampled with a standard methodology that allows the comparison between biomes and regions. Our objectives are to (i) assess in-stream wood stock in Amazon and Cerrado biomes across six different regions, (ii) describe channel and catchment characteristics of these neotropical streams which may influence wood load, (iii) provide an overview of the differences in wood stock across regions around the world especially in tropical ones, and (iv) compare the in-stream wood amounts from Brazilian neotropical biomes with those from comparable temperate biomes in USA. Based on these objectives we formulated two hypotheses: (H_1) Cerrado streams contain less and smaller in-stream wood than Amazon streams, because of the thinner and smaller trees of Cerrado riparian forests, the primary source of wood; (H_2) Tropical streams contain less in-stream wood than temperate streams, because of the potentiality higher transport and decay rates in tropical streams.

2. Methods

The wood data used in this study was part of a larger, systematic sampling study of Brazilian streams carried out using a standardised methodology developed by the USEPA and deployed across America (Hughes & Peck, 2008; USEPA, 2013; Junqueira *et al.*, 2016; Leal *et al.*, 2016; Betts *et al.*, 2021). Sample reaches were randomly selected and then observations were made during the dry season of instream wood, stream channel morphology, bed substrate, and adjacent riparian vegetation cover and structure.

2.1. Study area

We surveyed 258 reaches of wadeable streams (one site per stream) located in six different Brazilian regions (Figure 1, 2, Table 1), of which two are located in the Amazon Forest, and four in Cerrado (the Brazilian Savanna) (Table 2). The study regions are located in different river basins, and the Amazon ones include more than one basin within the region. The two Amazon regions are characterized by a mosaic of mechanized agriculture, extensive and intensive pastures, forestry (mainly exotic Eucalyptus spp. and *Schizolobium amazonicum*, especially in the region of Paragominas), densely populated colonies of small farms and land reform settlements, and large areas of undisturbed and disturbed primary and secondary forest

(Gardner *et al.*, 2013). The four Cerrado regions are subject to a high degree of anthropogenic influence mainly by agriculture and livestock, preserving only small fragments of native vegetation (Macedo *et al.*, 2014).

Table I-1 - Summary descriptions of the six study regions.

Region name	**Region Code**	**Biome**	**River Basin**	**Number of study sites**	**Region Area (Km²)**	**Forest cover (%)**
Paragominas	PGM	Amazon	Capim and Gurupi	51	19,342	69
Santarém	STM	Amazon	Curuá-Una, Tapajós and Amazonas	48	27,281	60
Nova Ponte	NP	Cerrado	Araguari	40	7,373	36
Três Marias	TM	Cerrado	São Francisco	40	12,816	45
Volta Grande	VG	Cerrado	Grande	40	3,428	12
São Simão	SS	Cerrado	Paranaíba	39	13,902	13

Table I-2 - Summary descriptions of the Brazilian study biomes.

Biome characteristic	**Amazon**	**Cerrado**
Climate	Tropical hot-humid	Tropical semi-humid
Annual precipitation average (mm/year)	2220	1437
Annual temperature average (°C)	25.9	23.7
Annual temperature range (°C)	12	18
Area (million km²)	6.3	2.0
Relative area of the Brazilian territory (%)	49	22

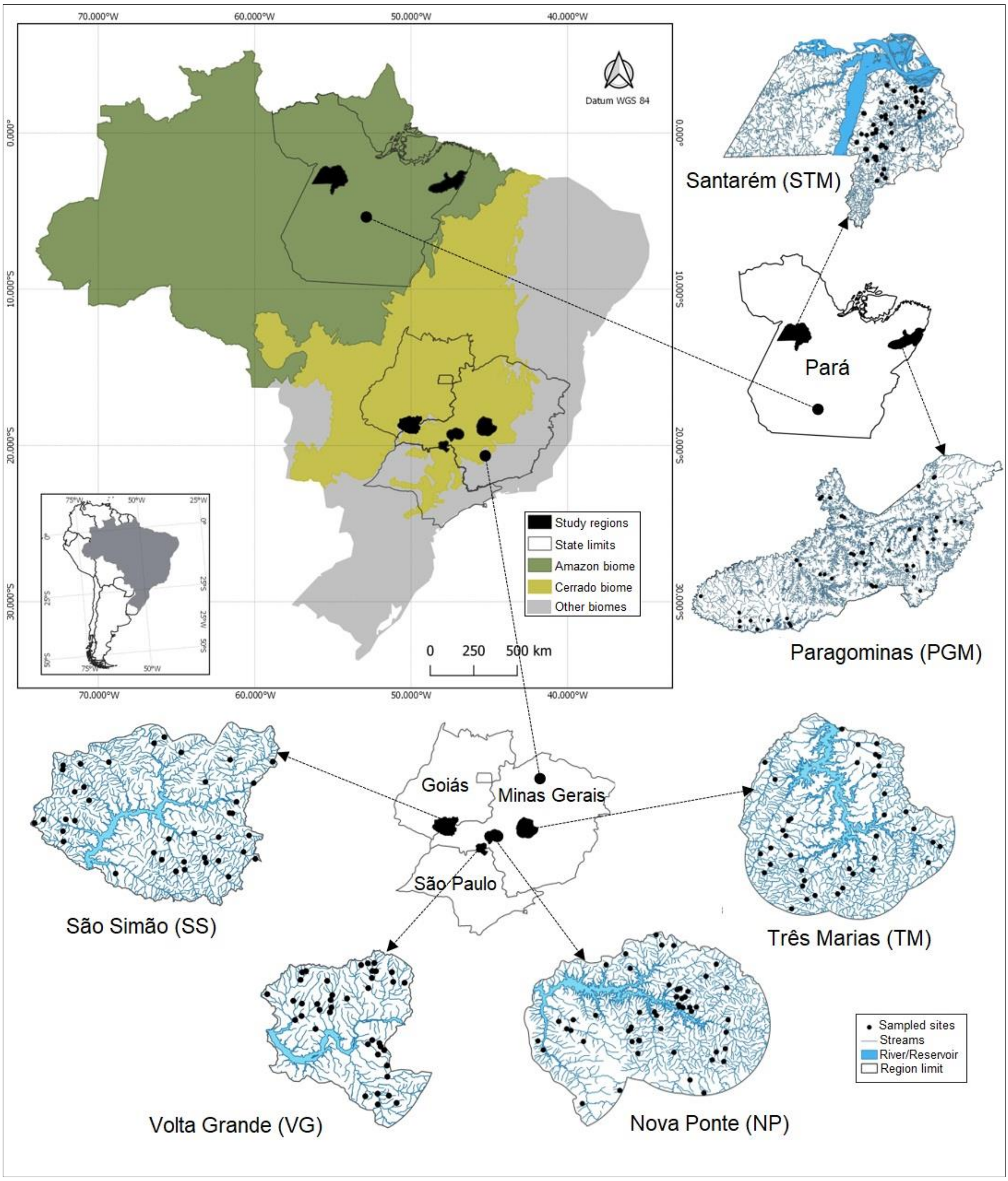


Figure I-1 - Location map of the study sample sites in six study regions across three biomes in Brazil.

Figure I-2 - Pictures of typical study streams located in Amazon and Cerrado biomes. One example of each study region is presented. (A) Paragominas- PGM (Amazon), (B) Santarém - STM (Amazon), (C) Nova Ponte - NP (Cerrado), (D) Três Marias - TM (Cerrado), (E) Volta Grande- VG (Cerrado) and (F) São Simão- SS (Cerrrado).

2.2. Data collection

In the Amazon biome we sampled 51 wadeable streams in Paragominas (PGM) and 48 in Santarém (STM), distributed over a gradient of forest cover as described in Gardner *et al.* (2013). In Cerrado we sampled 40 streams in Nova Ponte (NP), 40 in Três Marias (TM), 40 in Volta Grande (VG) and 39 in São Simão (SS). In each basin, we selected sample sites using a randomized, spatially balanced draw as described by Macedo *et al.* (2014). At each stream we sampled one reach, where field crews made systematic measurements and observations of wood, stream channel morphology, bed substrate, and riparian vegetation cover and structure during the dry season, using a USEPA methodology (Hughes & Peck, 2008; USEPA, 2013).

The sample reach length at each site was set proportional to the stream mean wetted width (40 times the mean width), with a minimum of 150 m. All large wood pieces (LW) were counted along each reach. A LW piece was defined as being inside the bankfull channel with a length ≥1.5 m and diameter ≥0.1 m at the small end (note, if small end diameter was <0.1m, the wood piece was defined as the length between large end and the point where the diameter=0.1m). To calculate wood volume, each piece was categorised into one of five size classes (T = tiny, S = small, M = medium, L = large, X = extra-large). A nominal mean volume was calculated for each piece of LW according to its diameter-length class membership (Equation 1), such the intermediate classes (S, M and L) are composed by three nominal means each (Kaufmann *et al.*, 1999) (Table 3).

$$Volume = \pi\left[0.5\left(minDiam + \left(\frac{maxDiam - minDiam}{3}\right)\right)\right]^2\left[minLength + \left(\frac{maxLength - minLength}{3}\right)\right]$$

(Equation 1)

Table I-3 - The twelve wood size classes described according to length and diameter and their respective mean nominal volume calculated from Equation 1.

Diameter	**Length**		
	1.5 - 5 m	> 5 - 15 m	> 15 m
0.1 - 0.3 m	**T** = 0.058	$\mathbf{S_3}$ = 0.182	$\mathbf{M_3}$ = 0.438
> 0.3 m - 0.6 m	$\mathbf{S_1}$= 0.333	$\mathbf{M_2}$ = 1.042	$\mathbf{L_3}$ = 2.501
> 0.6 m - 0.8 m	$\mathbf{S_2}$ = 0.932	$\mathbf{L_1}$ = 2.911	$\mathbf{L_4}$ = 6.988
> 0.8 m	$\mathbf{M_1}$ = 3.016	$\mathbf{L_2}$ = 9.421	**X** = 22.62

T (tiny); $S = S_1 + S_2 + S_3$ (small); $M = M_1 + M_2 + M_3$ (medium); $L = L_1 + L_2 + L_3$ (large); X (extra-large)

Besides LW, we also measured multiple variables that may influence wood storage. Still following USEPA methods, we measured channel morphology (including bankfull[2] width and height, thalweg depth, slope, sinuosity), bed material (bedrock, concrete, boulder, cobble, coarse gravel, fine gravel, sand, silt and clay, hardpan, fine litter, coarse litter, wood, roots, macrophyte or algae) and riparian vegetation. The riparian vegetation measure consists of a visual estimation of the areal cover of each one of the three vegetation layers (canopy, understory, and ground cover) located on both banks within a 10-meter field of view. The maximum cover in each layer is 100%, so the sum of the areal covers for the combined three layers could add up to 300% (USEPA, 2013). Because we are interested in the riparian forest as a source of LW, we only considered the woody riparian vegetation (XCMGW), excluding

---

[2] The bankfull channel corresponds to the seasonal bed area which is flooded during the annual rainy season.

herbs, grasses and non-woody shrubs. There are no stream gauges in any of the sampled catchments, so we measured discharge at the time of sampling (during the low flow season) by the floating object technique and also estimated bankfull discharge using a slope-area method of Kaufmann *et al.* (2008) and Kaufmann *et al.* (2009). The complete list of measured variables may be consulted in the supplementary material (S1) and the detailed methods in Hughes & Peck (2008) and USEPA (2013).

We delimited the catchment area upstream of each sample site from digital elevation models (DEMs) with 30 m resolution for NP, TM, VG, SS and PGM regions (generated using TopoData-IBGE; Valeriano & Rossetti, 2012), and 90 m resolution for STM region (SRTM-NASA; Jarvis *et al.*, 2008). We obtained the drainage network for Cerrado regions from a national database, with data available per municipality (spatial resolution 1:25,000; FBDS, 2009). For the Amazon regions, the drainage network map was constructed using the hydrological model ArcSWAT (Di Luzio *et al.*, 2004) with subsequent manual correction. We used satellite images (Landsat TM and ETM+ images, 30 m resolution, year 2010) to map land use and quantify the native vegetation cover that includes mature[3] and young[4] forest and different types of savanna (woodland savanna, parkland savanna, grassy-woody savanna, and palm swamp). Despite the different types of native vegetation in each biome, here we refer to all of them as forest to facilitate understanding and comparisons. We considered forest cover at three spatial scales relevant to wood stock: (i) forest in the whole catchment upstream of the site (catchment forest cover); (ii) riparian forest upstream of the site within a 100 m wide buffer along the stream network (network riparian forest cover); (iii) riparian forest within a 100 m buffer along the sample reach site (local riparian forest cover). The spatial data were processed in geographic information systems (ArcMap 10.5 and QGis 3.4).

2.3. Data analysis

From field measurements we obtained LW counts and volume per size class for each stream. To allow proportional comparisons among different streams we calculated four in-stream wood metrics: two scaled by channel length [abundance (number of pieces) and volume (m^3) per 100 m (C1W_100, V1W_100)], and two scaled by bankfull channel surface area

---

[3] Mature forest = primary (never deforested areas) + degraded (areas under selective logging) + old secondary forest (areas under regeneration with more than 10 years since the last deforestation event).

[4] Young forest = secondary growth forest (areas under regeneration process with less than 10 years since the last deforestation event.

[abundance (pieces) and volume (m³) per 100m² (C1W_100MSQ, V1W_100MSQ)]. We grouped streams according to regions and biomes. To test our first hypothesis, we compared average wood loads and dimensions applying analysis of variance (ANOVA) and Tukey's test (Harris, 2001). We compared regions according to the forest cover and to the visual evaluation metric, using ANOVA followed by post-hoc Tukey's test. When necessary non-normally distributed data were log transformed.

To understand our results in a global framework we made a literature review and compared our results with other studies around the world. Considering each study average, we ranked the wood load assessments according to the biome analysed. Because there is no consensus about the metric used to represent wood load, we selected the three most adopted metrics in the consulted papers (wood pieces and volume per 100 m and volume per 100m²) and built one rank for each one. We made further comparisons adopting the volume per channel area (m³/100m²) as the main wood load metric and tested average differences between our and other three tropical wood assessments. We also compared the streams and catchments characteristics between studies, always transforming non-normal distributed data.

Finally, to test the second hypothesis, we compared our data with another dataset provided by the USEPA National Aquatic Resource Surveys (USEPA 2016b, 2020), which contains information from 2,502 streams sampled in nine ecoregions across the USA using the same field sampling protocol as ours, allowing direct statistical comparisons. To facilitate comparison between tropical and temperate regions we assigned each U.S. ecoregion to the world biomes classification, applying the same criteria as the one used by Trimble and van Aarde (2012). The USA regions were classified in four categories of the world biomes (Table 4) and the tropical regions, until now assigned as Amazon and Cerrado biomes, were now classified as Tropical Moist Forest and Tropical and Subtropical Grasslands, Savannas and Shrublands respectively. In the comparison between datasets, we considered the four in-stream wood metrics (C1W_100MSQ, V1W_100MSQ, C1W_100, V1W_100) and performed ANOVA followed by post-hoc Tukey's test, always log transforming the non-normal distributed response variables.

Table I-4 - Summary description of the USA ecoregions (USEPA 2016a).

Ecoregion	Code	Description	World Biome
Western Mountains	WMT	Extensive high mountain ranges and plateaus separated by wide valleys and lowlands. Sub-arid to arid and mild in southern lower valleys; humid and cold at higher	Temperate Coniferous Forest

		elevations. The wettest climates of North America occur in the coastal rain forests of this region. Forests dominated by coniferous trees, but broadleaf deciduous trees common in riparian areas.	
Coastal Plains	CPL	Temperate wet to subtropical plains and wetlands, forests dominated by coniferous trees. Includes extensive wetlands and flooded forests.	Temperate Coniferous Forest
Northern Appalachian Mountains	NAP	Hilly to mountainous terrain with cold to temperate, mesic climate. Largely forested uplands dominated by broadleaf deciduous trees.	Broadleaf Deciduous Forest
Southern Appalachian Mountains	SAP	Temperate, wet, largely forested uplands dominated by broadleaf deciduous trees	Broadleaf Deciduous Forest
Upper Midwest	UMW	Cool-temperate mesic climate with cold winters and short warm summers. Glaciated plains and uplands with mixed boreal woodlands of broadleaf and coniferous trees, including flooded forests	Broadleaf Deciduous Forest
Southern Plains	SPL	Smooth and irregular plains with low hills and tablelands. Dry temperate climate. Originally perennial tall-grass and short grass prairie, with short-grass prairie in the north and savanna in the south	Temperate grasslands savannas and shrublands
Northern Plains	NPL	Irregular plains, dry continental climate, with short hot summers and cold winters. Originally prairie grasslands, now extensively grazed or cultivated, trees are sparse.	Temperate grasslands savannas and shrublands
Temperate plains	TPL	Temperate, mesic climate with cold winters and hot, humid summers. Smooth plains originally perennial tall-grass prairie are now extensively cultivated. Wetter climate than SPL or NPL. The eastern part was originally broadleaf deciduous forests replaced by cropland.	Temperate grasslands savannas and shrublands
Xeric lands	XER	Mix of plains, with hills, low mountains, high-relief tablelands, piedmont, high mountains, and intermountain basins and valleys. climate varies widely from warm and dry to temperate, and from very dry to mesic. Sparse vegetation due to water shortage. Stream in the Xeric region are primarily in the mountains and are considerably	Deserts and xeric shrublands

	wetter than the desert lowlands, and generally have wooded riparian areas.	

3. Results

3.1. Amazon vs. Cerrado in-stream wood

3.1.1. Measures of tropical in-stream wood

A total of 8,495 wood pieces were counted in 258 sampled streams representing a volume of 1762 m^3. The average number and volume per 100 m of channel was 20.8 and 4.21 respectively, and the average volume per 100 m^2 of channel was 3.9 and 0.86 m^3 respectively with great variability among streams. The diameter and length of pieces were remarkably similar among the six studied regions, being approximately 4 m in length and 0.25 m diameter. Relative to channel dimensions, we observed the smallest LW length average in STM (LW length/channel width = 0.42) and the largest in TM (LW length/channel width = 0.91). The ratio between LW diameter and channel depth was similar in all regions, ranging from 0.18 in NP to 0.31 in STM (see supplementary material S2). When analysing LW abundance and volume per channel length we did not observed any differences among regions (ANOVA: F(5, 252) = 2.09, p = 0.06; F(5, 252) = 0.72, p = 0.61) (Figure 3b, d), whereas when analysing according to channel area, STM region presented the lowest averages (Figure 3a, c) (ANOVA: F(5, 252) = 3.56, p = 0.004; F(5, 252) = 3.49, p = 0.004). Despite the wood storage average being similar among regions, there was a great variability within all regions (see supplementary material S2).

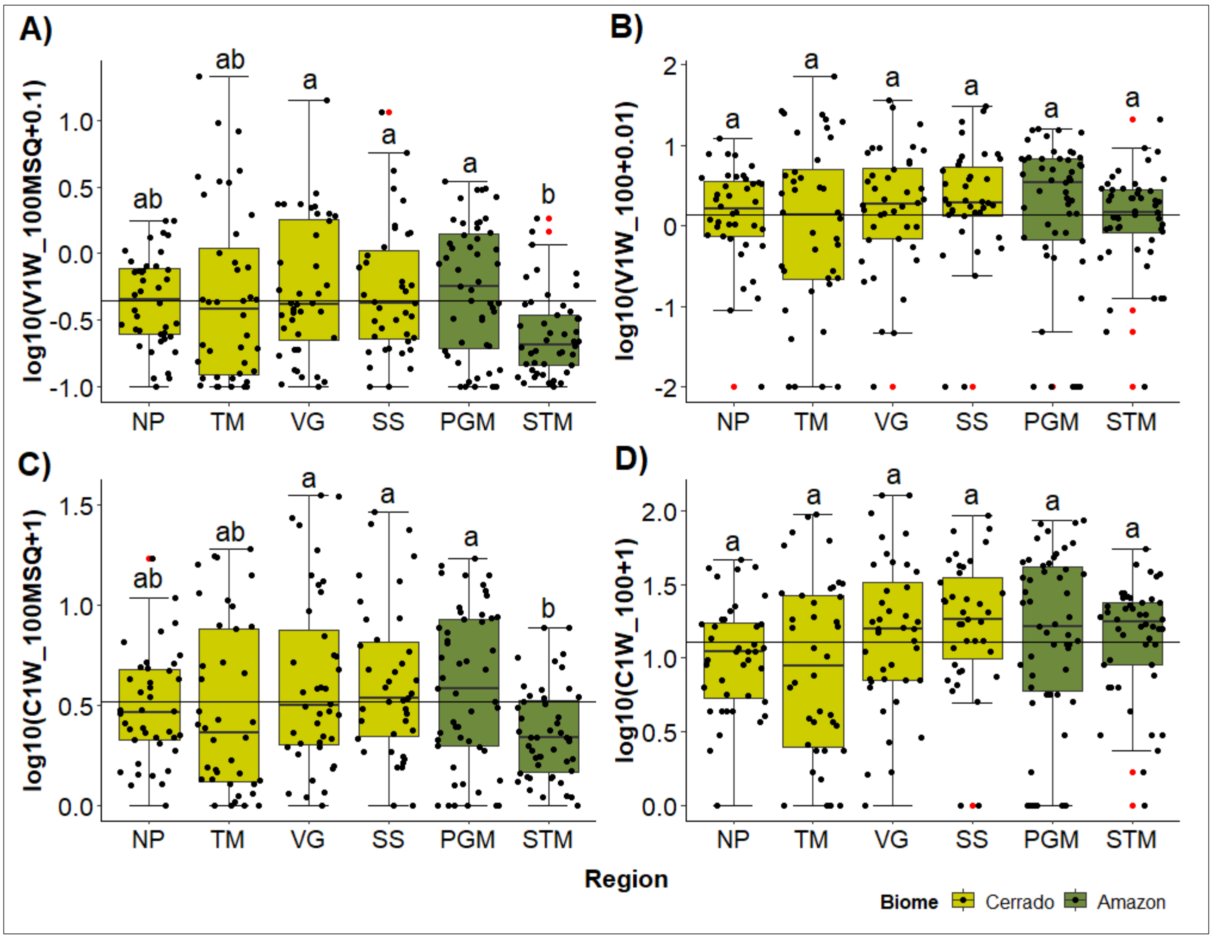
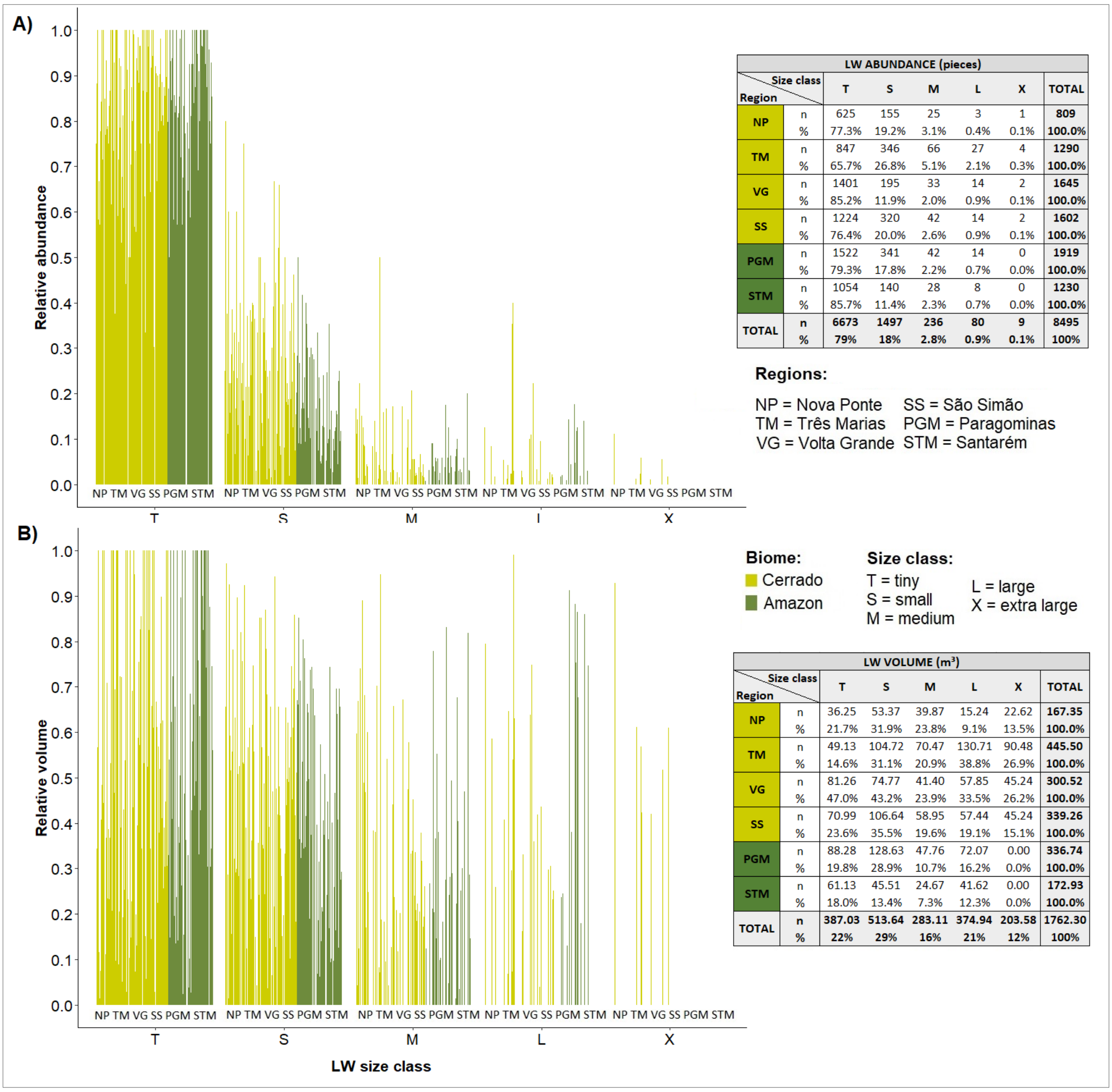


Figure I-3 - Large wood (LW) volume per 100 m² - V1W_100MSQ (A), LW volume per 100 m (V1W_100) (B), LW pieces per 100 m² (C1W_100MSQ) (C), and LW pieces per 100 m (C1W_100) (D), all metrics in logarithmic scale for the six studied regions. The line crossing the chart represents the mean for all regions. In the boxplots the line represents the median, the box is the first (25%) and the third (75%) quartiles, the whiskers extend to the most extreme data point which is no more than 1.5 times the length of the box away from the box, the red dots are the outliers defined by the '1.5 rule'[5], the black dots show the values of each stream. The colours in the boxes indicate the biome where each region is located. Different letters next to whiskers indicate which groups differed in post–hoc comparisons (Tukey's test).

Wood stock in all streams was dominated by pieces classified as 'tiny' and 'small' (96.2%). Amazon streams did not contain any 'extra-large' pieces, and the proportion of 'large' pieces was low and similar in Amazon (0.7%) and in Cerrado streams (1.0%) (Figure 4a). Despite being few (only 1.0% of the pieces), 'large' and 'extra-large' pieces contributed disproportionately to the volume of wood, representing 33%. Nonetheless, 'tiny' and 'small' pieces are the overwhelming majority of in-stream LW (97%) and provide most of the wood volume (51%) (Figure 4b).

---

[5] Outlier is a data point lesser than Q_1 - 1.5*(Q_3-Q_1) or greater than Q_3 + 1.5*(Q_3-Q_1), where Q_1 = the first quartile and Q_3 = the third quartile.



LW ABUNDANCE (pieces)

Region \ Size class		T	S	M	L	X	TOTAL
NP	n	625	155	25	3	1	**809**
	%	77.3%	19.2%	3.1%	0.4%	0.1%	**100.0%**
TM	n	847	346	66	27	4	**1290**
	%	65.7%	26.8%	5.1%	2.1%	0.3%	**100.0%**
VG	n	1401	195	33	14	2	**1645**
	%	85.2%	11.9%	2.0%	0.9%	0.1%	**100.0%**
SS	n	1224	320	42	14	2	**1602**
	%	76.4%	20.0%	2.6%	0.9%	0.1%	**100.0%**
PGM	n	1522	341	42	14	0	**1919**
	%	79.3%	17.8%	2.2%	0.7%	0.0%	**100.0%**
STM	n	1054	140	28	8	0	**1230**
	%	85.7%	11.4%	2.3%	0.7%	0.0%	**100.0%**
TOTAL	n	**6673**	**1497**	**236**	**80**	**9**	**8495**
	%	**79%**	**18%**	**2.8%**	**0.9%**	**0.1%**	**100%**

LW VOLUME (m^3)

Region \ Size class		T	S	M	L	X	TOTAL
NP	n	36.25	53.37	39.87	15.24	22.62	**167.35**
	%	21.7%	31.9%	23.8%	9.1%	13.5%	**100.0%**
TM	n	49.13	104.72	70.47	130.71	90.48	**445.50**
	%	14.6%	31.1%	20.9%	38.8%	26.9%	**100.0%**
VG	n	81.26	74.77	41.40	57.85	45.24	**300.52**
	%	47.0%	43.2%	23.9%	33.5%	26.2%	**100.0%**
SS	n	70.99	106.64	58.95	57.44	45.24	**339.26**
	%	23.6%	35.5%	19.6%	19.1%	15.1%	**100.0%**
PGM	n	88.28	128.63	47.76	72.07	0.00	**336.74**
	%	19.8%	28.9%	10.7%	16.2%	0.0%	**100.0%**
STM	n	61.13	45.51	24.67	41.62	0.00	**172.93**
	%	18.0%	13.4%	7.3%	12.3%	0.0%	**100.0%**
TOTAL	n	**387.03**	**513.64**	**283.11**	**374.94**	**203.58**	**1762.30**
	%	**22%**	**29%**	**16%**	**21%**	**12%**	**100%**

Figure I-4 - Diagrams of relative abundance (A) and volume (B) per size class in each site. Regions are indicated by letters and biomes by colours.

3.1.2. Catchments and channels characteristics

Amazon and Cerrado catchments had similar mean slope among all regions, but catchment area varied greatly, from 0.4 to 227 km² and the bankfull width from less than 1 m to more than 100 m (see supplementary material S3). Três Marias (TM) is the region with larger catchments (45.2 km² on average) and NP with the smaller ones (10.7 km²), while the Amazon catchments present intermediate values. Channel morphology was similar among regions within biomes whereas differed greatly between the two biomes. Amazon streams, especially in STM, had wider and shallower bankfull channels, reflecting lower bankfull discharges.

Amazon streams had lower gradients resulting in weak stream power, and few riffles, rapids or waterfalls. Whereas in Cerrado, slope was twice greater and stream power six times greater and both variables were more heterogeneous among streams, which suggests a higher capacity for wood transport than in the Amazon streams. Bed texture differed markedly between the two biomes (supplementary material S3). Amazon streams had small grain size with low variation, with streambeds predominantly composed of sand and silt. On the other hand, Cerrado streams showed a large variety of substrates among streams including bedrock (> 4,000 mm), boulders (250 - 4,000 mm), cobble (64 – 250 mm), coarse gravel (16 - 64 mm), fine gravel (2 - 16 mm), sand (0.06 - 2 mm), and silt (< 0.06 mm).

The catchment and network riparian forest cover in Amazon streams averaged 80 to 90%, compared with 10 to 60% for Cerrado streams (Figure 5a-b, supplementary material S3). Greater variation in riparian tree cover immediately bordering streams (Fig 5c-d) reduces the distinction among regions and biomes (Figure 4c-d). Thus, despite Cerrado streams having few forest remnants in their catchments, they nonetheless have some riparian forest along their banks. However, the riparian forests in Cerrado streams must be narrow (narrower than the resolution limit of the remote imagery, that is 30 m) since they were still lower than the Amazon in the 100 m buffer estimate (except by TM), but equal in the visual evaluation to PGM.

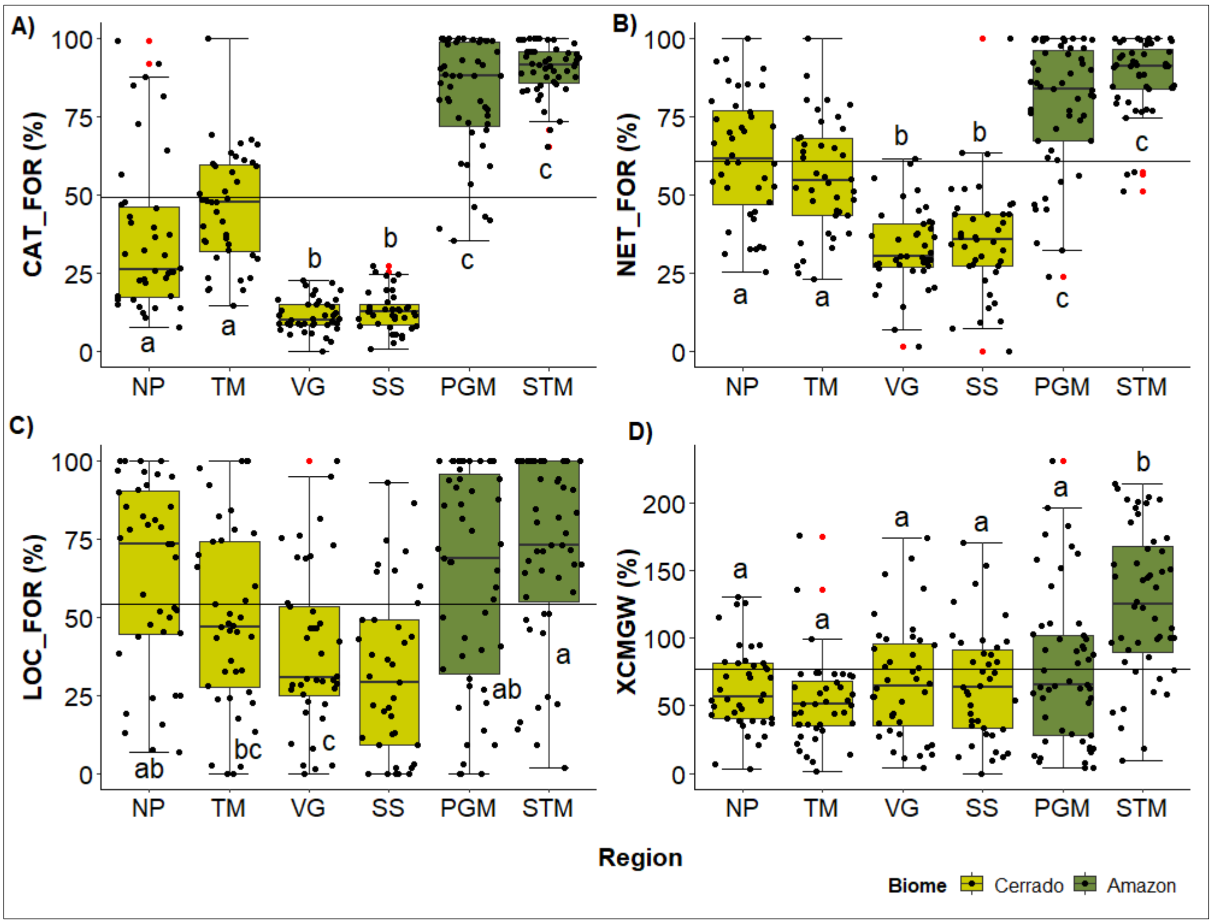


Figure I-5 - Catchment forest cover (CAT_FOR) (A), riparian forest cover in the upstream network within 100m buffer (NET_FOR) (B), riparian local forest cover along the sampled reach within 100m buffer (LOC_FOR) (C), and visual evaluation of the woody riparian forest (XCMGW) (D) per each study region. The line crossing the chart represents the mean for all regions. In the boxplots the line represents the median, the box is the first (25%) and the third (75%) quartiles, the whiskers extend to the most extreme data point which is no more than 1.5 times the length of the box away from the box, the red dots are the outliers defined by the '1.5 rule', the black dots show the values of each stream. The colours in the boxes indicate the biome where each region is located. Different letters next to whiskers indicate which groups differed in post–hoc comparisons (Tukey's test)

3.2. Brazil streams vs. other temperate and tropical streams in the literature

Our in-stream wood amounts are below the average when we consider studies around all the word (Figure 6a). When we rank 23 studies according LW abundance per channel length and LW volume per channel area our study occupies the 11th position and the 9th position when considering the volume of wood per channel length (Figure 7) (see supplementary material S4 for more details). Only considering the tropical biomes, we compared our results with three others performed in similar biomes as ours: Cadol *et al.* (2009) in a Tropical Rainforest area in Costa Rica, Paula *et al.* (2013) in a transition area between the Brazilian biomes Cerrado and Atlantic Forest, and Pettit *et al.* 2005 in a Savanna River in South Africa. Our wood volume per channel area average was lower than the Costa Rica study (even the Amazon ones), higher than the other Brazilian study and similar to the South Africa one (Figure 6b). When we compared only our most forested streams (considering a forest cover higher than 80%), both Amazon regions still present lower wood volume average than Costa Rica streams (ANOVA: F(2, 92) = 118.35; p<0.01). When we compared our forest cover data with those from Paula *et al.* (2013), we found that our catchments present similar or less forest amounts than theirs (ANOVA: F(4, 172) = 20.1949, p < 0.01). We also compared the ratio of LW piece and channel dimensions from Cerrado streams with those from Paula *et al.* (2013), and they had higher value both to LW length/channel width and LW diameter/channel depth (Kruskal-Wallis test: LW length/channel width: H(4, 163) = 14.84 , p < 0.01; LW diameter/channel depth: H(4, 164) = 38.74 , p < 0.01).

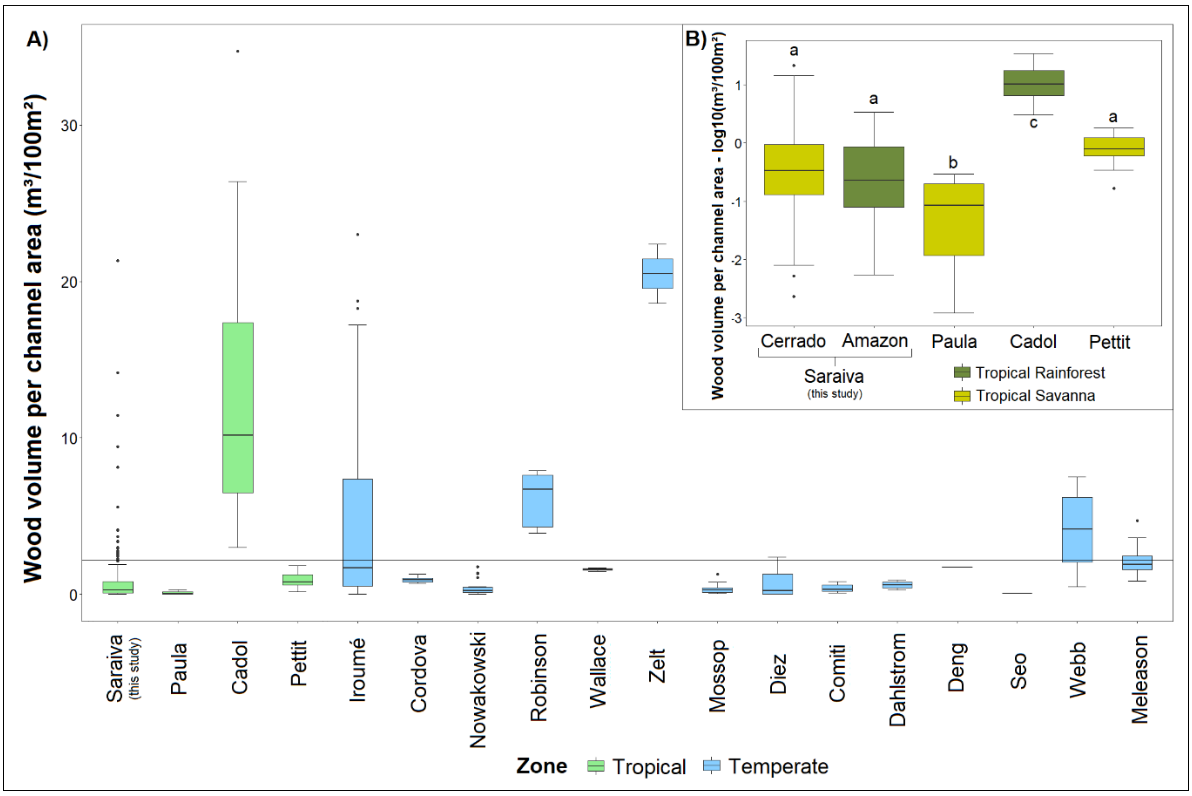


Figure I-6 - (A) In-stream wood volume averages in other studies available in the world literature, (B) In-stream wood volume averages in the tropical zone. Each study is indicated by the name of the first author. In the boxplots the line represents the median, the box is the first (25%) and the third (75%) quartiles, the whiskers extend to the most extreme data point which is no more than 1.5 times the length of the box away from the box, and the black dots are the outliers defined by the '1.5 rule'. The box colour indicates the regions where the study is located (the climatic zone in A and the tropical biome in B). Different letters above the whiskers indicate significant mean difference according post-hoc Tukey test.

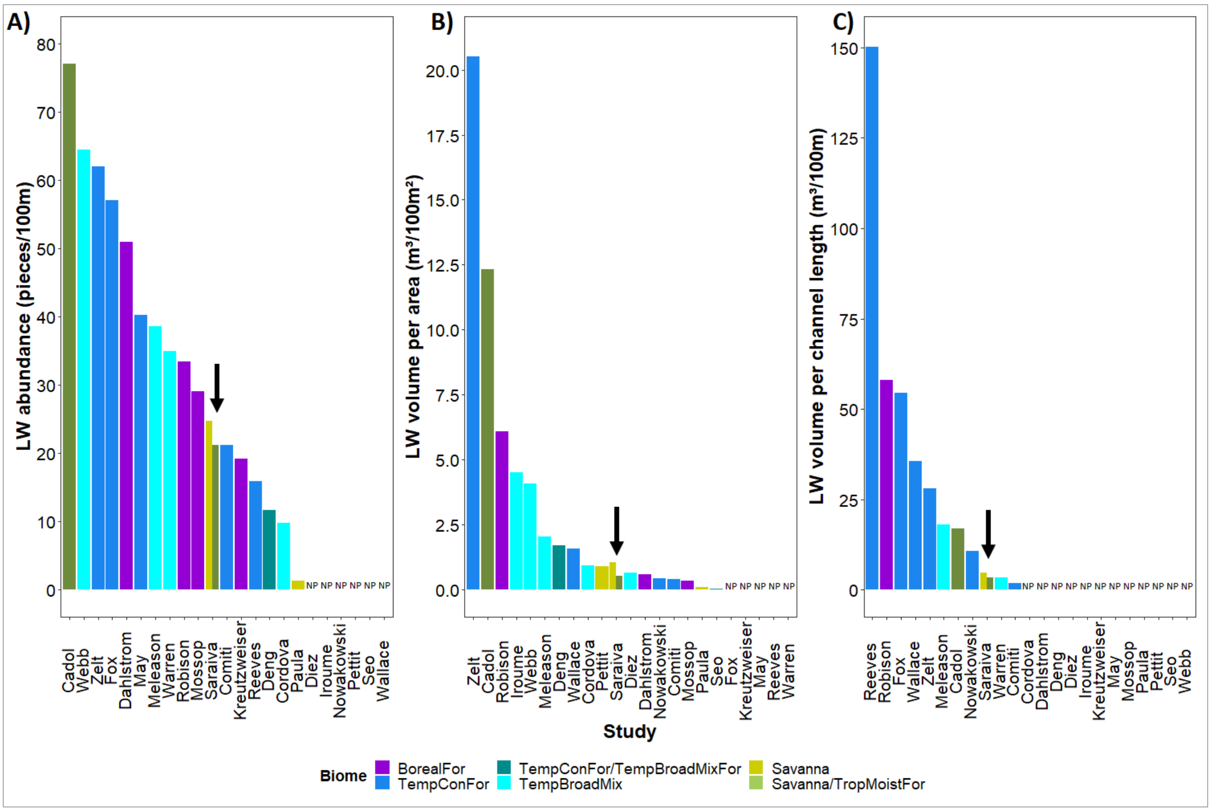


Figure I-7 - Rank of in-stream wood abundance per channel length (A), in-stream volume per channel area (B) and per channel length (C) around the world. Each colour represents a world biome. The arrow points out to the present study.

3.3. Tropical vs. temperate in-stream wood (using the same methods)

We have contrasted our results with those documented in the literature, but the differences in methods survey limits the interpretation of the differences detected. So, we now direct compare the wood stock between tropical and temperate streams by using comparable datasets obtained by the application of the same filed survey protocol. When comparing Brazil and USA LW volume per channel area (V1W_100MSQ), streams in tropical forests (i.e. Tropical Moist Forest regions - PGM, STM) contain similar amounts of wood to those in temperate forests (i.e. Temperate Coniferous Forest regions - WMT, CPL, and Broadleaf Deciduous Forest regions - NAP, SAP, UMW) (Figure 8a). However, streams in Brazilian tropical savanna (Tropical and Subtropical Grasslands, Savannas and Shrublands = Cerrado - NP, TM, VG, SS) have more in-stream wood than in the USA xeric region (Deserts and Xeric Shrublands - XER) and two of their temperate savanna regions (Temperate Grasslands, Savannas and Shrublands - SPL, NPL), but in similar quantities to USA temperate plains (TPL) and temperate forests. When considering the wood volume per channel length (V1W_100) temperate forest regions tend to contain more in-stream wood than tropical forests (Figure 8b), and the temperate savanna almost equal the tropical savanna stock. It is interesting to note that the volume of wood in STM region is more similar to the temperate savanna regions than to the tropical savanna or temperate forest regions.

When considering the LW abundance per channel area (Figure 8c) tropical regions tend to contain more pieces, with tropical savanna regions (NP, TM, VG, SS) having higher values than temperate savanna regions (SPL, NPL, TPL) and xeric lands (XER). Tropical forests (PGM, STM) have higher or similar wood amounts than temperate forest regions (WMT, CPL, NAP, SP, UMW). When scaling LW abundance per channel length (Figure 8d), temperate wood numbers approach the tropical ones, but are still lower. The temperate savanna and xeric regions of the US contained the lowest LW abundance of all regions. In contrast to wood volume, STM (tropical forest) wood abundance was significantly higher than temperate savanna and xeric regions.

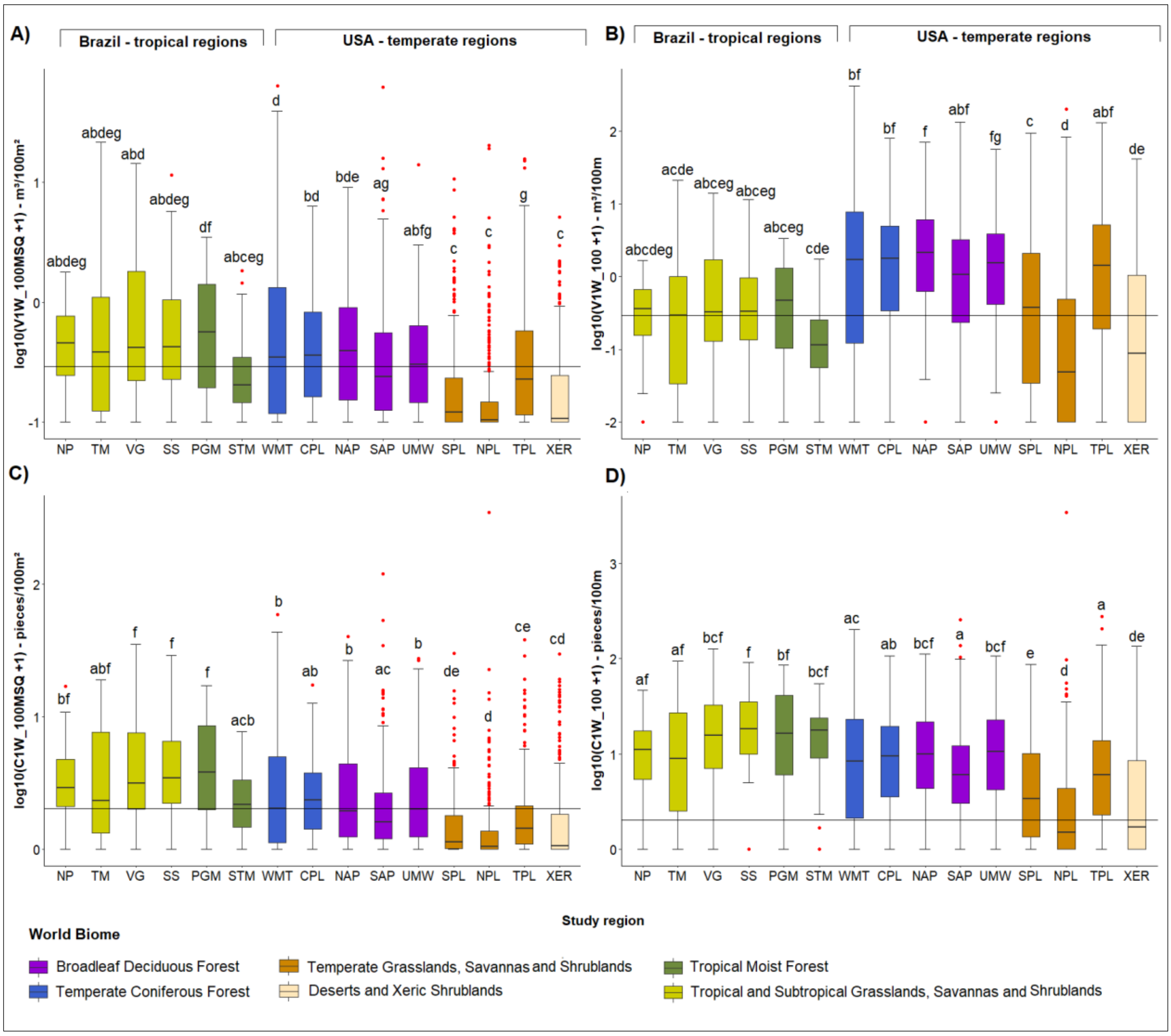
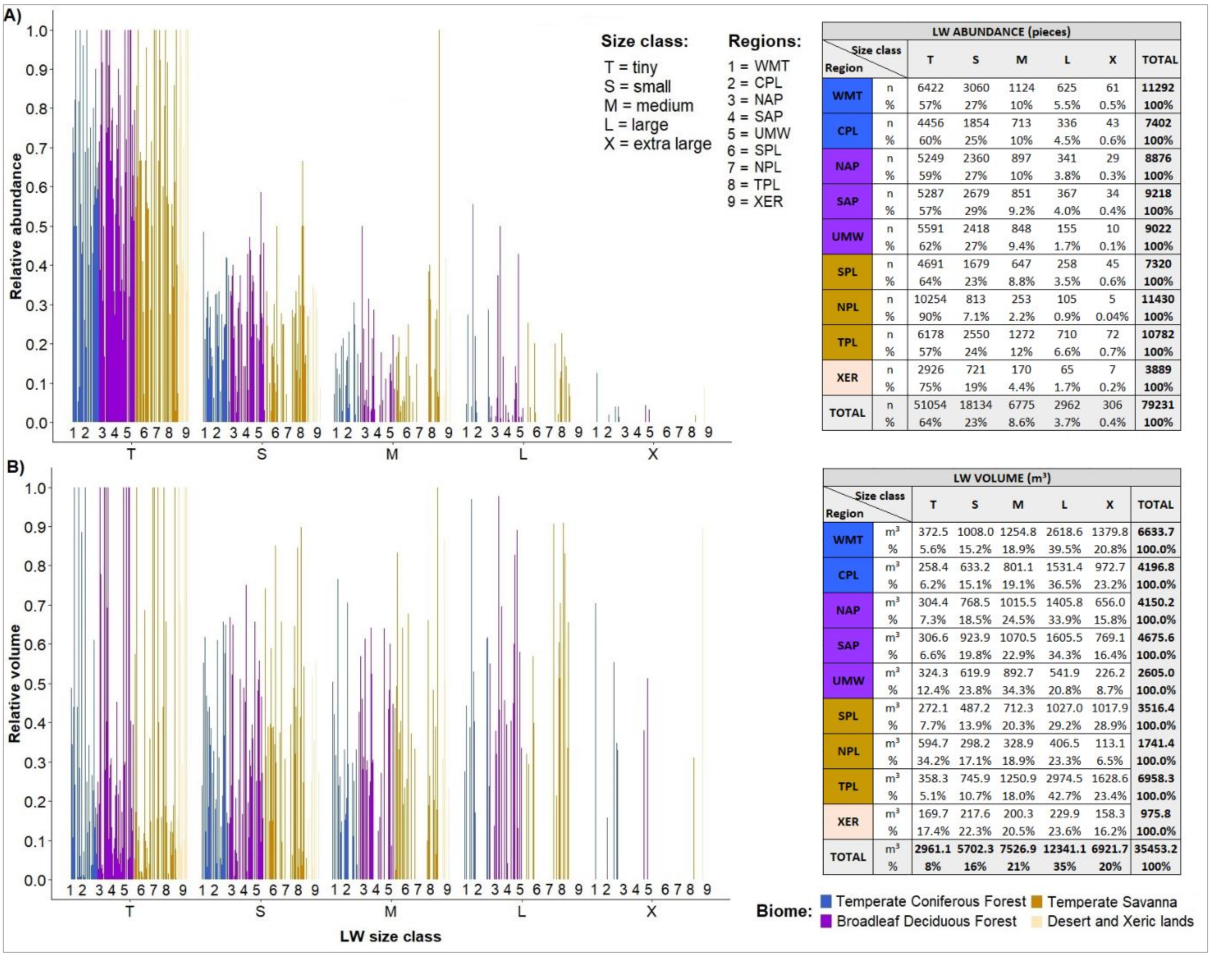


Figure I-8 - Large wood (LW) volume per 100 m² (V1W_100MSQ) (A), LW volume per 100 m (V1W_100) (B), LW pieces per 100 m² (C1W_100MSQ) (C) and LW pieces per 100 m (C1W_100)

(D) in logarithmic scale for Brazil and USA regions. The line crossing the chart represents the mean for all regions. In the boxplots the line represents the median, the box is the first (25%) and the third (75%) quartiles, the whiskers extend to the most extreme data point which is no more than 1.5 times the length of the box away from the box, the red dots are the outliers defined by the '1.5 rule'. The colours in the boxes indicate the biome where each region is located. Different letters next to whiskers indicate which groups differed in post–hoc comparisons (Tukey's test).

Temperate and tropical regions differed in terms of LW size (Figure 4 and 9). Similarly, to tropical streams, 'tiny' and 'small' pieces were dominant in temperate streams (T = 64%, S = 23%), but the lower LW volume averages in the small size classes (T = 8, S = 16%) indicate that the temperate streams have less small wood pieces than the tropical ones. This becomes more evident when adding this result with the previous one (Figure 8c, d) that showed that temperate streams tend to have less LW pieces. The large pieces (i.e. 'extra-large', 'large' and 'medium') were more frequent in temperate (X = 20%, L = 35%, M = 21%) than tropical systems. The lowest LW volume were in the NPL and XER regions and were associated with a predominance of 'tiny' wood pieces (T = 90% and 75% respectively) and scarcity of 'large' and 'extra-large' LW (L = 0.9% and 1.7%, X = 0.04% and 0.2%).



LW ABUNDANCE (pieces)

Region \ Size class		T	S	M	L	X	TOTAL
WMT	n	6422	3060	1124	625	61	**11292**
	%	57%	27%	10%	5.5%	0.5%	**100%**
CPL	n	4456	1854	713	336	43	**7402**
	%	60%	25%	10%	4.5%	0.6%	**100%**
NAP	n	5249	2360	897	341	29	**8876**
	%	59%	27%	10%	3.8%	0.3%	**100%**
SAP	n	5287	2679	851	367	34	**9218**
	%	57%	29%	9.2%	4.0%	0.4%	**100%**
UMW	n	5591	2418	848	155	10	**9022**
	%	62%	27%	9.4%	1.7%	0.1%	**100%**
SPL	n	4691	1679	647	258	45	**7320**
	%	64%	23%	8.8%	3.5%	0.6%	**100%**
NPL	n	10254	813	253	105	5	**11430**
	%	90%	7.1%	2.2%	0.9%	0.04%	**100%**
TPL	n	6178	2550	1272	710	72	**10782**
	%	57%	24%	12%	6.6%	0.7%	**100%**
XER	n	2926	721	170	65	7	**3889**
	%	75%	19%	4.4%	1.7%	0.2%	**100%**
TOTAL	n	51054	18134	6775	2962	306	**79231**
	%	64%	23%	8.6%	3.7%	0.4%	**100%**

LW VOLUME (m^3)

Region \ Size class		T	S	M	L	X	TOTAL
WMT	m^3	372.5	1008.0	1254.8	2618.6	1379.8	**6633.7**
	%	5.6%	15.2%	18.9%	39.5%	20.8%	**100.0%**
CPL	m^3	258.4	633.2	801.1	1531.4	972.7	**4196.8**
	%	6.2%	15.1%	19.1%	36.5%	23.2%	**100.0%**
NAP	m^3	304.4	768.5	1015.5	1405.8	656.0	**4150.2**
	%	7.3%	18.5%	24.5%	33.9%	15.8%	**100.0%**
SAP	m^3	306.6	923.9	1070.5	1605.5	769.1	**4675.6**
	%	6.6%	19.8%	22.9%	34.3%	16.4%	**100.0%**
UMW	m^3	324.3	619.9	892.7	541.9	226.2	**2605.0**
	%	12.4%	23.8%	34.3%	20.8%	8.7%	**100.0%**
SPL	m^3	272.1	487.2	712.3	1027.0	1017.9	**3516.4**
	%	7.7%	13.9%	20.3%	29.2%	28.9%	**100.0%**
NPL	m^3	594.7	298.2	328.9	406.5	113.1	**1741.4**
	%	34.2%	17.1%	18.9%	23.3%	6.5%	**100.0%**
TPL	m^3	358.3	745.9	1250.9	2974.5	1628.6	**6958.3**
	%	5.1%	10.7%	18.0%	42.7%	23.4%	**100.0%**
XER	m^3	169.7	217.6	200.3	229.9	158.3	**975.8**
	%	17.4%	22.3%	20.5%	23.6%	16.2%	**100.0%**
TOTAL	m^3	**2961.1**	**5702.3**	**7526.9**	**12341.1**	**6921.7**	**35453.2**
	%	**8%**	**16%**	**21%**	**35%**	**20%**	**100%**

Figure I-9 - Diagrams of relative abundance (A) and relative volume (B) per size class in each site. Regions are indicated by numbers and biomes by colours.

We found a positive relationship between LW abundance and volume per region (regression analysis: $y = 0.0416 + 0.1464*x$; $r = 0.91$; $p < 0.01$; $r^2 = 0.83$) (Figure 10a), indicating that the more pieces per channel area, the greater is the in-stream wood volume per area. The points above the line indicate the regions which have proportionally higher volume per number of wood, that is, have the biggest pieces. The points below the line indicate the regions which have proportionally less volume per number of wood, that is, have the smallest pieces. The tropical regions from both savanna and forest biomes (except TM) and the temperate savanna (except TPL) have relatively smaller sized wood pieces for their volume, whereas more of the wood volume in the temperate forest regions, especially WMT but except UMW, is made up of large pieces of wood. Ranking the 15 study regions (Figure 10b) according to LW abundance, tropical regions occupy the first four positions, except NP (7th) and STM (12th). When considering LW volume, the tropical regions lose the first position to WMT (Temperate Coniferous Forest biome), which is the region with the largest pieces.

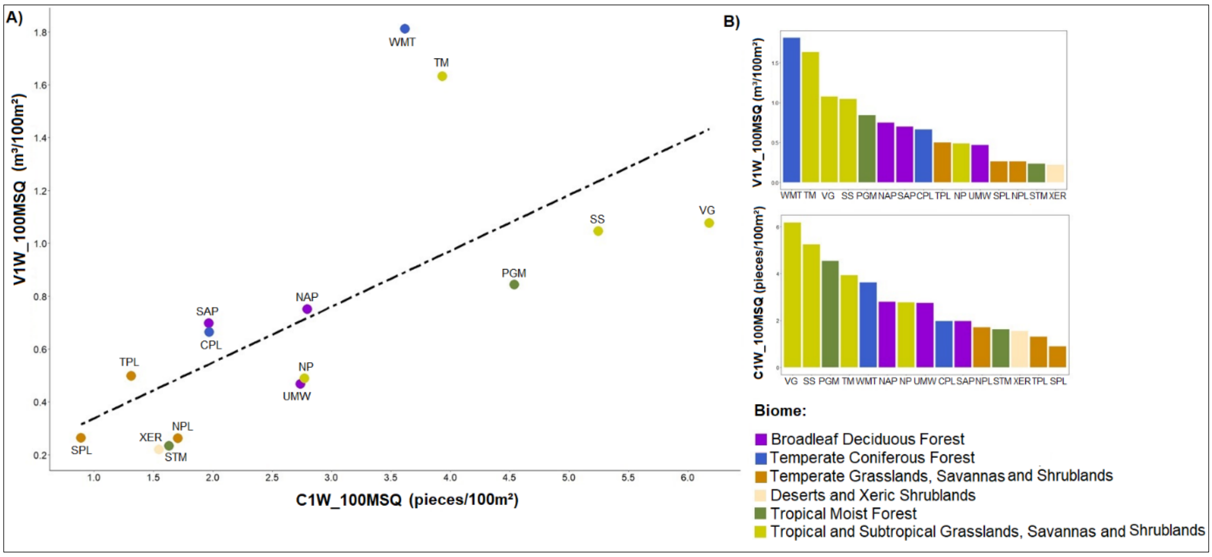


Figure I-10 - Average large wood (LW) abundance (C1W_100MSQ) against average LW volume per channel area (V1W_100MSQ) (A) and LW abundance and volume ranks per channel area (B) for Brazil and USA regions. The colours in the points and columns indicate the biome where each region is located.

Tropical forest regions (PGM and STM, but especially STM) present higher forest cover in the catchment than temperate forest regions (WMT, CPL, NAP, SAP and UMW) and much higher values than temperate grasslands and savannas (SPL, NPL and TPL) and xeric land (XER) (Figure 11a). Two of the tropical savanna regions (NP and TM) present higher forest cover than temperate savannas, but similar to xeric land. The other two tropical savanna regions (VG, SS) have similar forest cover to temperate savannas, especially in NPL that is mostly grassland rather than savanna (with most trees found in riparian zones). When analysing the riparian forest located on the channel banks (Figure 11b), only STM (tropical forest) and NPL (temperate savanna) regions presented significant differences in cover compared to all other regions, with the first having the highest and the second the lowest values. The other tropical and temperate forests or tropical and temperate savannas did not differ between themselves.

Analysing the channel dimensions, temperate streams surveyed are wider and shallower than tropical streams, except for those from STM region (Figure 11c, d). Channel width is largest for the temperate savanna streams, which are all at least three times wider than their tropical counterparts. There is no significant difference in channel depth between streams. Note that STM channel width and depth are more similar to the temperate streams than to the other tropical regions.

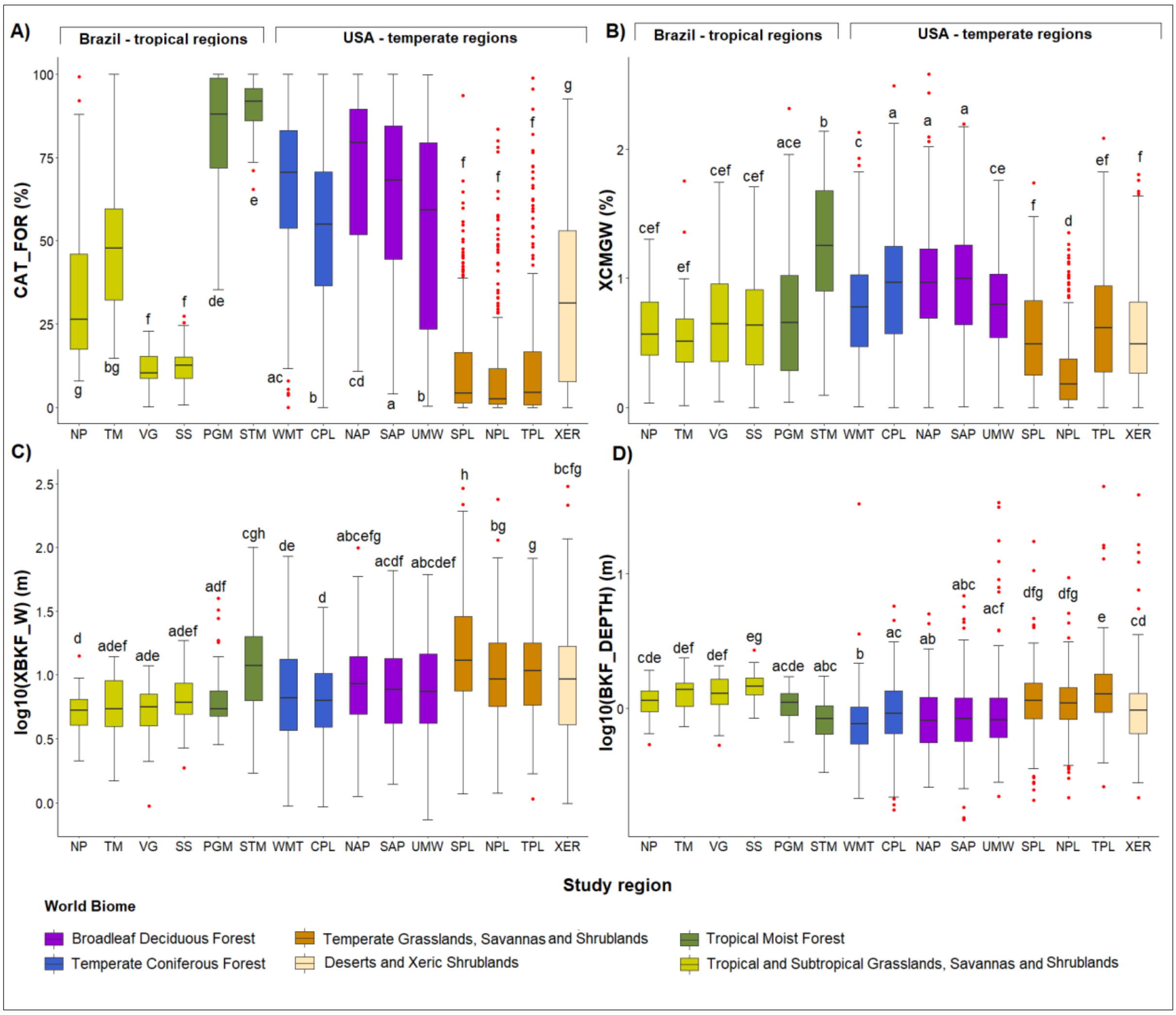


Figure I-11 - (A) Catchment forest cover (CAT_FOR), (B) visual evaluation of the woody riparian forest - XCMGW, (C) log of the bankfull channel width - XBKF_W and (D) log of the bankfull channel depth - BKF_DEPTH for Brazilian and USA regions. In the boxplots the line represents the median, the box is the first (25%) and the third (75%) quartiles, the whiskers extend to the most extreme data point which is no more than 1.5 times the length of the box away from the box, the red dots are the outliers defined by the '1.5 rule'. The colours in the boxes indicate the biome where each region is located. Different letters next to whiskers indicate significant difference in post–hoc comparisons.

4. Discussion

Our study is the first to extensively describe in-stream wood in tropical Amazon Forest, with savanna Cerrado streams. We also considered explanatory variables including geoclimatic, geomorphic and landcover data to identify the factors likely to be responsible for the differences. Surprisingly, Amazon and Cerrado streams have similar amounts and sizes of wood. Also contradicting what we expected, these tropical streams did not contain lower wood volume than those in temperate zone of the USA. Tropical Forest (Amazon streams) have in-stream wood in similar amounts to Temperate Forest, and Tropical Savanna (Cerrado streams) contain more in-stream wood than Temperate Savanna. Although streams in the temperate biomes had larger wood pieces and less small sized pieces. Thus, the high abundance of small sized LW in tropical streams compensates for the lack of larger logs, resulting in similar volumes of wood in streams from both climatic zones. We discuss our findings by trying to relate the wood stock found with the expectations for tropical streams according to the literature, identifying the particularities of the analysed biomes. We draw on the description of catchments, channels, riparian forest and wood stock to indicate the likely mechanisms influencing wood load and suggest the logical next steps for in-stream wood research in tropical regions.

4.1. Amazon vs. Cerrado in-stream wood

Amazon streams have greater forest cover in the catchment and in the riparian zones than Cerrado streams. Despite that, streams from both biomes contained similar amounts and sizes of wood, contrary to our first hypothesis. Thus, the wood stock existing in streams did not correspond in amount and size to the riparian forest characteristics. Riparian forest in both biomes differed not only in quantity (indicated by forest cover metrics), but also in layer structure (indicated by the visual estimative metric). Of all the regions, STM had the greatest height, cover, and density of trees in the riparian forest. Because tree density, species composition, age, and proximity of the forest to the stream channel affect LW recruitment (McDade *et al.*, 1990; Robison & Beschta, 1990; Van Sickle & Gregory, 1990; Paula *et al.*, 2013; Costigan *et al.*, 2015), more wood is expected in streams located in old–growth and less–impacted forest areas (Benda *et al.*, 2002; Emery *et al.*, 2003; Keeton *et al.*, 2007; Beckman & Wohl, 2014b). That is why we expected that Amazon streams, especially in STM, would have more wood than Cerrado streams. However, our results showed LW abundance did not differ between Amazon and Cerrado streams.

Cerrado and PGM streams had more confined channels with well–defined banks than those in STM. Because of the flat relief, streambed sediment characteristics (predominance of silt) and the large size of the vegetation in STM streams, the water flows between trees and rootwards without excavating a well–defined channel. The unconfined channel characteristic of STM streams leads the overflow to easily occupy adjacent areas, so that the bankfull channel is wider in this region compared to the others (see bankfull width averages in Table 6). Thus, LW may be more easily exported to the riparian zone, resulting in lateral output of wood. Lateral outputs are influenced by the spatial extent, magnitude, frequency, duration, and rate of rise of the overbank flow. Extensive, frequent, and prolonged flooding may balance the transport of wood in and out of the channel (i.e. between stream and riparian zone) (Wohl, 2017). Floodplains able to trap floating LW, such as the forested ones, may limit its transport back into the channel (Wohl, 2017). The higher density of decomposer organisms in the forest floor, such as termites, wood–feeding beetles and fungi could lead to higher decay rates for LW pieces located on the STM floodplain (Martius, 1997), helping to explain the lower amount of wood in this region.

The possible higher loss through lateral output combined with an enhanced decay rate in the riparian zones and a lower recruitment rate through bank erosion and forest stability may explain why STM streams have less wood volume. Our results suggest that STM has lower recruitment of big woody debris as seen by the lack of 'extra-large' pieces and the less quantity of smaller size class pieces, resulting in lower wood volume overall. Bank erosion can be the dominant source of wood, importing entire trees to the channel, especially in high energy rivers with erodible banks (Latterell & Naiman, 2007; Lassettre *et al.*, 2008; Moulin *et al.*, 2011). However, STM streams are characterized by low margin slope and poorly-defined banks, which might reduce the likelihood of margin erosion and consequent recruitment from tree fall. Deforestation and forest degradation may also influence the recruitment of trees by changing forest cover and age of trees in catchment and riparian zones (Wohl *et al.*, 2019). STM is the most well-preserved among our tropical study regions and has greater forest cover and denser riparian forest (Figure 4). Consequently, the riparian forest in STM sites might be more stable and with lower chance of large trees falling into the streams. Benda *et al.* (2002) have already detected a similar result when comparing second growth and old-growth forested streams in temperate regions. They found lower volume in the old-growth forested streams due to lower forest mortality and bank erosion rates.

Considering LW size, the most consistent pattern across the Brazilian biomes and regions was the much higher number of wood pieces in the smaller size classes. As suggested by Cadol & Wohl (2010) this can be a result of the branching morphology of tropical trees, which may contribute more small pieces by dropping branches into streams instead of main boles. Since branches are more easily carried downstream and decomposed because of their smaller dimensions (Lienkaemper & Swanson, 1987; Jacobson *et al.*, 1999; Haga *et al.*, 2002; Merten *et al.*, 2013), one would expect to find few small pieces and smaller loads in tropical streams overall. However, the high numbers of smaller pieces stored in these tropical streams reflect the high replacement rate of wood that allows persistent storage despite high rates of transport and decay (Wohl *et al.*, 2012a).

4.2. Brazil streams vs. other temperate and tropical streams in the literature

Comparing our results with others around the world we verified that our streams present less wood (volume per area metric) than the average. However, we could not agree that this is a general trend to tropical streams related to temperate streams. Considering wood surveys from tropical and temperate zone we verified that the study performed in Costa Rica Tropical Forest (Cadol *et al.*, 2009) presented the second higher wood volume average, lower only than a study performed in a temperate conifer forest in the USA pacific northwest (Zelt & Wohl, 2004). In a great overview paper about in-stream large wood across time and space Wohl (2017) verified that wood loads tend to be especially high in streams of the Pacific Northwest relative to other regions because this region includes Temperate Rain Forests with high primary productivity and low rates of wood decay compared to tropical regions. According to this argument, we would expect more in-stream wood in Temperate Moist Forests followed by Tropical Moist Forests. However, ranking all the surveyed studies according to wood load we checked that the position in the rank depends on the wood metric used. If we consider the number of LW pieces per channel length, the streams from Costa Rica occupy the first position and our streams the eleventh one. Whereas if we consider the volume per channel length, the Costa Rica study move to the seventh position and our streams to the nineth one. Considering the most commonly used metric, the wood volume per meter square, the Costa Rica study occupy the second position and our study the eleventh again. Observing Costa Rica study, we could say that tropical streams tend to present more wood in numbers, but less in volume compared to Temperate and Boreal Conifer Forests, mainly when you do not consider the channel dimensions (linear metrics). However, the huge difference between our and their results regarding wood load values do not allow us to make any generalisation about tropical in-stream wood numbers. Also, the differences in survey methods cannot be disregarded.

Considering only tropical streams, when comparing our results with those from Cadol *et al.* (2009) we note that their streams present higher wood volume average than ours. Another study performed in Brazilian streams (Paula *et al.*, 2013) presents the lower average. Our volumes are intermediate along with the study performed in the African savannah (Pettit *et al.*, 2005), but because the conditions under what the South African study was performed (in a large river after an extreme flood event), we decided not focusing our comparisons with it, because it would be less informative. Instead, we decided to compare our Cerrado results with the other Brazilian study (Paula *et al.*, 2013) and our Amazon results with Costa Rica study

(Cadol *et al.*, 2009). Regarding Amazon and Costa Rica comparison, both studies was performed in a tropical rainforest. So, we would expect similar in-stream wood values. The first possible reason to explain the difference detected would be the land use change and the reasonable deforestation degree in Amazon catchments. However, when we considered only the most preserved catchments in Amazon, the wood load persisted lower than Costa Rica study. So, the reason why Amazon presents less wood must lie on the differences between the study areas.

La Selva Biological Station in Costa Rica was described by the authors as an old-growth tropical wet forest located in low elevation ranges (34-110m) with a topography varying from low-gradient valley bottoms to steep segments. Stream channels of lower gradient tends to have beds of silty fine sand and dune-ripple or pool-riffle morphology, whereas steeper segments have gravel and boulder-size sediments and pool-riffle or step-pool morphology. They described the hydrograph as flashy due to the responsiveness of streams to rainfall and high transport capacity. In turn, Amazon streams are located inside the Amazon Forest in relief area varying between the Amazon plain and plateau. Elevation ranges between sites (4 -163 m), and all streams are low gradient channels with sand bed and glide flow not presenting riffles, rapids or waterfalls. Therefore, Amazon streams may have lower transport capacity which is reflected in the low values of stream power and larger seasonal bed, reflected in high bankfull channel values. If this is true, then the lower transport rates and the bigger floodplain in Amazon streams might provide better opportunities to the decomposer agents (Martius, 1997), once a LW is more likely to stay trapped at the same place into stream or on the floodplain. Mass tree mortality events promoted by hurricanes, volcanism, windstorms and landslides are important wood source to streams (Wohl, 2017). As demonstrated by Wohl *et al.* (2012a), the wood load in tropical may be dominated by episodic or steady recruitment processes. However, in this case, mass recruitment processes do not seem to be important and wood load is dominated by steady processes, which is evidenced by the scarcity of logjams in La Selva and no record in Amazon of such extreme events. Lastly, but very important, once more we cannot disregard the difference in the methodology applied to survey LW in both studies.

We also compared our Cerrado results with the other Brazilian study (Paula *et al.*, 2013) performed in a similar transition zone between Cerrado and Atlantic forest. Despite expecting to find similar wood load in both studies, we detected higher wood volume in our streams than they in theirs, in spite of our catchments presenting similar (in NP and TM) and lower (in VG and SS) forest cover percentage. Also, the LW pieces in our study presented lower relative lengths and diameter relative to the channel than theirs, which makes the result even more unexpected. Two possible explanations arose from this: (i) the differences on the survey methodology; (ii) differences in the history of human activities between the study areas. Because Paula *et al.* (2013) catchments are located in São Paulo state, closer to the coast in the border between Atlantic Forest and Cerrado biome, they have been experiencing deforestation since the end of the 18th century (Victor *et al.*, 2005). In turn, our catchments, located distant from the coast in the interior of Minas Gerais state on the border with Goiás state and São Paulo northwest, they have a much more recent history of deforestation, which effectively began at the end of 20th century during 1970 decade (Miziara and Ferreira, 2007). We do not expect still found on Cerrado streams LW pieces recruited decades ago, before the deforestation process has started in our catchments. Neither the high transport rates nor decay in these tropical streams would allow that. However, the conservations status of the remaining riparian forest might differ in ours and theirs study area. According to Paula *et al.* (2011) the vegetation present on São Paulo study catchments is secondary and highly degraded because the largest trees were removed (selective logging). The poor quality of these forests was one of the authors arguments to explain the low wood load on their streams, because of their simplified structure (Brown and Lugo, 1990). Higher wood loads are commonly found in old-growth forests streams corridors (e.g., Gurnell, 2003, 2013; Beckman and Wohl, 2014a) and the recruitment rates change as a forest ages following a disturbance episode (e.g., Andrus *et al.*, 1988; Spies *et al.*, 1988; Murphy and Koski, 1989). Because our catchments were more recently deforested, we expect a superior layer structure of the remaining riparian forest due to the less elapsed time and also to a more effective environmental legislation and inspection after the institution of the first Brazilian national forest code in 1965 (Soares-Filho *et al.*, 2014). An older forest with a more complex structure in our Cerrado, potentially would result in the higher in-stream wood volume detected. However, the lack common metrics to measure the quality of the riparian forest in both studies prevent us to deep in the comparison between our and their study. Also, in the absence of long-term temporal data about deforestation and wood loads limit our understanding of natural or historical range in wood load variability (Wohl, 2011, 2017).

4.3. Tropical vs. temperate in-stream wood (using the same methods)

When we compared our dataset with another surveyed using the same methods. contrary to our second hypothesis, tropical streams did not contain less in-stream wood than temperate streams. In forest biomes, tropical and temperate streams had similar volumes of LW per channel area, but tropical streams tended to have lower volume per channel length and higher LW abundance whether per channel area or length. In savanna biomes, tropical regions contained more in-stream wood than temperate ones, especially when considering the abundance and volume per channel area (except TPL). As the riparian vegetation is the primary source of wood to streams, one would expect that the in-stream wood stock reflects the catchment or the riparian forest cover, but we did not detect a general and direct relationship between in-stream wood and riparian forest metrics. Despite having greater forest cover, the Tropical Forest regions had similar volumes of in-stream wood as Temperate Forests. With regard to savanna, the Dry-Temperate Savanna and Grassland region with less woody riparian vegetation (NPL) was the one with the lowest in-stream wood stock together with the Xeric region. Almost the only trees in this region are riparian trees and they are mainly on rivers and larger streams. The other Temperate Savanna regions did not differ from Tropical Savanna regions the in respect of riparian vegetation amounts. However, the Tropical Savannas presented higher amounts of wood, suggesting that other factors beyond the riparian forest may contribute to explain in-stream wood.

The size of LW provides an important indicator of what could be behind in-stream wood stock. While in tropical streams, tiny and small pieces represent most of the wood volume, in temperate streams, medium and large pieces dominate. The branching morphology of tropical trees and their dropping branches are good explanations here, so that in tropical streams small wood from tree branches fall constantly (Cadol & Wohl, 2010) such that they are equivalent in volume to the large logs of the temperate streams. Temperate streams were also poorer in small pieces and more abundant in big LW, especially regions located in the temperate coniferous forest biome (i.e. WTM), characterized by high volumes of in-stream wood. A recent review of in-stream wood across the globe, indicates that wood stock tends to be especially high in streams from the Pacific Northwest relative to other regions of the world because temperate rainforests have high primary productivity and low rates of wood decay compared to tropical regions (Wohl, 2017). In the tropics, the decay of wood is faster because of the high humidity and temperature (Panshin *et al.*, 1964; Zabel & Morrell, 1992). In the Amazon, the environmental conditions may be especially prone to wood decay because the floodplain is subject to recurrent flood and dry events providing better opportunities for decomposers (Martius, 1997). The transport rates are also higher in tropical environments because of the greater magnitude and frequency of floods (Wohl & Jaeger, 2009), which may either move wood pieces out of the reach (downstream transport) or accelerate the decomposition of wood through abrasion (Merten *et al.*, 2013). Thus, the lack of big pieces in tropical streams can be explained by potentially higher decay and transport rate; even when large boles fall from the riparian forest, they do not remain there for long because decay or transport agents quickly degrade or move them. Obviously, these agents will also mobilise the small pieces even more easily, but the rate of replacement of the small sized wood is so high and fast (Cadol & Wohl, 2010) that tropical streams always keep a wood volume comparable to temperate streams despite not having big logs.

Comparing the in-stream wood data between tropical and temperate forest biomes, the explanation for the similar volume of wood per channel area might be the result of the balance between input and output forces. When formulating our second hypothesis, we imagined that output factors (i.e., wood decay and downstream transport) would predominate in tropical streams resulting in lower wood stock. Nonetheless, the similar volumes of in-stream wood in tropical and temperate forested streams suggest that input factors (i.e., local recruitment) are particularly important in tropical streams.

It is important to point out that the channel dimensions need to be considered when analysing the wood stock. When the LW volume was scaled by length of channel, the USA streams presented higher wood volumes than Amazon streams. Indeed, when analysing the channel width, it is possible to see that temperate streams are relatively wider. Thus, a higher value of wood volume for temperate streams is only detectable when disregarding the channel area. However, when analysing the LW abundance, tropical streams had similar to higher wood stock compared to temperate streams whether or not the channel area was considered. This result reinforces the importance of recruitment processes and the predominant small size of tropical in-stream wood, already discussed in the size profile analysis.

Similar but stronger patterns seem to repeat in savanna streams which have higher wood stock averages despite not presenting more riparian forest than the temperate ones. According to Grace *et al.* (2006) savannas located in arid and semi-arid regions have lower values of primary productivity. In the case of the Brazilian Savanna (Cerrado) the productivity rate can be higher even during the dry season because the trees have deep roots to access water. Therefore, the higher primary productivity of the Cerrado due to the wetter and hotter climate (Kicklighter *et al.*, 1999) might result in higher rates of branches dropping into streams. Indeed, the temperate savanna region with the lowest average of in-stream wood (i.e. NPL – dominated by grassland vegetation and impacted by livestock grazing) is characterized by an arid and cold climate, while the Temperate Savanna with the wetter climate (TPL) presented the highest load similar to the tropical savanna average. However, because the transport factors seem to prevail in Tropical Savanna (Cerrado) streams, most falling branches are likely to be delivered from upstream reaches, and certainly in higher amounts than what is being transported downstream.

This is in accordance with the results found by (Paula *et al.*, 2013) in a study of agricultural Brazilian streams, in which they detected a strong positive relationship between upstream riparian forest and LW variables. We did not detect this direct linkage between upstream forest and LW volume here, but as mentioned before, indirect effects and interactions among variables may be affecting our ability to directly infer wood predictors, demanding further analysis, which we do in the second article.

5. Conclusion

The differences in survey methods and metrics applied in diverse studies around the world may limit the ability of the river research to understand the variation on in-stream wood loads across the globe. As recommended by Wohl *et al.* (2010), standard techniques for measuring and reporting in-stream wood would allow us to examine the regional differences on wood amounts, whether they are natural or human-induced. This shows the importance of the present study for being the first one to report Amazon and Cerrado streams wood stock and to direct contrast comparable extensive datasets from different climatic regions and biomes. The differences or similarities in wood stock detected here between regions and biomes, whether tropical or temperate environments, and the consequent differences in the likely mechanisms behind them, indicate that we cannot simply generalise to other regions, even within the same biome or climatic zone. Therefore, further studies should deepen our understanding of the natural and anthropogenic terms in the wood budget. Special focus should be given in measuring the transport and wood decay rates, which seem to be the most important wood predictors in tropical streams (Cadol *et al.*, 2009). While we are still trying to understand the natural wood regime, widespread human-induced changes have already unbalanced the process, generally reducing recruitment rate and the size of the pieces recruited, increasing transport and thus decreasing wood storage (Wohl *et al.*, 2019). The multiplicity of factors that could affect wood load across space and time and the likely interactions and indirect effects among them, makes the task of understanding wood dynamics even more challenging, but the increasing pace of anthropogenic disturbances makes the task urgent.

Acknowledgements

We are grateful for financial support from Companhia Energética de Minas Gerais (CEMIG) and Instituto Nacional de Ciência e Tecnologia - Biodiversidade e Uso da Terra na Amazônia (CNPq; 574008/2008-0), Empresa Brasileira de Pesquisa Agropecuária (Embrapa; SEG:

02.08.06.005.00), the UK government Darwin Initiative (17-023), The Nature Conservancy, Natural Environment Research Council (NERC; NE/F01614X/1 and NE/G000816/1), and Fulbright Brasil. Individual funding included a Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) scholarship in Brazil and a Science without Borders Grant in Australia (PDSE-88881.361954/2019-01) to SOS. Our manuscript was subjected to review by the U.S. Environmental Protection Agency National Health and Environmental Effects Research Laboratory's Western Ecology Division and approved for publication. Approval does not signify that the contents reflect the views of the Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

References

Abbe, T.B. & Montgomery, D.R. (1996) Large woody debris jams, channel hydraulics and habitat formation in large rivers. *Regulated Rivers Research Management*, **12**, 201–221.

Andrus, C.W., Long, B.A. & Froelich, H. A. (1988) Woody debris and its contribution to pool formation in a coast stream 50 yr after logging. *Canadian Journal of Fisheries and and Aquatic Science*, **45**, 2080-2086.

Beckman, N.D. & Wohl, E. (2014a) Carbon storage in mountainous headwater streams: The role of old-growth forest and logjams. *Water Resources Research*, **50**, 2376–2393.

Beckman, N.D. & Wohl, E. (2014b) Effects of forest stand age on the characteristics of logjams in mountainous forest streams. *Earth Surface Processes and Landforms*, **39**, 1421–1431.

Benda, L.E., Bigelow, P. & Worsley, T.M. (2002) Recruitment of wood to streams in old-growth and second-growth redwood forests, northern California, U.S.A. *Canadian Journal of Forest Research*, **32**, 1460–1477.

Betts, J.T., Urquhart, G.R., Román-Heracleo, J. & Flores Mc.rea, J.C. (2021) Effects of deforestation from cattle ranching over time on protected rainforest streams in the Rama-Kriol Territory, Nicaragua. *Hydrobiologia*, **0123456789**.

Bilby, R.E. & Bisson, P.A. (1998) *Function and Distibution of Large Woody Debris. River ecology and management: lessons from the Pacific Coastal Ecoregion* (ed. by R.E. Naiman, R. J.; Bilby), pp. 324–346. Springer, New York.

Bisson, P.A., Bilby, R.E., Bryant, M.D., Dolloff, C.A., Grette, G.B., House, R.A., Murphy, M.L., Koski, V. & Sedell, J.R. (1987) *Large Woody Debris in Forested Streams in the Pacific Northwest: Past, Present, and Future. Streamside Management: Forestry and Fisheries Interactions* (ed. by E.O. Salo) and T.W. Cundy), pp. 144–190. University of Washington, Seattle.

Brown, S. & Lugo, A.E. (1990) Tropical secondary forests. *Journal of Tropical Ecology*, **6**, 1–32.

Cadol, D. & Wohl, E. (2010) Wood retention and transport in tropical, headwater streams, La Selva Biological Station, Costa Rica. *Geomorphology*, **123**, 61–73.

Cadol, D., Wohl, E., Goode, J.R. & Jaeger, K.L. (2009) Wood distribution in neotropical forested headwater streams of La Selva, Costa Rica. *Earth Surface Processes and Landforms*, **34**, 1198–1215.

Costigan, K.H., Soltesz, P.J. & Jaeger, K.L. (2015) Large wood in central Appalachian headwater streams: Controls on and potential changes to wood loads from infestation of hemlock woolly adelgid. *Earth Surface Processes and Landforms*, **40**, 1746–1763.

Di Luzio, M., Srinivasan, R. & Arnold, J.G. (2004) A GIS-coupled hydrological model system for the watershed assessment of agricultural nonpoint and point sources of pollution. *Transactions in GIS*, **8**, 113–136.

Emery, J.C., Gurnell, A.M., Clifford, N.J., Petts, G.E., Morrissey, I.P. & Soar, P.J. (2003) Classifying the hydraulic performance of riffle-pool bedforms for habitat assessment and river rehabilitation design. *River Research and Applications*, **19**, 533–549.

Faustini, J.M. & Jones, J.A. (2003) Influence of large woody debris on channel morphology and dynamics in steep, boulder-rich mountain streams, western Cascades, Oregon. *Geomorphology*, **51**, 187–205.

FBDS - Fundação Brasileira para o Desenvolvimento Sustentável (2009) Mapeamento em Alta Resolução dos Biomas Brasileiros. Rio de Janeiro, Brasil. Available from FBDS web page: http://geo.fbds.org.br/. Date accessed: 2021-10-29.

Frainer, A., Polvi, L.E., Jansson, R. & McKie, B.G. (2018) Enhanced ecosystem functioning following stream restoration: The roles of habitat heterogeneity and invertebrate species traits. *Journal of Applied Ecology*, **55**, 377–385.

Gardner, T.A., Ferreira, J., Barlow, J., Lees, A.C., Parry, L., Vieira, I.C.G., Berenguer, E., Abramovay, R., Aleixo, A., Andretti, C., Aragao, L.E.O.C., Araujo, I., de Avila, W.S., Bardgett, R.D., Batistella, M., Begotti, R.A., Beldini, T., de Blas, D.E., Braga, R.F., Braga, D. d. L., de Brito, J.G., de Camargo, P.B., Campos dos Santos, F., de Oliveira, V.C., Cordeiro, A.C.N., Cardoso, T.M., de Carvalho, D.R., Castelani, S.A., Chaul, J.C.M., Cerri, C.E., Costa, F. d. A., da Costa, C.D.F., Coudel, E., Coutinho, A.C., Cunha, D., D’Antona, A., Dezincourt, J., Dias-Silva, K., Durigan, M., Esquerdo, J.C.D.M., Feres, J., Ferraz, S.F. d. B., Ferreira, A.E. d. M., Fiorini, A.C., da Silva, L.V.F., Frazao, F.S., Garrett, R., Gomes, A. d. S., Goncalves, K. d. S., Guerrero, J.B., Hamada, N., Hughes, R.M., Igliori, D.C., Jesus, E. d. C., Juen, L., Junior, M., Junior, J.M.B. d. O., Junior, R.C. d. O., Junior, C.S., Kaufmann, P., Korasaki, V., Leal, C.G., Leitao, R., Lima, N., Almeida, M. d. F.L., Lourival, R., Louzada, J., Nally, R.M., Marchand, S., Maues, M.M., Moreira, F.M.S., Morsello, C., Moura, N., Nessimian, J., Nunes, S., Oliveira, V.H.F., Pardini, R., Pereira, H.C., Pompeu, P.S., Ribas, C.R., Rossetti, F., Schmidt, F.A., da Silva, R., da Silva, R.C.V.M., da Silva, T.F.M.R., Silveira, J., Siqueira, J. V., de Carvalho, T.S., Solar, R.R.C., Tancredi, N.S.H., Thomson, J.R., Torres, P.C., Vaz-de-Mello, F.Z., Veiga, R.C.S., Venturieri, A., Viana, C., Weinhold, D., Zanetti, R. & Zuanon, J. (2013) A social and ecological assessment of tropical land uses at multiple scales: the Sustainable Amazon Network. *Philosophical Transactions of the Royal Society B: Biological Sciences*, **368**, 20120166–20120166.

Gomi, T., Sidle, R.C., Noguchi, S., Negishi, J.N., Nik, A.R. & Sasaki, S. (2006) Sediment and wood accumulations in humid tropical headwater streams: Effects of logging and riparian buffers. *Forest Ecology and Management*, **224**, 166–175.

Gurnell, A.M. (2003) Wood storage and mobility. In The Ecology and Management of Wood in World Rivers, Gregory SV, Boyer KL, Gurnell AM (eds). *American Fisheries Society Symposium* 37. American Fisheries Society: Bethesda, MD; 75–91.

Gurnell, A.M. (2013) Wood in fluvial systems, in Treatise on Geomorphology, vol. 9, edited by J. Shroder and E. Wohl, chap. 236, pp. 163–188, Academic Press, San Diego, Calif., doi:10.1016/B978-0-12-374739-6.00236-0.

Grace, J., José, J.S., Meir, P., Miranda, H.S. & Montes, R.A. (2006) Productivity and carbon fluxes of tropical savannas. *Journal of Biogeography,* **33**, 387–400.

Haga, H., Kumagai, T., Otsuki, K. & Ogawa, S. (2002) Transport and retention of coarse woody debris in mountain streams: An in-situ field experiment of log transport and a field survey of coarse woody debris distribution. *Water Resources Research*, **38**, 1-1-1–16.

Harris, R.J. (2001) *A primer of multivariate statistics*. Psychology Press. 634p.

Hughes, R.M. & Peck, D. V. (2008) Acquiring data for large aquatic resource surveys: the art of compromise among science, logistics, and reality. *Journal of the North American Benthological Society,* **27**, 837–859.

Jarvis A., Reuter, H.I., Nelson, A. & Guevara, E. (2008) *Hole-filled SRTM for the globe Version 4*. Available from the CGIAR- CSI SRTM 90m Database. http://srtm.csi.cgiar.org

Jacobson, P.J., Jacobson, K.M., Angermeier, P.L. & Cherry, D.S. (1999) Transport, retention, and ecological significance of woody debris within a large ephemeral river. *Journal of the North American Benthological* Society, **18**, 429–444.

Junqueira, N.T., Macedo, D.R., de Souza, R.C.R., Hughes, R.M., Callisto, M. & Pompeu, P.S. (2016) Influence of environmental variables on stream fish fauna at multiple spatial scales. *Neotropical Ichthyology,* **14**.

Kaufmann, P.R. & Hughes, R.M. (2006) Geomorphic and anthropogenic influences on fish and amphibians in pacific northwest coastal streams. *American Fisheries Society Symposium,* **2006**, 429–455.

Kaufmann, P.R., Larsen, D.P. & Faustini, J.M. (2009) Bed stability and sedimentation associated with human disturbances in Pacific Northwest streams. *Journal of the American Water Resources Association,* **45**, 434–459.

Kaufmann, P.R., Levine, P., Robison, E.G., Seeliger, C. & Peck, D. V (1999) *Quantifying Physical Habitat in, EPA/620/R-*. U.S. Environmental Protection Agency, Washington, DC.

Keeton, W.S., Kraft, C.E. & Warren, D.R. (2007) Mature and old-growth riparian forests: Structure, dynamics, and effects on adirondack stream habitats. *Ecological Applications*, **17**, 852–868.

Kicklighter, D.W., Bondeau, A., Schloss, A.L., Kaduk, J. & Mcguire, A.D. (1999) Comparing global models of terrestrial net primary productivity (NPP): Global pattern and differentiation by major biomes. *Global Change Biology,* **5**, 16–24.

Lassettre, N.S., Piégay, H., Dufour, S. & Rollet, A.-J. (2008) Decadal changes in distribution and frequency of wood in a free meandering river, the Ain River, France. *Earth Surface Processes and Landforms*, **33**, 1098–1112.

Latterell, J.J. & Naiman, R.J. (2007) Sources and dynamics of large logs in a temperate floodplain river. *Ecological Applications*, **17**, 1127–1141.

Leal, C.G., Pompeu, P.S., Gardner, T.A., Leitão, R.P., Hughes, R.M., Kaufmann, P.R., Zuanon, J., de Paula, F.R., Ferraz, S.F.B., Thomson, J.R., Mac Nally, R., Ferreira, J. &

Barlow, J. (2016) Multi-scale assessment of human-induced changes to Amazonian instream habitats. *Landscape Ecology*, **31**, 1725–1745.

Leitão, R.P., Zuanon, J., Mouillot, D., Leal, C.G., Hughes, R.M., Kaufmann, P.R., Villéger, S., Pompeu, P.S., Kasper, D., de Paula, F.R., Ferraz, S.F.B. & Gardner, T.A. (2018) Disentangling the pathways of land use impacts on the functional structure of fish assemblages in Amazon streams. *Ecography*, **41**, 219–232.

Lienkaemper, G.W. & Swanson, F.J. (1987) Dynamics of large woody debris in streams in old-growth Douglas-fir forests. *Canadian Journal of Forest Research*, **17**, 150–156.

Lininger, K.B., Wohl, E., Sutfin, N.A. & Rose, J.R. (2017) Floodplain downed wood volumes: a comparison across three biomes. *Earth Surface Processes and Landforms*, **42**, 1248–1261.

Macedo, D.R., Hughes, R.M., Ferreira, W.R., Firmiano, K.R., Silva, D.R.O., Ligeiro, R., Kaufmann, P.R. & Callisto, M. (2016) Development of a benthic macroinvertebrate multimetric index (MMI) for Neotropical Savanna headwater streams. *Ecological Indicators*, **64**, 132–141.

Macedo, D.R., Pompeu, P.S., Morais, L., Castro, M.A., Alves, C.B.M., França, J.S., Sanches, B.O., Uchôa, J. & Callisto, M. (2014) *Sampling site selection, land use and cover, field reconnaissance, and sampling. Ecological conditions in hydropower basins* (ed. by M. Callisto, R.M. Hughes, J.M. Lopes, and M.A. Castro), pp. 61–83. Companhia Energética de Minas Gerais, Belo Horizonte, Brazil.

Martius, C. (1997) *Decomposition of Wood. The Central Amazon Floodplain: Ecology of a Pulsing System* (ed. by W.J. Junk), pp. 267–276. Springer, Plön, Germany.

McDade, M.H., Swanson, F.J., McKee, W.A., Franklin, J.F. & Van Sickle, J. (1990) Source distances for coarse woody debris entering small streams in werstern Oregon and Washington. *Canadian Journal of Fisheries and Aquatic Science*, **20**, 326–330.

Merten, E.C., Vaz, P.G., Decker-Fritz, J.A., Finlay, J.C. & Stefan, H.G. (2013) Relative importance of breakage and decay as processes depleting large wood from streams. *Geomorphology*, **190**, 40–47.

Miziara, F. & Ferreira, N.C. (2007) *Expansão da fronteira agrícola e evolução da ocupação e uso do espaço no Estado de Goiás: subsídios à política ambiental. A encruzilhada socioambiental: biodiversidade, economia e sustentabilidade no Cerrado* (ed. by L.G. Ferreira-Jr.), pp. 107–125. UFG, Goiânia.

Montgomery, D.R., Beamer, E.M., Pess, G.R. & Quinn, T.P. (1999) Channel type and salmonid spawning distribution and abundance. *Canadian Journal of Fisheries and Aquatic Sciences*, **56**, 377–387.

Moulin, B., Schenk, E.R. & Hupp, C.R. (2011) Distribution and characterization of in-channel large wood in relation to geomorphic patterns on a low-gradient river. *Earth Surface Processes and Landforms*, **36**, 1137–1151.

Murphy, M.L. & Koski, K.V. (1989) Input and depletion of woody debris in Alaska streams and implications for streamside management. *North American Journal of Fisheries Management*, **9** :427–436.

Panshin, A.J., De Zeeuw, C., Brown, H.P. (1964) *Textbook of Wood Technology*. McGraw-Hill: New York.

Parente, L., Nogueira, S., Baumann, L., Almeida, C., Maurano, L., Affonso, A.G., Ferreira, L. (2021) Quality assessment of the PRODES Cerrado deforestation data. *Remote Sensing Applications: Society and Environment*, **21** DOI: 10.1016/j.rsase.2020.100444

Paula, F.R., Ferraz, S.F.D.B., Gerhard, P., Vettorazzi, C.A. & Ferreira, A. (2011) Large woody debris input and its influence on channel structure in agricultural lands of Southeast Brazil. *Environmental Management*, **48**, 750–763.

Paula, F.R., Gerhard, P., Wenger, S.J., Ferreira, A., Vettorazzi, C.A. & de Barros Ferraz, S.F. (2013) Influence of forest cover on in-stream large wood in an agricultural landscape of southeastern Brazil: A multi-scale analysis. *Landscape Ecology,* **28**, 13–27.

Pereira, E.J.A.L., Ribeiro, L.C. S., Freitas, L.F.S, Pereira, H.B. B. (2020) Brazilian policy and agribusiness damage the Amazon rainforest. Land Use Policy, **92,** 104491. DOI: 10.1016/j.landusepol.2020.104491 [online] Available from: https://doi.org/10.1016/j.landusepol.2020.104491

Pettit, N.E. & Naiman, R.J. (2005) Flood-deposited wood debris and its contribution to heterogeneity and regeneration in a semi-arid riparian landscape. *Oecologia*, **145**, 434–444.

Pettit, N.E., Naiman, R.J., Rogers, K.H. & Little, J.E. (2005) Post-flooding distribution and characteristics of large woody debris piles along the semi-arid Sabie River, South Africa. *River Research and Applications,* **21**, 27–38.

Pettit, N.E., Warfe, D.M., Kennard, M.J., Pusey, B.J., Davies, P.M. & Douglas, M.M. (2013) Dynamics of in-stream wood and its importance as fish habitat in a large tropical floodplain river. *River Research and Applications,* **29**, 864–875.

Pompeu, P.S. & Yuhara, T.Y. (2018) Impactos de manilhas rodoviárias sobre o ambiente físico de riachos. In A. Bager. (Ed.). *Infraestrutura viária & biodiversidade: métodos e diagnósticos*, 1, 147–158. Universidade Federal de Lavras, Lavras, MG.

Power, M.E. (2003) Life cycles, limiting factors, and behavioral ecology of four Loricariid catfishes in a Panamanian stream. *Catfishes* (ed. by G. Arratia, B.G. Kapoor, M. Chardon, and R. Diogo), pp. 581–600. Science Publishers, Enfield.

Robison, E.G. & Beschta, R.L. (1990) Characteristics of coarse woody debris for several coastal streams of southeast Alaska, USA. *Canadian Journal of Fisheries and Aquatic Sciences*, **47**, 1684–1693.

Rosenfeld, J.S. & Huato, L. (2003) Relationship between Large Woody Debris Characteristics and Pool Formation in Small Coastal British Columbia Streams. *North American Journal of Fisheries Management*, **23**, 928–938.

Silva-Junior, C.H.L., Pessoa, A.C.M., Carvalho, N.S., Reis, J.B.C., Anderson, L.O., Aragão, L.E.O.C. (2021) The Brazilian Amazon deforestation rate in 2020 is the greatest of the decade. *Nature Ecology and Evolution,* **5**, 144–145. DOI: 10.1038/s41559-020-01368-x [online] Available from: http://dx.doi.org/10.1038/s41559-020-01368-x

Soares-Filho, B., Rajão, R., Macedo, M., Carneiro, A., Costa, W., Coe, M., Rodrigues, H. & Alencar, A. (2014) Cracking Brazil' s Forest Code Supplemental. *Science*, **344**, 363–364.

Spies, T.A., Franklin, J.F. & Thomas, T.B. (1988) Coarse woody debris in Douglas-fir forests of Western Oregon and Washington. *Ecology*, **696**, 1689-1702.

Sutfin, N.A., Wohl, E.E. & Dwire, K.A. (2016) Banking carbon: A review of organic carbon storage and physical factors influencing retention in floodplains and riparian ecosystems. *Earth Surface Processes and Landforms*, **41**, 38–60.

Swanson, F.J., Gregory, S. V., Iroumé, A., Ruiz-Villanueva, V. & Wohl, E. (2020) Reflections on the history of research on large wood in rivers. *Earth Surface Processes and Landforms*, **esp.4814**.

Trigueiro, W.R, Nabout, J.C., Tessarolo, G. (2020) Uncovering the spatial variability of recent deforestation drivers in the Brazilian Cerrado. *Journal of Environmental Management*, **275** DOI: 10.1016/j.jenvman.2020.111243

Trimble, M.J. & van Aarde, R.J. (2012) Geographical and taxonomic biases in research on biodiversity in human-modified landscapes. *Ecosphere*, **3**, art119.

USEPA - U.S. Environmental Protection Agency (2013) *National Rivers and Streams Assessment 2013-2014: Field Operations Manual – Wadeable*., EPA-841-B-. Office of Water, Washington, DC.

USEPA - U.S. Environmental Protection Agency (2016a) *National Rivers and Streams Assessment 2008–2009: a collaborative survey*. EPA/841/R-16/007. Office of Water and Office of Research and Development, Washington, DC.

USEPA - U.S. Environmental Protection Agency (2016b) *National Aquatic Resource Surveys. National Rivers and Streams Assessment 2008-2009 (data and metadata files)*. Available from U.S. EPA web page: https://www.epa.gov/national-aquatic-resource-surveys/data-national-aquatic-resource-surveys. Date accessed: 2021-01-01.

USEPA - U.S. Environmental Protection Agency (2020) *National Aquatic Resource Surveys. National Rivers and Streams Assessment 2013-2014 (data and metadata files)*. Available from U.S. EPA web page: https://www.epa.gov/national-aquatic-resource-surveys/data-national-aquatic-resource-surveys. Date accessed: 2021-01-01

Valeriano, M. de M. & Rossetti, D. de F. (2012) Topodata: Brazilian full coverage refinement of SRTM data. *Applied Geography*, **32**, 300–309.

Van Sickle, J. & Gregory, S. V (1990) Modeling inputs of large woody debris to streams from falling trees. *Canadian Journal of Forest Research*, **20**, 1593–1601.

Victor, M.A.M., Cavalli, A.C., Guillaumon, J.R. & Filho, R.S. (2005) *Cem anos de devastação: revisitada 30 anos depois*, 1st edn. Ministério do Meio Ambiente, Brasília.

Wohl, E. (2017) Bridging the gaps: An overview of wood across time and space in diverse rivers. *Geomorphology*, **279**, 3–26.

Wohl, E. (2013) Floodplains and wood. *Earth-Science Reviews*, **123**, 194–212.

Wohl, E. (2011) What should these rivers look like? Historical range of variability and human impacts in the Colorado Front Range, USA. *Earth Surface Processes and Landforms*, **36**, 1378–1390.

Wohl, E., Bolton, S., Cadol, D., Comiti, F., Goode, J.R. & Mao, L. (2012a) A two end-member model of wood dynamics in headwater neotropical rivers. *Journal of Hydrology*, **462**–463, 67–76.

Wohl, E., Cenderelli, D.A., Dwire, K.A., Ryan-Burkett, S.E., Young, M.K. & Fausch, K.D. (2010) Large in-stream wood studies: A call for common metrics. *Earth Surface Processes and Landforms*, **35**, 618–625.

Wohl, E., Dwire, K., Sutfin, N., Polvi, L. & Bazan, R. (2012b) Mechanisms of carbon storage in mountainous headwater rivers. *Nature Communications*, **3**, 1263–1268.

Wohl, E. & Jaeger, K.L. (2009) Geomorphic implications of hydroclimatic differences among step-pool channels. *Journal of Hydrology*, **374**, 148–161.

Wohl, E., Kramer, N., Ruiz-Villanueva, V., Scott, D.N., Comiti, F., Gurnell, A.M., Piegay, H., Lininger, K.B., Jaeger, K.L., Walters, D.M. & Fausch, K.D. (2019) The natural wood regime in rivers. *BioScience*, **69**, 259–273.

Wohl, E., Lininger, K.B., Fox, M., Baillie, B.R. & Erskine, W.D. (2017) Instream large wood loads across bioclimatic regions. *Forest Ecology and Management*, **404**, 370–380.

Wohl, E., Ogden, F. L. & Goode, J. (2009) Episodic wood loading in a mountainous neotropical watershed. Geomorphology, **111**, 3–4, 149–159.

Wohl, E. & Scott, D.N. (2017) Wood and sediment storage and dynamics in river corridors. *Earth Surface Processes and Landforms*, **42**, 5–23.

Wright, J.P. & Flecker, A.S. (2004) Deforesting the riverscape: The effects of wood on fish diversity in a Venezuelan piedmont stream. *Biological Conservation*, **120**, 439–447.

Zabel, R. A.; Morrell, J. J. (1992) *Wood Microbiology: Decay and its Prevention*. San Diego: Academic Press.

Zelt, R.B. & Wohl, E.E. (2004) Channel and woody debris characteristics in adjacent burned and unburned watersheds a decade after wildfire, Park County, Wyoming. *Geomorphology*, **57**, 217–233.

Supplementary Material

S1. Channel and catchment measurements taken in field and spatial assessments**.**

	METRIC	**CÓD.**	**UNIT**
1.	Reach length	REACHLEN	m
2.	Wetted width	XWIDTH	m
3.	Bankfull width	XBKF_W	m
4.	Bankfull height	XBKF_H	m
5.	Thalweg depth	XDEPTH_T	cm
6.	Mean cross–section depth	XDEPTH_CS	cm
7.	Bankfull thalweg depth[6]	BKF_DEPTH	m
8.	Bankfull cross-section area[7]	BKF_AREA_CS	m²
9.	Bankfull planform area[8]	BKF_AREA_PF	m²
10.	Channel slope	XSLOPE_%	%
11.	Sinuosity	SINU	–
12.	Bed material type	SUBSTRATE	–
13.	Substrate size	DGM	mm
14.	Flow type	FLOW	–
15.	Mean residual depth	RP100	cm
16.	Sum of 3 Riparian forest vegetation areal cover on banks (visual evaluation)	XCMGW	Areal proportion–
17.	Large wood count per reach length	C1W_100	pieces/100m
18.	Large wood count per channel area	C1W_100MSQ	pieces/100m²
19.	Large wood volume per reach length	V1W_100	m³/100m
20.	Large wood volume per channel area	V1W_100MSQ	m³/100m²
21	Average length of large wood pieces	LW_LENGTH	m
22	Average diameter of large wood pieces	LW_DIAM	m
23.	Catchment mean elevation	CAT_ELEV	m
24.	Catchment mean slope	CAT_SLO	%
25.	Catchment area	CAT_AREA	Km²
26.	Catchment forest cover	CAT_FOR	%
27.	Riparian forest cover in the upstream network within 100m buffer	NET_FOR	%
28.	Riparian forest cover within 100m buffer along the study reach	LOC_FOR	%

---

[6] Bankfull height + thalweg depth

[7] Cross section depth * bankfull width

[8] Bankfull width * reach length

S2: Amounts and dimensions of LW in the six study regions. Mean, standard deviation and range are presented**.**

Biome	**Amazon** Mean ± SD (range)			**Cerrado** Mean ± SD (range)					**Both** Mean ± SD (range)
Region **Metric**	**PGM**	**STM**	**Sub-total**	**SS**	**NP**	**TM**	**VG**	**Sub-total**	**Total**
LW pieces (nº)	37.63 ± 36.16 (0 – 127)	25.63 ± 17.33 (0 – 81)	31.81 ± 29.11 (0 – 127)	41.08 ± 35.02 (0 – 138)	20.23 ± 17.89 (0 – 69)	32.25 ± 42.54 (0 – 169)	41.13 ± 47.81 (0 – 193)	33.62 ± 38.19 (0 – 193)	32.93 ± 34.94 (0 – 193)
LW volume (m^3)	6.60 ± 6.77 (0 – 24.26)	3.60 ± 5.04 (0 – 31.16)	5.15 ± 6.15 (0 – 31.16)	8.70 ± 14.81 (0.00 – 73.96)	4.18 ± 4.74 (0.00 – 24.34)	11.14 ± 20.00 (0.00 – 106.94)	7.51 ± 11.76 (0.00 – 53.94)	7.88 ± 14.05 (0.00 – 106.94)	6.83 ± 11.73 (0.00 – 106.94)
LW diameter (m)	0.26 ± 0.04 (0.20 – 0.34)	0.23 ± 0.03 (0.20 – 0.33)	0.24 ± 0.04 (0.20 – 0.34)	0.26 ± 0.05 (0.20 – 0.37)	0.26 ± 0.05 (0.20 – 0.33)	0.28 ± 0.07 (0.20 – 0.44)	0.25 ± 0.06 (0.20 – 0.45)	0.26 ± 0.06 (0.20 – 0.45)	0.26 ± 0.05 (0.20 – 0.45)
LW length (m)	3.93 ± 0.59 (3.25 – 5.64)	3.68 ± 0.52 (3.25 – 5.46)	3.80 ± 0.57 (3.25 – 5.64)	3.94 ± 0.68 (3.25 – 6.21)	4.07 ± 0.69 (3.25 – 5.74)	4.37 ± 1.19 (3.25 – 7.90)	3.92 ± 0.79 (3.25 – 6.88)	4.07 ± 0.87 (3.25 – 7.90)	3.97 ± 0.78 (3.25 – 7.90)
LW abundance (nº/100m)	25.08 ± 24.10 (0.00 – 84.67)	17.08 ± 11.55 (0.00 – 54.00)	21.21 ± 19.41 (0.00 – 84.67)	24.70 ± 21.78 (0.00 – 91.33)	13.19 ± 11.96 (0.00 – 46.00)	18.48 ± 24.42 (0.00 – 93.33)	25.68 ± 31.69 (0.00 – 127.33)	20.49 ± 23.88 (0.00 – 127.33)	20.76 ± 22.23 (0.00 – 127.33
LW abundance (nº/100m^2)	4.54 ± 4.51 (0.00 – 0.16)	1.63 ± 1.60 (0.00 – 0.07)	3.13 ± 3.71 (0.00 – 0.16)	5.25 ± 6.87 (0.00 – 0.28)	2.77 ± 3.00 (0.00 – 0.16)	3.93 ± 5.35 (0.00 – 0.18)	6.18 ± 8.98 (0.00 – 0.34)	4.53 ± 6.50 (0.00 – 0.34)	3.99 ± 5.63 (0.00 – 0.34)
LW load (m^3/100m)	4.40 ± 4.52 (0.00 – 16.18)	2.40 ± 3.36 (0.00 – 20.77)	3.43 ± 4.10 (0.00 – 20.77)	4.71 ± 6.92 (0.00 – 30.72)	2.55 ± 2.62 (0.00 – 12.17)	6.82 ± 13.11 (0.00 – 71.29)	4.67 ± 7.52 (0.00 – 35.96)	4.69 ± 8.48 (0.00 – 71.29)	4.21 ± 7.14 (0.00 – 71.29)
LW load (m^3/100m^2)	0.84 ± 0.93 (0.00 – 3.39)	0.23 ± 0.35 (0.00 – 1.73)	0.55 ± 0.77 (0.00 – 3.39)	1.05 ± 2.07 (0.00 – 11.42)	0.49 ± 0.45 (0.00 – 1.68)	1.63 ± 3.83 (0.00 – 21.32)	1.08 ± 2.29 (0.00 – 14.17)	1.06 ± 2.48 (0.00 – 14.17)	0.86 ± 2.02 (0.00 – 21.32)
LW diam./ channel depth	0.24 ± 0.08 0.12 – 0.16)	0.31± 0.13 0.12 – 0.72)	0.28 ± 0.11 (0.12 – 0.72)	0.18 ± 0.05 (0.11 – 0.34)	0.24 ± 0.08 (0.12 – 0.46)	0.22 ± 0.07 (0.11 – 0.34)	0.21 ± 0.09 (0.10 – 0.54)	0.21 ± 0.08 (0.10 – 0.54)	0.24 ± 0.10 (0.10 – 0.72)
LW length/ channel width	0.73 ± 0.33 (0.08 – 1.66)	0.42 ± 0.36 (0.03 – 1.91)	0.57 ± 0.38 (0.03 – 1.91	0.70 ± 0.39 (0.18 – 2.01)	0.85 ± 0.35 (0.27 – 1.61)	0.91 ± 0.61 (0.26 – 2.45)	0.86 ± 0.73 (0.27 – 4.75)	0.83 ± 0.54 (0.18 – 4.75)	0.73 ± 0.50 (0.03 – 4.75)

S3: Catchment and channel characteristics of the streams belonging to the six studied regions. Mean, standard deviation and range are presented.

Biome	**Amazon** Mean ± SD (range)		**Cerrado** Mean ± SD (range)			
Region **Metric**	**PGM**	**STM**	**SS**	**NP**	**TM**	**VG**
Catchment characteristics						
Area (Km²)	12.55 ± 12.39 (0.44 – 50.37)	28.70 ± 47.07 (0.83 – 227.13)	30.23 ± 26.93 (0.37 – 108.45)	10.74 ± 10.70 (1.38 – 50.74)	45.23 ± 47.21 (0.45 – 164.97)	27.53 ± 30.22 (2.64 – 116.43)
Catchment slope (%)	4.64 ± 1.86 (1.55 – 9.49)	7.22 ± 2.95 (3.96 – 14.80)	5.59 ± 1.81 (3.10 – 9.65)	8.24 ± 3.03 (3.16 – 17.16)	7.36 ± 3.22 (3.40 – 16.72)	5.94 ± 1.85 (3.21 – 12.74)
Catchment forest cover (%)	81.13 ± 18.68 (35.39 – 100.00)	90.43 ± 8.03 (65.38 – 100.00)	12.99 ± 6.35 (0.81 – 27.37)	36.57 ± 24.98 (7.84 – 99.19)	45.57 ± 18.03 (14.78 – 100.00)	11.56 ± 5.32 (0.10 – 22.80)
Network forest cover (%)	78.76 ± 20.38 (23.84 – 100)	88.26 ± 11.4 (51.23 – 100)	35.78 ± 18.11 (0.00 – 100)	62.33 ± 20.13 (25.29 – 100)	55.75 ± 18.41 (23.21 – 100)	33.08 ± 12.91 (1.39 – 61.71)
Channel characteristics						
Bankfull width (m)	8.00 ± 7.26 (2.86 – 39.73)	17.33 ± 18.24 (1.70 – 100)	6.92 ± 3.22 (1.87 – 18.71)	5.45 ± 2.31 (2.13 – 14.06)	6.52 ± 3.59 (1.48 – 13.99)	6.00 ± 2.70 (0.94 – 11.87)
Bankfull depth (m)	1.10 ± 0.26 (0.56 – 1.71)	0.85 ± 0.31 (0.34 – 1.74)	1.50 ± 0.36 (0.85 – 2.71)	1.18 ± 0.33 (0.54 – 1.92)	1.34 ± 0.38 (0.74 – 2.36)	1.33 ± 0.36 (0.54 – 2.08)
Bankfull width/ bankfull depth (w/d)	7.93 ± 8.09 (2.68 – 38.62)	19.10 ± 15.77 (3.15 – 85.95)	4.67 ± 2.08 (1.50 – 12.42)	5.01 ± 3.23 (1.47 – 21.70)	5.02 ± 2.94 (1.77 – 13.84)	4.50 ± 1.70 (1.75 – 9.18)
Channel slope (%)	0.32 ± 0.27 (0.02 – 1.60)	0.67 ± 0.69 (0.06 – 3.07)	0.81 ± 0.56 (0.05 – 2.64)	1.35 ± 0.84 (0.39 – 4.76)	0.60 ± 0.59 (0.01 – 2.38)	0.82 ± 1.22 (0.07 – 6.86)
Bankfull discharge (m³/s)	5.02 ± 5.28 (0.42 – 28.33)	8.42 ± 10.64 (0.12 – 42.20)	29.38 ± 26.70 2.17 – 105.00)	25.18 ± 57.74 (0.88 – 360.19)	9.76 ± 10.05 (0.63 – 43.44)	16.92 ± 21.22 (0.17 – 106.21)
Stream power (W/m)	242.14 ± 630.49 (0.87 – 4,441.77)	429.78 ± 573.48 (6.75 – 2,452.60)	2960.58 ± 4895.76 (41.15 – 27,131.23)	3190.61 ± 7032.15 (87.62 – 43,181.52)	707.72 ± 1145.51 (1.56 – 4,944.90)	2145.38 ± 5595.36 (12.72 – 29,771.34)
Hydraulic resistance	0.09 ± 0.089 (0.02 – 0.50)	0.17 ± 0.11 (0.00 – 0.16)	0.02 ± 0.02 (0.00 – 0.09)	0.03 ± 0.03 (0.00 – 0.50)	0.08 ± 0.07 (0.01 – 0.34)	0.04 ± 0.05 (0.00 – 0.24)
Substrate size (mm)	0.70 ± 1.79 (0.01 – 12.69)	1.45 ± 8.12 (0.01 – 56.45)	29.91 ± 126.51 (0.01 – 780.90)	8.69 ± 21.42 (0.02 – 129.78)	168.34 ± 590.46 (0.01 – 3,613.40)	72.81 ± 335.15 (0.01 – 2,113.95)
Woody riparian forest (%)	77.72 ± 56.02 (3.86 – 231.14)	126.11 ± 54.93 (9.55 – 213.98)	65.55 ± 41.80 (0.00 – 170.57)	62.60 ± 30.90 (3.41 – 130.11)	52.87 ± 32.63 (1.59 – 175.34)	67.98 ± 42.44 (4.32 – 174.43)
Local forest cover (%)	62.11 ± 35.36 (0.00 – 100.00)	70.60 ± 28.80 (1.79 – 100.00)	31.92 ± 26.91 (0.00 – 92.86)	63.47 ± 29.85 (6.67 – 100.00)	49.51 ± 29.35 (0.00 – 100.00)	40.01 ± 25.88 (0.00 – 100.00)

S4. Large wood assessments in streams around the world according to biome. The world biomes were classified following Trimble & van Aarde (2012).

Biome	Study	LW abund. n/100m	LW volume m^3/100m	LW volume $m^3/100m^2$	LW length (m)	LW diameter (m)	Channel width (m)	Slope (%)
Boreal forest / Taiga	Dahlstrom & Nilsson (2004)	51.00	-	0.59	2.60	0.10	1.95	0.06
	Kreutzweiser *et al.* (2005)	19.25	-	-	-	0.17	4.93	0.02
	Mossop & Bradford (2004)	29.12	-	0.34	3.97	0.15	5.20	0.02
	Robison & Beschta (1990)	33.40	58.00	6.08	7.40	0.53	11.40	0.02
Temperate Broadleaf and mixed forest	Cordova *et al.* (2007)	9.83	-	0.93	-	-	5.46	0.01
	Diez *et al.* (2001)	-	-	0.66	-	-	5.34*	0.09
	Iroumé *et al.* (2014)	-	-	4.52	-	-	9.91	0.07
	Meleason *et al.* (2005)	38.64	17.97	2.06	-	-	3.79	0.05
	Warren & Kraft (2008)	34.94	3.53	-	-	-	-	-
	Webb & Erskine (2005)	64.50	-	4.08	-	-	-	-
Temp. Conifer Forest/ Temp. Broadleaf Forest	Deng *et al.* (2002)	11.68	-	1.72	-	-	-	-
	Seo & Nakamura (2009)	-	-	0.04	-	-	19.12	0.10
Temperate Conifer Forest	Comiti *et al.* (2006)	21.20	1.90	0.40	2.54	0.14	-	0.16
	Fox & Bolton (2007)	57.02	54.57	-	-	-	-	-
	May & Gresswell (2003)	40.25	-	-	-	-	3.82	0.14
	Nowakowski & Wohl (2008)	-	10.72	0.43	2.74	0.14	5.12*	-
	Reeves *et al.* (20003)	15.91	150.14	-	-	-	-	-
	Wallace & Benke (1984)	-	35.60	1.58	-	-	4.92	-
	Zelt & Wohl (2004)	62.00	28.07	20.50	6.90	0.21	10.05	0.02
Tropical and Subtropical Moist Broadleaf Forest	Cadol *et al.* (2009)	77.07	17.03	12.33	3.95	0.19	7.44	0.02
	Paula *et al.* (2013)	1.31	-	0.09	4.25	0.17	2.21*	0.12
	Saraiva *et al.* (present study)	21.21	3.43	0.55	3.80	0.24	12.52	0.00
Tropical Forest/ Savanna	Saraiva *et al.* (present study)	24.70	4.71	1.05	3.94	0.26	6.92	0.01
Savanna	Pettit *et al.* (2005)	-	-	0.90	-	-	277.52	-
	Saraiva *et al.* (present study)	19.12	4.68	1.07	4.11	0.27	5.99	0.01

* *Wetted channel width*

ARTIGO II - *Wood predictors in neotropical streams: assessing the effects of regional and local controls in Amazon and Cerrado catchments*

Sarah de Oliveira Saraiva; Philip Robert Kaufmann; Ian Rutherfurd; Cecília Gontijo Leal; Rafael Pereira Leitão; Diego Rodrigues Macedo; Paulo dos Santos Pompeu

(Manuscrito redigido na língua e formato indicado para revista - número de linhas foi retirado para melhor adequação ao formato da tese)

WOOD PREDICTORS IN NEOTROPICAL STREAMS: ASSESSING THE EFFECTS OF REGIONAL AND LOCAL CONTROLS IN AMAZON AND CERRADO CATCHMENTS

SARAIVA, S. O.[1*], KAUFMANN[2], P. R., RUTHERFURD, I[3]., LEAL[4], C. G., LEITÃO[5], R. P., MACEDO[5], D. R., POMPEU, P. S[1].

[1] *Departamento de Ecologia e Conservação, Instituto de Ciências Naturais, Universidade Federal de Lavras, Lavras - MG, Brazil, 37.200-900.*
[2] *Western Ecology Division, National Health and Environmental Effects Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, 200 SW 35th Street, Corvallis, OR 97333, USA.*
[3] *School of Geography, The University of Melbourne, 221 Bouverie St, Carlton, 3010, Melbourne - VIC, Australia.*
[4] *Escola Superior de Agricultura Luiz de Queiroz (ESALQ), Universidade de São Paulo, Piracicaba - SP, 13.418-900.*
[5] *Departamento de Biologia Geral, Universidade Federal de Minas Gerais, Belo Horizonte, Brazil, 31270-901.*

** Corresponding author*

Abstract

The in-stream wood regime consists of wood recruitment, transport, retention and decay in river corridors. In tropical streams transport and decay forces seem to exert special effect in determining the amounts of wood stored, such regional factors may be of prominent importance. However, as few studies have been performed in the tropical zone, many uncertainties still remain. The in-stream wood regime of Amazon and Cerrado biomes is not known, and rapidly changing land-use in these neotropical biomes threatens efforts to understand their natural wood regime. We investigated the main predictors of in-stream wood in agriculturally-impacted catchments of the Amazon and Cerrado in order to identify the critical factors controlling wood recruitment and load. Using the structural equation modelling technique, we attempted to disentangle the complex net of regional and local controls. We found that local drivers such as piece size and channel dimensions, discharge, stream power and riparian forest were the most important predictors of wood. The sources of wood were similar in both biomes, but the channel features that determine wood stock vary greatly between them. Although the in-stream wood of Amazon and Cerrado streams seems to reflect the local factors, the apparent small influence of regional factors may be only a result of an already disrupted wood regime.

Keywords: in-stream wood, wood budget, contemporary wood regime, channel features, landscape scale.

1. Introduction

The in-stream wood regime, one leg of the tripod[9] of physical processes that support ecological processes in rivers, consists of wood recruitment, transport, and storage in river corridors (Wohl *et al.*, 2019). It is controlled by local and regional factors that affect the sources

---

[9] The tripod is formed by the natural water flow, sediment flux, and wood regime (Wohl et al., 2019).

and sinks of wood. The wood load is summarized by the wood budget equation proposed by Benda and Sias (2003), where the amount of wood in a given stream reach in a given period of time is the result of the balance between input (lateral and fluvial recruitment) and output forces (lateral deposit, downstream transport and decay processes). This model has been successfully applied in wood load investigations worldwide, with the caveat that the contribution of the different terms of equation may change depending on the environment analysed.

In the case of tropical streams, Cadol *et al.* (2009) have demonstrated that the fluvial transport has increased importance in determining the amount of wood stored in stream channels, with higher rates of this term when compared to temperate streams. They also pointed out decay as being likely as important as transport in tropical wood budget equation but recommended further investigations. More than ten years later, studies evaluating the decomposition of wood in tropical streams remain scarce (but see Jones *et al.*, 2019). However, available information about wood decomposition on tropical forest floors (Barbosa *et al.*, 2017; Clark *et al.*, 2002; Delaney *et al.*, 1998; Harmon *et al.*, 1995; Lewis *et al.*, 2004) suggest that wood in tropics is very transient, being completely degraded in less than a decade, while in temperate river corridors wood remains stored for decades, centuries or even millennia (Guyette *et al.*, 2008; Hyatt and Naiman, 2001).

Therefore, there is a general consensus that the wood regime in tropical streams is more dynamic. However, this consensus was built based on a small number of studies and sparse regional coverage. There is a great geographic imbalance among regions studied across the globe, and a lack of information about many types of climates, forests and flowing water systems (Swanson *et al.*, 2020). To our knowledge, the wood regime in rivers of the largest tropical forest and hydrographic basin in the world, the Amazon, has never been studied. There are only few studies inventorying the coarse wood debris on its floodplains (Chao *et al.*, 2008; Martius, 1997; Silva *et al.*, 2016) and only one quantifying large wood (LW) into streams (Chapter 1), which is also the only study of instream wood in the Cerrado (the Brazilian Savanna), the second largest biome in South America. Further threatening efforts to quantify wood in these neotropical streams is the current high rate of deforestation in these two neotropical biomes in the last few years, triggered mainly by agriculture and livestock expansion (Parente *et al.*, 2021; Pereira *et al.*, 2020; Silva Junior *et al.*, 2021; Trigueiro *et al.*, 2020). Unfortunately, we may well lose the natural wood regime in the neotropical streams before we are able to describe it.

Land-use change in the riparian zones has been disrupting wood recruitment and retention worldwide, resulting in reduced instream wood amounts (Wohl *et al.*, 2019). Because of the transiency of wood in tropical streams, it is expected that they naturally contain less wood than comparable temperate streams (Wohl, 2017), and even less in human-impacted catchments. However, this seems not always to be the case in agricultural landscapes. Paula *et al.* (2011) found similar LW abundance in Southeast Brazil when compared to temperate secondary forested streams in Germany and similar or higher LW volume when compared to temperate old-growth forested streams in New Zealand and Japan, respectively. Likewise, in the first chapter when direct comparing streams, we found similar amounts of LW in Brazilian tropical forest and savanna and temperate counterparts in the USA. Both studies indicate that the differences between tropical and temperate wood stock seems to be more related to the distribution of wood size than the total number of pieces of instream wood. Tropical streams tend to have more small-sized wood than the temperate ones, probably due to a high and unceasing dropping rate of branches (Cadol and Wohl, 2010), which is apparently intensified when the riparian forest was submitted to some degradation level. However, with so limited knowledge from the tropical zone it is difficult to make generalisations, again making it imperative that further studies expand the geographic range of both surveyed sites and sites where instream wood controls are intensively studied.

The factors that regulate the dynamics of wood in a river basin may vary in the spatial scale. Given the importance of transport in the tropical wood regimes, the influence of regional factors in affecting instream wood is prominent. Under a landscape perspective, the wood regime is determined by the drainage network, the surrounding forests and the processes that link both (Swanson, 2003). Thus, many large-scale variables such as geomorphic and hydroclimatic features of the catchment (Wohl and Jaeger, 2009b), network configuration, basin size and shape, drainage, and confluence density (Benda *et al.*, 2004), and the areal cover and distance of upstream forests (Paula *et al.*, 2013; Swanson, 2003), might exert some degree of control on wood transport. However, local controls cannot be disregarded since they act by providing wood to the channel and allowing its retention or transportation, which may be enhanced in tropical streams given the high rate of wood replacement. Therefore, size, age, structure, density, distance and health of the local riparian forest (Bilby and Bisson, 1998; Costigan *et al.*, 2015; McDade *et al.*, 1990; Van Sickle and Gregory, 1990), channel dimensions, gradient, discharge, confinement, bed material and bank erosion propensity (Bilby and Bisson, 1998; Comiti *et al.*, 2016; Keller and Swanson, 1979; Martin *et al.*, 2018; Wohl and Jaeger, 2009a) also need to be considered as possible in-stream wood controls. Moreover, disturbances and episodic events, such as blowdowns and landslides are also important sources of wood that can prevail in some catchments (Robison and Beschta, 1990; Wohl *et al.*, 2012b).

Similarly, decay agents and enablers, such as environmental conditions, decomposing organisms, and wood species (Bärlocher and Boddy, 2016; Mackensen *et al.*, 2003; Martius, 1997), can have significant roles in breaking down wood in tropical systems. With this vast number of potential wood controls and with the much wider range of possible interactions between them, the task of understanding their effects is challenging but nonetheless urgent because of rapid deforestation in neotropical biomes. Therefore, our goal is to fill this gap of knowledge using a powerful and reliable multivariate statistical tool to disentangling the multifaceted and complex nature of the relationships between wood and the landscape and channel features of Cerrado and Amazon streams.

2. Methodology and Methods

2.1 Study area

This study is based on an instream habitat assessment performed in Brazilian catchments located in agricultural impacted landscapes of Cerrado and Amazon biomes. A total of 258 stream reaches (sites) were sampled, with sites distributed across six different regions: two in the Amazon and four in the Cerrado. The two Amazon regions are located in Pará state (Figure 1) and are characterized by a mosaic of mechanized agriculture, extensive and intensive pastures, forestry, densely populated colonies of small farms and settlements, and large areas of undisturbed and disturbed primary and secondary forest (Gardner *et al.*, 2013) (Table 1). The four Cerrado regions are located in the centre of the country in Minas Gerais state and on the borders of this state with Goiás and São Paulo states (Figure 1), being subject to a high degree of anthropogenic influence mainly by agriculture and livestock, preserving only small fragments of native vegetation (Macedo *et al.*, 2014) (Table 1).

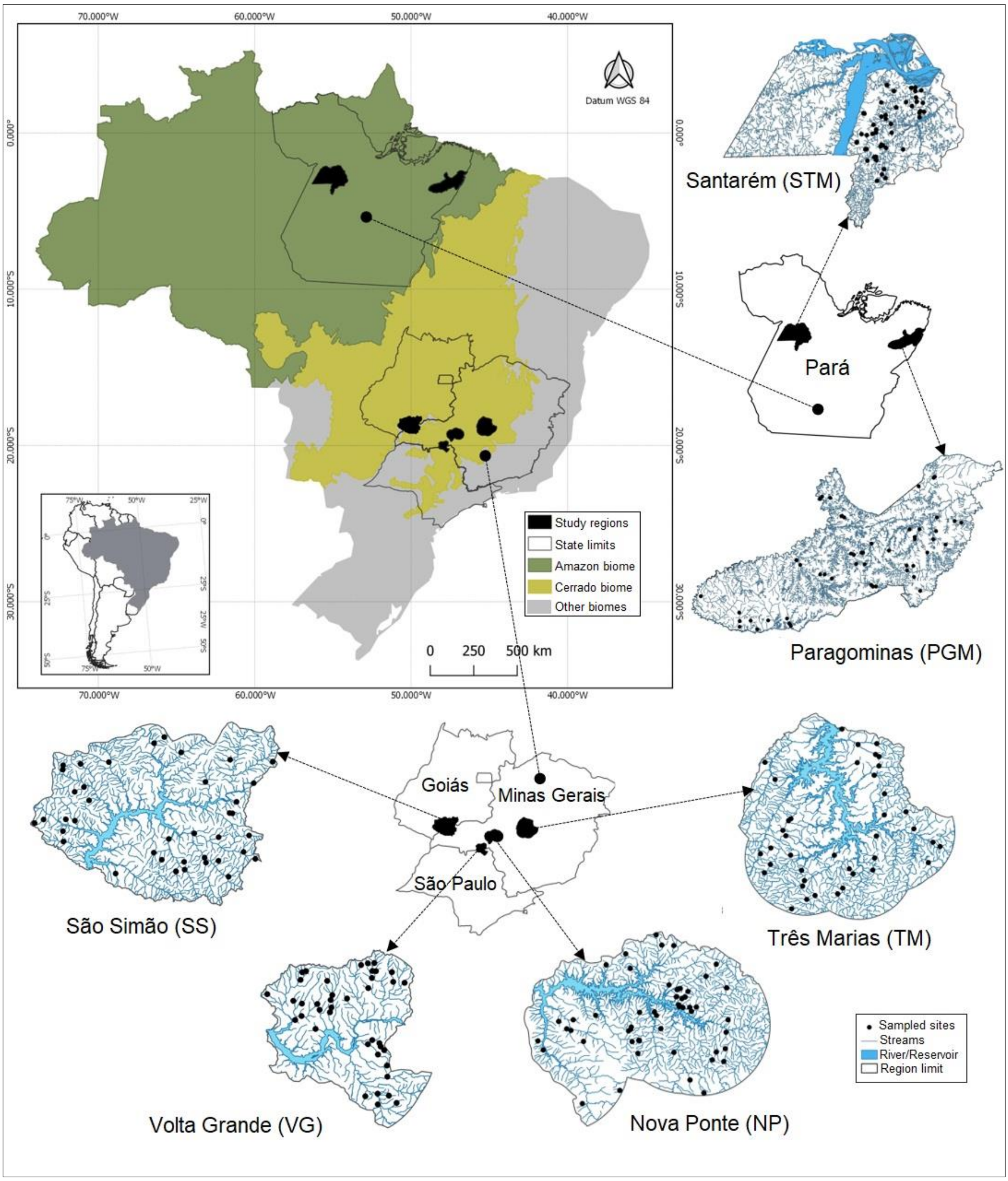


Figure II-1 - Map of the study sites in six study regions across Brazilian biomes.

Table II-1 - Summary description of the study catchments grouped by region. Mean, standard deviation and range are presented. Mean ± SD (range)

Region name	**Region Code**	**Biome**	**Number of study sites**	**Area (Km²)**	**Forest cover (%)**	**Agricultural land cover (%)**
Parago-minas	PGM	Amazon	51	12.55 ± 12.39 (0.44 – 50.37)	68.85 ± 27.02 (2.71 - 100)	2.52 ± 7.40 (0 - 44.03)
Santarém	STM	Amazon	48	28.70 ± 47.07 (0.83 – 227.13)	60.15 ± 31.18 (4.79 - 100)	7.66 ± 13.87 (0 - 59.45)
Nova Ponte	NP	Cerrado	40	10.74 ± 10.70 (1.38 – 50.74)	36.57 ± 24.98 (7.84 - 99.19)	63.06 ± 24.76 (0.81 - 91.83)
Três Marias	TM	Cerrado	40	45.23 ± 47.21 (0.45 – 164.97)	45.57 ± 18.03 (14.78 - 100)	53.81 ± 17.36 (0 - 80.27)
Volta Grande	VG	Cerrado	40	27.53 ± 30.22 (2.64 – 116.43)	11.56 ± 5.32 (0.10 - 22.78)	86.22 ± 9.21 (37.87 - 96.82)
São Simão	SS	Cerrado	39	30.23 ± 26.93 (0.37 – 108.45)	12.99 ± 6.35 (0.81 - 27.37)	85.94 ± 8.85 (48.79 - 99.19)

2.2 Data collection

We surveyed 99 wadeable streams in Amazon (51 in Paragominas - PGM and 48 in Santarém - STM), and 159 streams in Cerrado (40 in Nova Ponte - NP, 40 in Três Marias - TM, 40 in Volta Grande – VG, and 39 in São Simão - SS). At each stream we sampled one reach, where field crews made systematic measurements and observations of wood, stream channel morphology, bed substrate, riparian vegetation cover and structure during the dry season, using the USEPA methodology (Hughes and Peck, 2008; USEPA, 2013) with minor adaptations for tropical streams (see Junqueira *et al.*, 2016; Leal *et al.*, 2016). Sample reach lengths at each site were set proportional to the stream mean wetted width (40 times the mean width), with a minimum of 150 m.

Along the reach we counted all the large wood pieces (LW), which were defined as being all the pieces located inside the bankfull channel with a length ≥1.5 m and diameter ≥0.1 m at the small end (note, if small end diameter was <0.1m, the wood piece was defined as the length between large end and the point where the diameter = 0.1m). Each piece was categorised into one of five size classes (Table 2) to calculate a nominal mean volume for each piece of LW according to its diameter-length class membership (see Kaufmann *et al.*, 1999).

Table II-2 - The five wood size classes described according to length and diameter and their respective mean nominal volume calculated from Equation 1.

Diameter	Length		
	1.5 - 5 m	> 5 - 15 m	> 15 m
0.1 - 0.3 m	**T**	**S**	**M**
> 0.3 m - 0.6 m	**S**	**M**	**L**
> 0.6 m - 0.8 m	**S**	**L**	**L**
> 0.8 m	**M**	**L**	**X**

* T = tiny, S = small, M = medium, L = large and X = extra-large

In order to identify the main wood controls, we measured multiple variables at local and regional scale. At the local scale, still following USEPA methods, we sampled channel morphology measuring its dimensions such as the bankfull[10] width and height, the thalweg depth, and incision height. We also measured the channel slope and sinuosity and the bed material, classifying it as bedrock, concrete, boulder, cobble, coarse gravel, fine gravel, sand, silt and clay, hardpan, fine litter, coarse litter, wood, roots, macrophyte or algae. To characterize the riparian vegetation, we made a visual estimation of the areal cover of each one of the three vegetation layers (canopy, understory, and ground cover) located on both banks within a 10-meter field of view. The maximum cover in each layer is 100%, so the sum of the areal covers for the combined three layers could add up to 300% (USEPA, 2013). Because we are interested in the riparian forest as a source of LW, in the present study we only considered the woody riparian vegetation, excluding herbs, grasses and non-woody shrubs. As there are no stream gauges in any of the sampled catchments, we measured discharge at the time of sampling (during the low flow season) by the floating object technique and also estimated bankfull discharge using a slope-area method of Kaufmann *et al.* (2008) and Kaufmann *et al.* (2009). The detailed methods for each variable measured on channels can be checked in Hughes and Peck (2008) and USEPA (2013).

To obtain the regional variables, we first delimited the catchment area upstream each sample site from a digital elevation model (DEM) with 30 m resolution for all study regions (generated using TopoData-IBGE; Valeriano and Rossetti, 2012), except for STM, for which we used a DEM with 90 m resolution (SRTM-NASA; Jarvis *et al.*, 2008). Having the upstream catchments for each site, then we obtained the drainage network from a national database available for Cerrado regions (spatial resolution 1:25,000; FBDS, 2009). For Amazon regions, we obtained the drainage network by applying the hydrological tool ArcSWAT on ArcGIS software (Di Luzio *et al.*, 2004) with subsequent manual correction. We used satellite images (Landsat TM and ETM+ images, 30 m resolution, year 2010) to map land use and quantify the native vegetation cover that includes mature and young forest and different types of savanna (woodland savanna, parkland savanna, grassy-woody savanna, and palm swamp). Despite the different types of native vegetation in each biome, here we refer to all of them as forest to facilitate understanding and comparisons. We considered forest cover at the catchment scale, which includes the forest in the whole catchment upstream of the site. All the spatial data were

---

[10] The bankfull channel corresponds to the seasonal bed area which is flooded during the annual rainy season.

processed in geographic information systems (ArcMap 10.5 and QGis 3.4). The complete list of measured variables and their descriptions is presented on Table 3.

Table II-3 - Summary of variables measured in the field assessments or obtained through geographic information systems (GIS).

Variable	**Code**	**Unit**	**Directly Measured?**	**Description**	**Reference**
Catchment elevation	CAT_ELEV	m	Yes	Altitude measured through GPS in field assessment.	-
Catchment slope	CAT_SLOPE	%	Yes	Slope obtained through GIS tools.	Valeriano and Rossetti (2012)
Catchment area	CAT_AREA	Km^2	Yes	Area measured through GIS tools.	Valeriano and Rossetti (2012)
Catchment shape	CAT_SHAPE	-	No	$\frac{(\text{Main stem length}[11])^2}{\text{CAT\_AREA}}$	Benda *et al.* (2004)
Confluence density	CONFL_DEN	confl /Km^2	No	$\frac{\text{Confluence number}[12]}{\text{CAT\_AREA}}$	Benda *et al.* (2004)
Drainage density	DRAIN_DEN	Km^{-1}	No	$\frac{\text{Network length}[13]}{\text{CAT\_AREA}}$	Benda *et al.* (2004)
Deforestation in the catchment	CAT_DEFOR	years	Yes	Land-use intensity index = time since last deforestation event obtained through GIS tools.	Ferraz *et al.* (2012)
Forest cover in the catchment	CAT_FOR	%	Yes	Mature forest located at the catchment scale measured through GIS tools.	Gardner *et al.*, (2013)
Riparian forest on the banks	RIP_FOR	-	Yes	Woody riparian forest located on the banks estimated through visual evaluation in field assessment.	Kaufmann *et al.* (1999)
Precipita-tion	PRECIP	mm	Yes	Historical average precipitation on the catchment upstream to the site.	Fick and Hijmans (2017)
Humidity	HUMID	kPa	Yes	Historical average water vapor pressure on the catchment upstream to the site.	Fick and Hijmans (2017)
Tempera-ture	TEMP	°C	Yes	Historical average temperature on the catchment upstream to the site	Fick and Hijmans (2017)
Channel slope	CHAN_SLOPE	%	Yes	The water surface slope measured in field assessment.	Kaufmann *et al.* (1999)

---

[11] Length (Km) of the main stem of the studied stream measured through GIS tools.

[12] Number of confluences in the upstream catchment counted through GIS tools.

[13] Total length of network accounting the length of all the streams located in the upstream catchment.

Bankfull discharge	QBF	m^3/s	No	Q_{bf}[14] $= \left(\frac{1}{C_t}\right)^{\frac{1}{2}} A_{xs}(gR_{bf}S)^{\frac{1}{2}}$	Kaufmann *et al.* (2008)
Discharge variation	Q_VAR	-	No	$\frac{\text{low flow discharge}^{15}}{\text{Qbf}}$	-
Stream power	STR_PWR		No	$\Omega = \rho g Q_{bf} S$[16]	Bagnold (1966)
Bank erosion	BANK_ERO	-		$\frac{\log D_{cbf}{}^{17}}{(\text{RIP\_FOR} + 1)}$	-
Channel confine-ment	CHAN_CONF	m	No	XINC_H[18] − CHAN_DEPTH	-
Channel width	CHAN_WIDTH	m	Yes	Bankfull channel width measured in field assessment.	Kaufmann *et al.* (1999)
Channel depth	CHAN_DEPTH	cm	Yes	Bankfull channel depth measured in field assessment.	Kaufmann *et al.* (1999)
Wood stability from piece length	WSTAB_L	-	No	$\frac{\text{LW length}}{\text{Channel width}}$	Cadol *et al.* (2009)
Wood stability from piece diameter	WSTAB_D	-	No	$\frac{\text{LW diameter}}{\text{Channel depth}}$	Cadol *et al.* (2009)
Wood volume per 100m reach length	WOOD1	$m^3/100m$	No	$\frac{\text{Wood volume}^{19}}{\text{Reach length}} \text{x} 100$	Kaufmann *et al.* (1999)
Wood volume per 100 m2 of channel area	WOOD2	$m^3/100m^2$	No	$\frac{\text{Wood volume}}{\text{Reach area}^{20}} \text{ x } 100$	Kaufmann *et al.* (1999)

2.3 Conceptual model

To understand the controls on wood in the study sites, we used the wood budget model proposed by Cadol *et al.* (2009) - the Benda and Sias (2003) model adapted for tropical headwaters streams - as our starting point. However, as we only sampled each stream once, we do not know the variation of wood load over time, such we had to modify the original model to Equation 1. A better understanding of the wood budget would allow us to identify the critical

---

[14] Where Q_{bf} = bankfull discharge; $C_t = 1.21 d_{res}^{1.08} (d_{res} + WOOD2/100)^{0.638}.\ d_{th\_bf}^{-3.32}$; d_{res} = residual depth according to Kaufmann et al. (1999); d_{th_bf} = CHAN_DEPTH; A_{xs} = cross-sectional area; $R_{bf} = 0.65 d_{th\_bf}$; g = acceleration due to gravity (9.8 m/s^2); S = CHAN_SLOPE

[15] low flow discharge = discharge measured in field assessment during the dry season.

[16] Where Ω = the stream power, ρ = the density of water (1000 kg/m3), g = acceleration due to gravity (9.8 m/s^2), Q = discharge (m^3/s), and S = channel slope.

[17] Where $D_{cbf} = 0.604.\ R_{bf}.$ slope / θ; $R_{bf} = 0.65.$ bankfull depth;
$\theta = 0.04.\ R_{ep}^{-0.24}$ if $R_{ep} \leq 26$ or $\theta = 0.5[0.22 R_{ep}^{-0.6} + 0.06(10\text{^}(-7.7 R_{ep}^{-0.6}))]$ if $R_{ep} > 26$

[18] XINC_H = Incision height measured in field assessment according to Kaufmann et al. (1999).

[19] Wood volume is calculated for each wood size class according to Kaufmann et al. (1999).

[20] Reach area is the result of the average bankfull width multiplied by the reach length

factors that maintain wood recruitment and stock into those streams. Following the same approach as Comiti *et al.* (2006) and Cadol *et al.* (2009), we did not directly measure recruitment, transport, or decay in our assessment of wood loads. Instead, we inferred each of the wood budget variables by examining correlations between wood volume and its potential predictors in a large sample of stream reaches. As the wood load is the result of the sum of lateral (L_i) and downstream input (Q_i) and subtraction of decay (D), lateral (L_o) and downstream output (Q_o), knowing the factors that affect each one of these equation terms and the relationship between them, will enable us to understand the wood regime.

$$S_c = L_i - L_o + \frac{\mathbf{Q_i}}{\Delta x} - \frac{\mathbf{Q_o}}{\Delta x} - D$$

Equation 1: The modified model of the wood budget. As proposed by Cadol et. al (2009) the transport terms have prominent importance in tropical streams. For application on this study, the time term was removed from the original equation proposed by Benda and Sias (2003). S_c = wood load; L_i = lateral input of wood form tree mortality and bank erosion; L_o = lateral output of wood by flood events; Q_i = fluvial input of wood from upstream reaches; Q_o = fluvial output of wood to downstream reaches; D = wood decay; Δx = reach length.

We used LW volume scaled by channel dimensions as our in-stream wood metric. We adopted two variables, the wood volume per 100 m stream length ($m^3/100m$) (WOOD1) and the wood volume per 100 m^2 of stream surface area ($m^3/100m^2$) (WOOD2), because of their different applications. The former is more appropriate when analysing the incoming or outgoing flux of wood, the latter is more suitable once the wood is in the channel affecting habitat, sediment, and flows. Therefore, the delivery of wood should be represented by WOOD1 and the wood storage by WOOD2. To facilitate this understanding, throughout this article we will refer to WOOD1 as wood load and to WOOD2 as wood stock. Importantly, WOOD2 is influenced by WOOD1 jointly with stream size, depth, flow variables, etc.

In this study we consider L_i as the wood delivered by tree mortality and bank erosion. Landslides and wind throw were not considered here since we have not observed evidence of such events in the study sites. Furthermore, the scarcity and the low density of riparian forest in most of Cerrado sites, and the mild slope particularly in Amazon sites, discount any significant importance of these events even if they occurred. Thus, we considered riparian forest cover and bank erosion as positive and direct influences on L_i. The first because the presence of trees near-bank and the forest characteristics such as size, density, age and structural integrity affect tree mortality rate (Costigan *et al.*, 2015; McDade *et al.*, 1990; Van Sickle and Gregory, 1990). The second, because bank erosion fells trees into the stream channel

(Comiti *et al.*, 2016; Wohl *et al.*, 2011). In addition to these direct effects, we also accounted for indirect effects on L_i. Discharge, stream power, channel slope and riparian forest may affect bank erosion, which in turn affect L_i (Keller and Swanson, 1979). Climate (i.e., humidity, temperature, and precipitation) and deforestation affect forest cover in the catchment scale and also the amount and quality of the riparian forest on the channel banks, which may affect L_i directly, or indirectly through bank erosion.

The lateral output (L_o) consists of logs exported from the stream to the riparian zone during flood events. Therefore, L_o may be affected mainly by the discharge, because an increase in water level would be needed for the logs to be carried out by the flow (Ruiz-Villanueva *et al.*, 2016b). However, this type of wood loss may be significantly reduced in confined channels (Bilby and Bisson, 1998; Martin *et al.*, 2018), since it would be necessary a greater increase in discharge and, thus, in the water level, before the flow reach the riparian zone, possibly depositing wood on it.

The confinement of the channel may also indirectly affect the downstream transport terms (Q_i and Q_o), but in the opposite direction. As in confined channels the discharge is increased by the constricted area, the stream power will be also increased and thus the stream transport capacity (Bilby and Wasserman, 1989). The stream power is also affected by channel slope, but this variable may also directly influence on wood mobilization since wood pieces are more prone to move down in steep streams (Cadol and Wohl, 2010; Wohl and Jaeger, 2009a). Regarding only Q_i, the input of wood from upstream regions depends on the presence and amounts of forests in upstream reaches, since those forests are important sources of wood (Paula *et al.*, 2013; Swanson, 2003). So, the forest cover in the upstream catchment may direct and positively affect the fluvial input of wood (Q_i). And greater the number of tributaries in a catchment, greater the potential incoming flux of wood from upstream forest patches. Therefore, the drainage and confluence density in the upstream catchment may reflect in higher Q_i.

The probability of a piece of wood being trapped in the channel is opposite to its chance of being transported downstream. The ratio between wood dimensions (length and diameter) and channel dimensions (width and depth) is frequently used as an indicator of wood stability (the inverse of wood mobility) (Cadol and Wohl, 2010; Dixon and Sear, 2014), since the larger the piece size relative to the channel, the less the chance of it being carried downstream (Lienkaemper and Swanson, 1987). Therefore, Q_o would be negatively affected by wood stability.

The last term of the equation, the decay (D), includes both physical and biochemical decomposition and varies according to the environmental conditions, wood species and the diversity of decomposer organisms (Harmon *et al.*, 1986; Martius, 1997). The physical decomposition includes breakage and abrasion resulting from the friction between the wood and the water flow and sediment transport. Therefore, the wood stability and resistance to breakage and the stream discharge should be the most important variables influencing physical decomposition. The biochemical decomposition is dependent on the abundance and diversity of decomposers, as well as the wood species are important. As we neither have data about the wood quality and species nor about the decomposer community, we did not include these variables in our conceptual model. As a surrogate to infer the influence of decay on wood load we used environmental conditions, since the wood decay is highly and positively influenced mainly by temperature and moisture (Boddy, 1983; Liu *et al.*, 2013). The variation in the discharge may also influence the decay through both physical and biochemical decomposition. Repeated submersion and exposure of logs may accelerate the decay process, since the submersion events provide moisture to the wood and the exposure provides oxygen and heat to the decomposing organisms, enhancing the biochemical processes (Cadol and Wohl, 2010; Jones *et al.*, 2019; Martius, 1997). In addition, the alternation between submerged and non-submerged conditions enables the occurrence of joint effects of physical and biochemical agents, in which the microorganisms decompose the organic matter, and the water flow washes it out (Bärlocher and Boddy, 2016; Harmon *et al.*, 1986). Therefore, besides temperature and humidity we also considered precipitation averages and discharge variation as surrogate for the decomposer agents that may affect wood decay.

Besides the variables mentioned above, there are many other factors indirectly affecting the wood budget terms and thus the wood load. In order to understand the wood regime in the studied streams, we built our conceptual model as a flow chart (Figure 2). We included all the variables that we had and expected to affect the wood budget directly or indirectly, based on the published literature and personal knowledge. Because we did not measure the wood budget terms, we showed them in the flow chart merely for illustrative purposes, to understand the expected relationships between predictors and in-stream wood. Instead of using the wood budget terms themselves in the pathway analysis (see data analysis section), we simply used wood volume, represented by wood load (WOOD1 – $m^3/100m$) and stock (WOOD2 – $m^3/100m^2$).

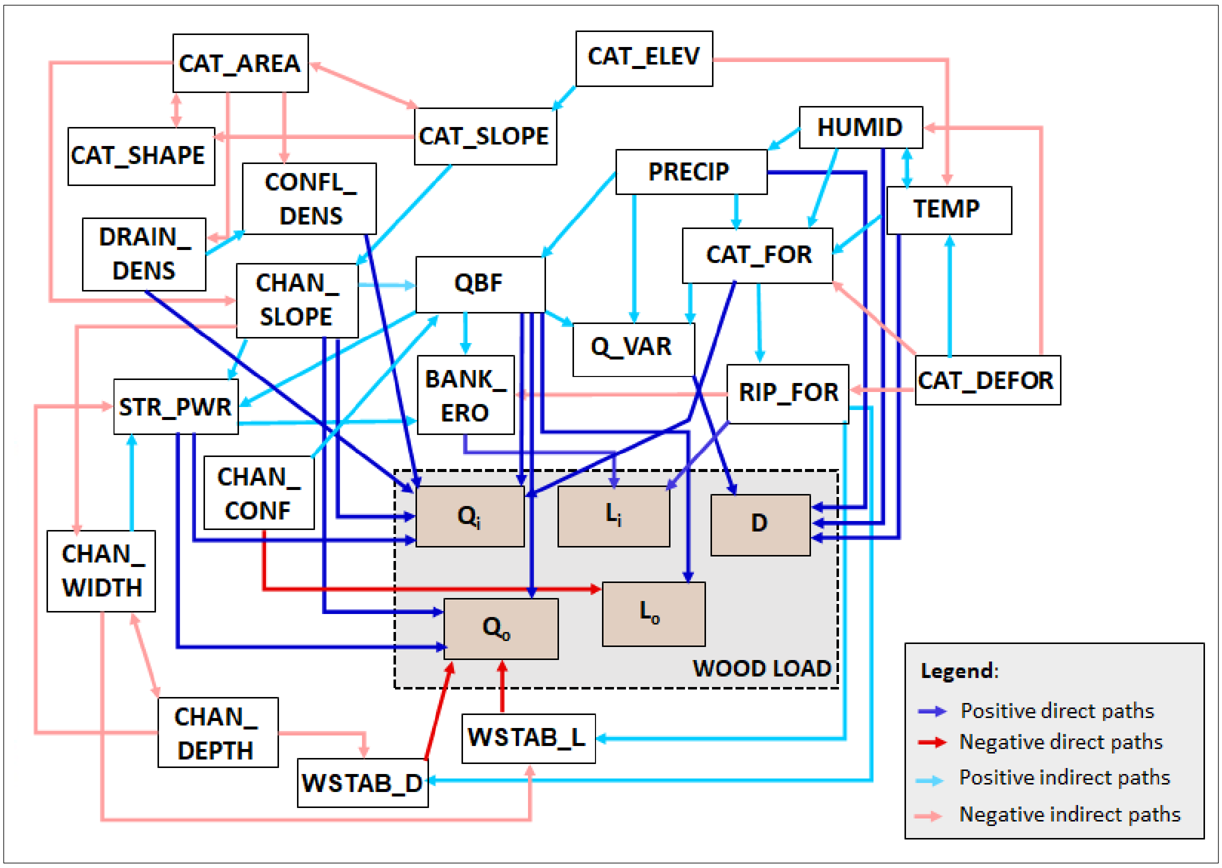


Figure II-2 - Conceptual model considering the potential predictors of instream wood in a tropical stream. One-way arrows indicate the expected effect of one variable on another and two-way arrows indicate expected correlations between them. The direct effects on wood load are indicated by dark blue and red arrows which link any potential causal variable to a response variable (the wood budget terms). The indirect effects are indicated by light blue and rose arrows which link one explanatory variable to another.

2.4 Data analysis

To test whether our conceptual model fits our dataset, we used structural equation modelling (SEM), also called pathway analysis, to confirm whether the potential predictors of wood load do explain the in-stream wood in Amazon and Cerrado streams. In the SEM statistical framework, it is possible to deal simultaneously with multiple processes to explain the functioning of a whole system (Shipley, 2000), including the direct and indirect effects between variables. In SEM, theoretically justified models are parameterized to find a solution that minimizes the difference between the model predictions and the observed data (Grace, 2008). This is made by combining regression and factorial analysis, enabling us to identify not only what explains the response variable, but how much of its variance is explained. To do so, we first applied the strictly confirmatory approach, in which we tested our conceptual model, concluding by its acceptance or refutation. Depending on whether the initial conceptual model is refuted in this step, we then proceed to the model development approach in which we set out to search for the most parsimonious model that better fits to our dataset. This is made by including or excluding paths and variables in the initial model to improve its fit to the data.

We used the local estimation method proposed by Shipley (2000) and ran the SEM in R software applying the piecewiseSEM package (Lefcheck, 2016). In the local estimation method, relationships for each endogenous[21] variable are estimated separately, fitting a linear model for each response, and then stringing together the inferences rather than trying to estimate all relationships at once (as in global estimation method) (Lefcheck, 2016). Through the test of directed separation (TDS), the piecewiseSEM indicates to us whether or not we are missing paths in our model, so that we can include those paths if the model does not fit well. In the same way we can exclude paths with non-significant relationships in the linear regression analyses. Therefore, with the caution to always ensure that each path is consistent with plausible ecological mechanisms, the search for the most suitable model is not arbitrary but guided by the strength of statistical evidence.

As piecewise SEM is a series of concatenated linear regressions, our data must meet the same assumptions as those for linear regression analysis (‘lm’[22]) otherwise we must specify the distribution of each response variable running a generalised linear model (‘glm’[23]). Because of the great number of variables and the high complexity of our initial model, we had difficulty in running ‘glm’ function in piecewiseSEM package. Thus, we decided to transform our non-normal distributed response variables using square root or log transformations and simply apply ‘lm’ function.

After running the SEM for our conceptual model, we verified that the data fit was poor ($p < 0.05$). Thus, we started the search for a better model by first excluding the non-significant paths between predictors and wood volume variables (direct paths), and then between the predictors themselves (indirect paths). Once our model had only significant pathways, we then analysed the “missing” paths indicated by TDS and added the ones we judged to represent plausible ecological mechanisms. The procedure of adding or removing paths was made one by one, always running the SEM again after each one. We analysed the results of each SEM iteration, sequentially choosing the next path to be excluded or included to the model. We stopped changing the model once we met three conditions: (i) a good fit ($p > 0.05$); (ii) all the

---

[21] In a SEM model, endogenous variables are those that have paths entering them, regardless of whether they also have paths emanating from them. On the other hand, exogenous variables only have paths emanating from them, in which case we do not try to explain what generates them.

[22] ‘lm’ is the function command to run linear regression in R software.

[23] ‘glm’ is the function command to run generalised linear regression in R software.

specified paths were significant; and (iii) no ecologically plausible paths were missing, that is, no significant relationships detected on TDS for the independence claims.

From the final model, we calculated the indirect and total effects for each pathway. The indirect effect is calculated by multiplying the direct effects linking a given pathway (e.g. to calculate the indirect effect of precipitation on wood load mediated by catchment forest, we multiplied the effect of precipitation on catchment forest by the effect of catchment forest on wood load), and the total effect is given by summing all direct and indirect effects linking a predictor (e.g. precipitation) and a response variable (e.g. wood load). After running the SEM for the global model (Amazon and Cerrado streams without grouping), we also ran a multigroup analysis per biome, in order to investigate whether wood predictors change or not depending on the biome. Finally, we plotted the predictors that differed between biomes against the wood volume metrics.

3. Results

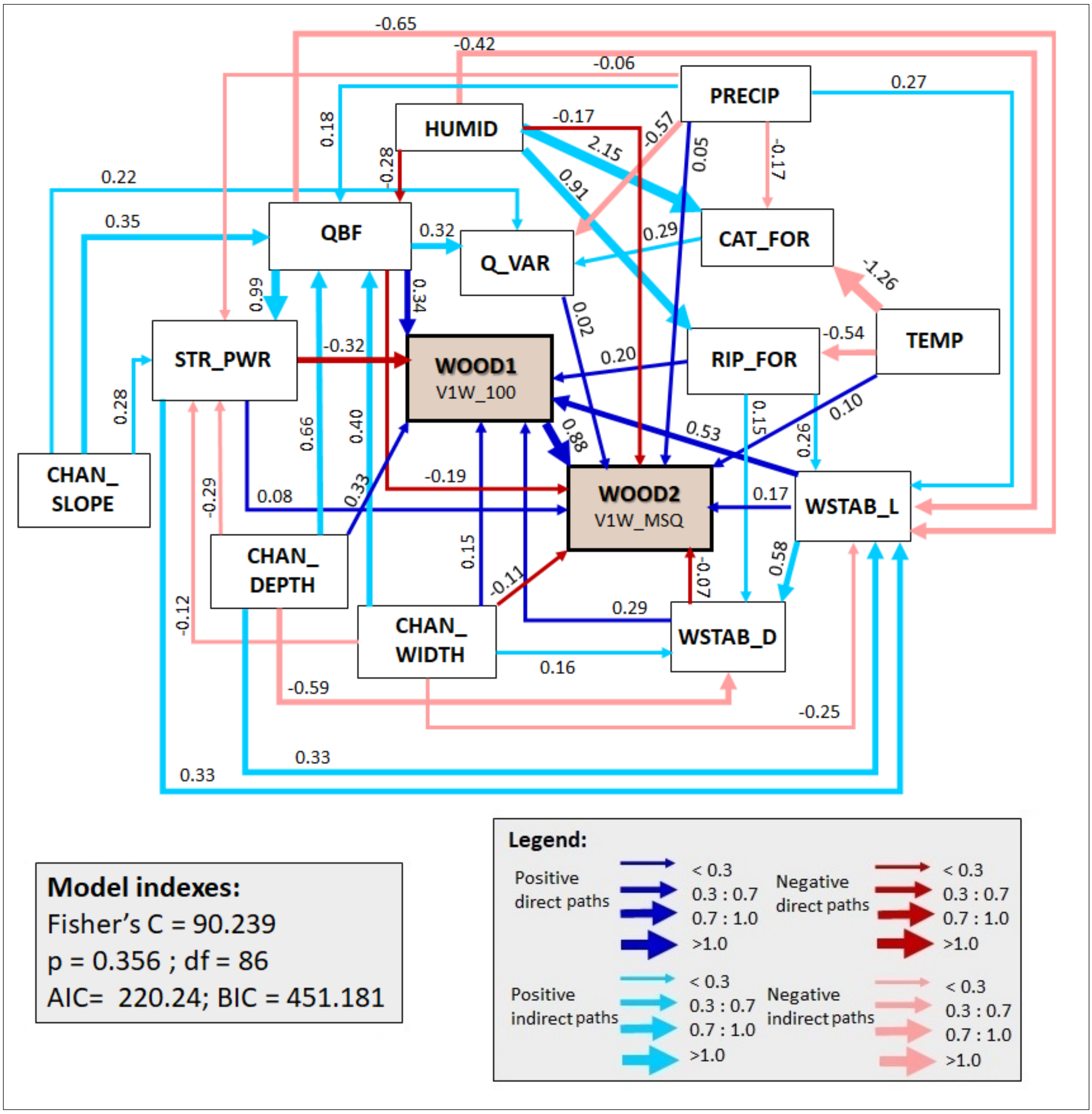
The most parsimonious model and closest to the conceptual model to explain in-stream wood in both Amazon and Cerrado regions contains 15 variables (seven exogenous, eight endogenous), 47 links and 235 pathways. The TDS indicated a number of 43 independence claims, none of them showing significant relationship between the variables involved, indicating that we were justified in excluding those relationships from our path diagram. Thus, we obtained a model-wide P = 0.356 (>0.05) implying that the hypothesized structure is supported by the data. The global goodness-of-fit Fisher's C = 90.24 and AIC = 220.24 (Figure 3). From this global model we calculated the direct, indirect, and total effect of each predictor variable on the response variables (Table 4). All the pathways and the partial effects of each predictor variable on the response ones are detailed in the supplementary material (S1).

As predicted in the conceptual model, bankfull discharge (QBF), stream power (STR_PWR), discharge variation (Q_VAR), temperature (TEMP), precipitation (PRECIP), humidity (HUMID), riparian forest (RIP_FOR), and wood stability (WSTAB-L and WSTAB-D) directly affected in-stream wood (WOOD1 or WOOD2). The channel depth (CHAN_DEPTH) and channel width (CHAN_WIDTH) also directly affected wood volume, although we expected that the effect of depth and width would be only indirect, mediated by WSTAB-L and WSTAB-D and also by WOOD1 on WOOD2 (because WOOD2 = WOOD1/ CHAN_WIDTH). Channel slope (CHAN_SLOPE) and forest cover in the catchment (CAT_FOR) had a small and indirect effect on wood (-0.10 and 0.01 respectively), whereas bank erosion (BANK_ERO), channel confinement (CHAN_CONF), confluence density (CONFL_DEN) and drainage density (DRAIN_DEN) apparently did not affect wood load and so were removed from the model. Likewise, wood volume did not respond to variables measured at a broader, catchment, scale (i.e., CAR_AREA, CAT_SHAPE, CAT_SLOPE, CAT_ELEV, CAT_DEFOR).

The variables that most directly explained wood load (WOOD1) was WSTAB-L (0.53), bankfull discharge (0.34), channel depth (0.33) and stream power (-0.32). The channel width also affected wood load directly (0.15), but the channel slope only indirectly (-0.10) mainly through stream power (0.28* - 0.32 = -0.09) and bankfull discharge (0.35 * 0.34 = 0.12). Considering the direct and indirect effects altogether, WSTAB_L is far the most important variable to explain wood load (0.53 + 0.17 = 0.70), followed by the riparian forest (0.20 + 0.23 = 0.43). The indirect effect of the riparian forest was through WSTAB_L (0.26 * 0.53 = 0.14) and WSTAB_D (0.15 * 0.29 = 0.04), increasing even more the importance of the stability of wood. The direct effect of riparian forest on wood load reflects the lateral recruitment in the wood budget equation (L_i), while the indirect effect reflects the hindrance to the transportation (Q_o), since it was positively related to the wood stability. The larger the riparian vegetation, the more stable the wood was as a consequence of the larger size of pieces. Regarding the downstream transportation (Q_i), we did not detect any direct effect of CAT_FOR on wood load, and the indirect effect came through discharge variation (0.29 * 0.02 = 0.01), instead of through RIP_FOR.

Besides affecting the wood load, these variables also affected the wood stock (WOOD2) but to a lower degree. The wood load itself was the variable that most influenced wood stock (0.88). QBF, STR_PWR and WSTAB_D had direct effects opposite to that observed for wood load (-0.19, 0.08, and -0.07 respectively). The riparian forest only affected wood stock indirectly through wood stability and wood load (0.40). The wood stock was also directly affected by the climatic predictors, which we used as surrogates for wood decay agents. We did expect that these variables had a negative effect on the wood stock, however, only humidity reduced WOOD2 (-0.17), whereas precipitation and temperature affected it positively (0.05 and 0.10 respectively), as well as discharge variation (0.02). This result shows that those variables tend to affect wood volume through other wood budget terms, L_i or Q_i, rather than decay (D), different from what we initially expected. Despite not affecting wood load (WOOD1) directly, climatic variables acted indirectly (HUMID = 0.15, PRECIP = 0.24 and TEMP = -0.23) in many ways, through riparian forest (TEMP = -0.54 * 0.20 = 0.11, HUMID

= 0.91 * 0.20 = 0.18), bankfull discharge (PRECIP = 0.18 * 0.34 = 0.06, HUMID= -0.28 * 0.34 = 0.09) and WSTAB-L (PRECIP = 0.27 * 0.53 = 0.14, HUMID = -0.42 * 0.53 = 0.22).



Model indexes:
Fisher's C = 90.239
p = 0.356 ; df = 86
AIC= 220.24; BIC = 451.181

Figure II-3 - The flow chart of the fitted SEM model to explain wood load in Cerrado and Amazon streams. The direct effects (paths) on wood load are indicated by dark colours while the indirect effects (paths) are indicated by light colours. The blue arrows indicate positive relationship and red arrows negative. The arrows weight indicates the magnitude of the predictor effect on the response variable. The numbers next to the arrows indicate the value of the SEM coefficients.

Table II-4 - Direct, indirect, and total effect of each predictor variable on the response variables (wood metrics).

Predictor	WOOD1			WOOD2		
	Direct effect	Indirect effect	Total effect	Direct effect	Indirect effect	Total effect
HUMID	0.00	0.15	0.15	-0.17	0.21	0.04
PRECIP	0.00	0.24	0.24	0.05	0.21	0.26
TEMP	0.00	-0.23	-0.23	0.10	-0.21	-0.11
CAT_FOR	0.00	0.00	0.00	0.00	0.01	0.01
RIP_FOR	0.20	0.23	0.43	0.00	0.40	0.40
QBF	0.34	-0.54	-0.20	-0.19	-0.13	-0.32
STR_PWR	-0.32	0.23	-0.09	0.08	-0.04	0.04
Q_VAR	0.00	0.00	0.00	0.02	0.00	0.02
CHAN_SLOPE	0.00	-0.10	-0.10	0.00	-0.10	-0.10
CHAN_WIDTH	0.15	-0.20	-0.05	-0.11	-0.11	-0.22
CHAN_DEPTH	0.33	-0.05	0.28	0.00	-0.05	-0.05
WSTAB_L	0.53	0.17	0.70	0.17	0.57	0.74
WSTAB_D	0.29	0.00	0.29	-0.07	0.26	0.19
WOOD1	-	-	-	0.88	0.00	0.88

Based on the final global model we ran the multi-group analysis per biome (Fisher's C = 74.95; p = 0.80) (Table 5). With regard to wood load (WOOD1), we found that examining the biomes separately only affected the role of wood stability (WSTAB_D), with this predictor ceasing to be important to explain wood in Amazon streams (Figure 3a). Regarding WOOD2, biome affected the relationships between wood and CHAN_WIDTH, QBF, STR_PWR, Q_VAR, HUMID, TEMP, WSTAB-L and WSTAB-D (Figure 3b-c). STR_PWR, HUMID, TEMP and WSTAB_D were no longer important to explain WOOD2 in Cerrado and Q_VAR in neither of the two biomes, when considering biome as a grouping variable. Biome also affected the relationship between predictor variables themselves, such as HUMID, TEMP and PRECIP on CAT_FOR, RIP_FOR, QBF and Q_VAR; CHAN_DEPTH and CHAN_DEPTH on WSTAB_L, WSTAB_D and QBF; the CHAN_SLOPE on STR_PWR; and CAT_FOR on Q_VAR (supplementary material, S2).

Table II-5 - Parameters estimated for the wood variables in the SEM multigroup analysis per biome. The predictors that differed in explaining wood between biomes are indicated by an asterisk. The significant relationship between predictor and wood metrics within biomes is highlighted in bold.

Predictor	**Amazon**				**Cerrado**			
	Estim.	Std. error	p-value	Std. estim.	Estim.	Std. error	p-value	Std. estim.
				WOOD1				
CHAN_WIDTH	**0.013**	**0.005**	**0.008**	**0.226**	**0.013**	**0.005**	**0.008**	**0.046**
CHAN_DEPTH	**0.699**	**0.199**	**<0.001**	**0.267**	**0.699**	**0.199**	**<0.001**	**0.312**
QBF	**0.504**	**0.236**	**0.034**	**0.303**	**0.504**	**0.236**	**0.034**	**0.321**
STR_PWR	**-0.329**	**0.121**	**0.007**	**-0.279**	**-0.329**	**0.121**	**0.007**	**-0.302**
RIP_FOR	**0.003**	**0.001**	**<0.001**	**0.244**	**0.003**	**0.001**	**<0.001**	**0.145**
WSTAB_L	**0.865**	**0.109**	**<0.001**	**0.557**	**0.865**	**0.109**	**<0.001**	**0.498**
WSTAB_D*	2.028	1.060	0.059	0.283	**5.953**	**1.141**	**<0.001**	**0.527**
				WOOD2				
CHAN_WIDT*	**-0.006**	**0.001**	**<0.001**	**-0.097**	**-0.044**	**0.003**	**<0.001**	**-0.146**
QBF*	**-0.429**	**0.075**	**<0.001**	**-0.232**	**-0.076**	**0.035**	**0.032**	**-0.044**
STR_PWR*	**0.132**	**0.041**	**0.002**	**0.101**	0.025	0.019	0.182	0.021
Q_VAR*	0.049	0.030	0.105	0.030	-0.003	0.007	0.665	-0.004
HUMID*	**-0.962**	**0.242**	**<0.001**	**-0.064**	0.039	0.158	0.807	0.004
PRECIP	**0.0002**	**0.0001**	**<0.001**	**0.018**	**0.0002**	**0.0001**	**<0.001**	**0.031**
TEMP*	**0.200**	**0.073**	**0.007**	**0.046**	0.002	0.015	0.893	0.002
WSTAB_L*	**0.350**	**0.043**	**<0.001**	**0.203**	**0.200**	**0.021**	**<0.001**	**0.105**
WSTAB_D*	**-0.761**	**0.196**	**<0.001**	**-0.096**	0.006	0.148	0.967	0.001
WOOD1	**0.970**	**0.012**	**<0.001**	**0.875**	**0.970**	**0.012**	**<0.001**	**0.886**

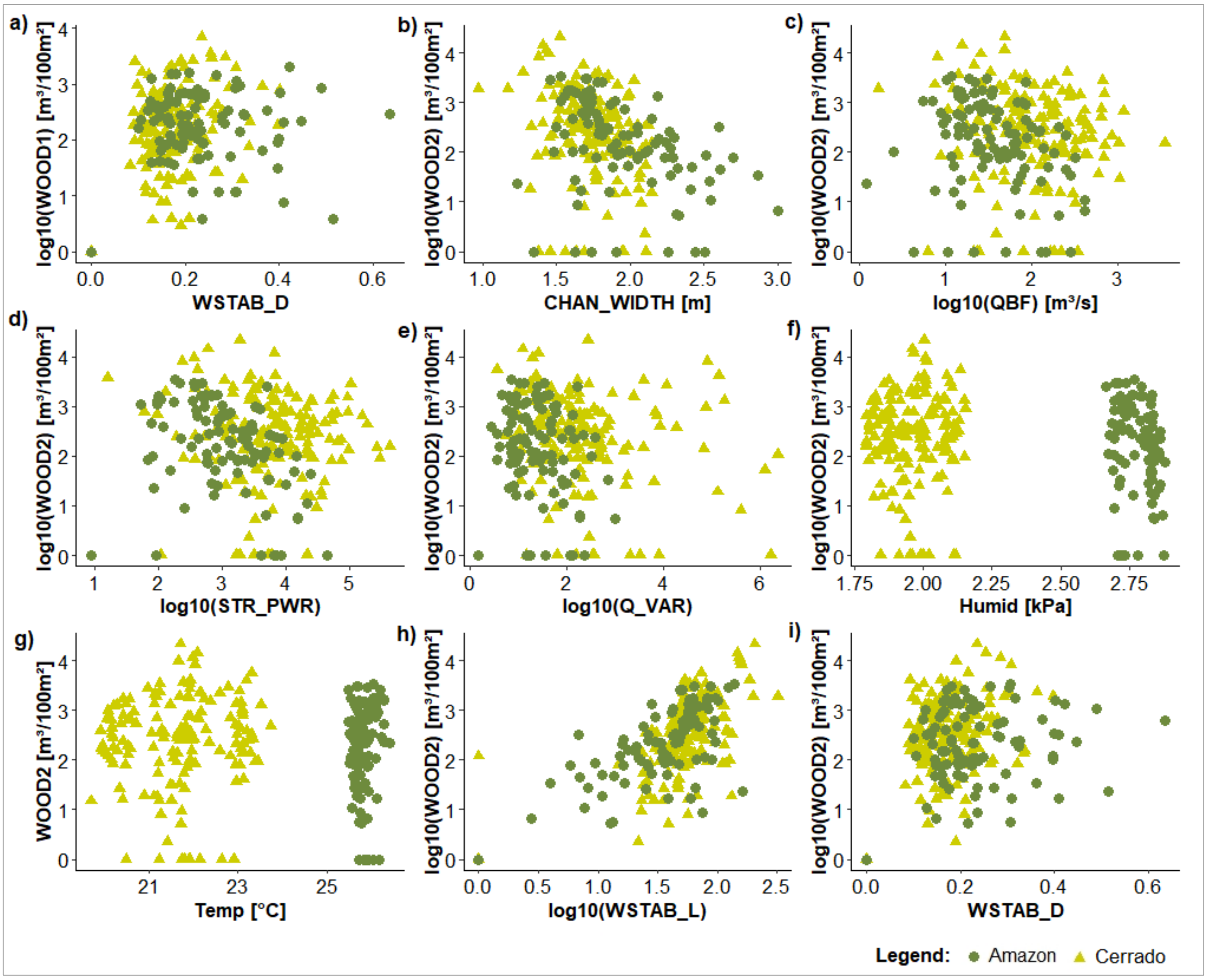


Figure II-4 - Dispersion plots between variables which differed on the SEM multigroup analysis per biome. a) wood volume per channel length (WOOD1) versus wood stability from piece length (WSTAB_D) and b) channel width (CHAN_WIDTH), c) bankfull discharge (QBF), d) stream power (STR_PWR), e) discharge variation (Q_VAR), f) humidity (Humid), g) temperature (Temp), h) wood stability from piece length (WSTAB-L), i) wood stability from piece diameter (WSTAB-D), all of them versus wood volume per channel area (WOOD2).

4. Discussion

The most important controls on wood in Amazon and Cerrado streams were wood stability, bankfull discharge, stream power, channel dimensions and riparian forest. The last one is the primary source of wood to the channels, delivering directly through dropping pieces or by floating downed wood from the riparian zone. However, wood amounts are more strongly determined by what streams can retain than by what wood is falling into the channel. Wood retention is controlled firstly by the piece size relative to the channel (wood stability) and channel dimensions, and secondly by the stream power to move it downstream. As we can see in the conceptual model (Figure 2) the wood stability, bankfull discharge and stream power are expected to be linked to the fluvial transport terms (Q_i and Q_o) of the wood budget. Our results confirmed these relationships (Figure 3), showing that the transport capacity or the resistance to transportation are the most important mechanisms behind wood load in Amazon and Cerrado. Discharge and stream power act by bringing wood from floodplain and upstream regions or removing it to downstream reaches, and the wood stability (mainly WSTAB-L and WSTAB-D in smaller scale) by keeping big pieces trapped on the channel. The importance of wood stability is also evidenced by the absence of direct effect of channel slope on wood load, indicating that even in steep streams the wood pieces remain stable if they are trapped.

As expected, the greater the stream power, the smaller the wood volume per length of channel, indicating that more wood is transported downstream. Wohl and Jaeger (2009a) reported that wood load is inversely correlated with stream power and despite some variations, it works well as a proxy indicator of relative transport capacity. Surprisingly, the bankfull discharge had a direct positive effect on wood, indicating it as an input source. So, discharge might have imported downed LW from the lateral seasonal bed or from banks by scouring and causing tree fall or unburying wood. Indeed, the floodplain may become one of the main sources of wood to forested streams through overbank flow (Latterell and Naiman, 2007). This occurs because floodplain attenuates peak flows reducing downstream transport and allowing buoyancy of downed wood or exhumation of buried pieces in alluvial channels (Wohl, 2013). This seems to apply to the streams we studied, especially those in the Amazon biome. Therefore, we expect the predominance of downstream transport forces in reaches with steeper slopes, and thus, higher stream power, while in low gradient reaches the wood supply might have come from the riparian zone during overflow events.

On the other hand, the wood stability is not indicative of wood transport itself, instead, it indicates the resistance to transport. Mobile pieces are usually shorter than the bankfull width; therefore, pieces that are large relative to the channel tend to remain trapped (Gurnell *et al.*, 2002; Lienkaemper and Swanson, 1987). This agrees with our results, since the ratio between piece length and channel width was in fact the most important factor explaining wood volume. Channel dimensions also affected wood volume. Because of the reduced transport capacity and the high wood retentiveness, small streams are known to have comparatively more wood than larger streams (Harmon *et al.*, 1986; Martin and Benda, 2001; Swanson, 2003). However, in our study, channel width and depth had a positive effect on wood volume when scaled by channel length (WOOD1). Nevertheless, when we scaled wood volume per channel area (WOOD2) this positive effect disappears in the case of channel depth and became negative in the case of the channel width, confirming that larger streams do tend to have less instream wood. The explanation for the different relationship detected between channel dimensions and wood volume depending on the metric is precisely the difference in the metric scale. As we adopted bankfull[24] measures instead of the wetted measures, a significant part of the wood volume is located outside the water, in the frequently flooded zone. The same amount of wood volume per length of channel will have greater instream volume per bankfull channel surface area in a small narrow stream than in a large, wide stream.

The local recruitment of wood was also important in predicting wood load in the studied streams, although to a lesser extent than wood stability. The denser the riparian forest, the greater the wood load. And the power of the riparian forest in predicting wood was not only direct, but also indirect through wood stability. This happens because more mature forest result in more stable pieces as a result of the larger size of the fallen trees that tend to remain trapped. Many studies have already shown that old-growth forest streams present in-stream wood in greater diameters and volumes, reflecting the more complex structure of those forests (e. g. Beckman and Wohl, 2014; Benda *et al.*, 2002; Keeton *et al.*, 2007). Besides the age of the riparian forest, its proximity to the channel also affects wood volumes (McDade *et al.*, 1990). Moreover, pieces may travel long distances so the wood stock in a reach may be reflecting the riparian forest from upstream regions (Iroumé *et al.*, 2010; Paula *et al.*, 2013; Ravazzolo *et al.*, 2015). Surprisingly, we did not detect any direct effect of the forest in the upstream catchment (CAT_FOR) on wood load, but we found an indirect effect on wood stock (WOOD2) through discharge variation. Thus, the in-stream wood in our streams may have been somewhat sensitive to the forest cover in the basin because it affects the hydrological regime, and not because it has the potential to provide wood. Indeed, catchments with sparse forest typically have altered disbalanced hydrological regimes (Kang *et al.*, 2001; Mahe *et al.*, 2005; Sriwongsitanon and Taesombat, 2011). Also, the lack of relationship between wood load (WOOD1) and catchment forest may indicate that relatively few LW pieces recruited in upstream regions are arriving in the studied reaches. This is different from what was found in another Brazilian biome, the Atlantic Forest, in streams also located in an agriculture-impacted landscape, where most of the wood was coming from upstream reaches (Paula *et al.*, 2013). Despite that, the predominant small size of LW in our study streams (Article 1) indicates that they can be easily transported. Thus, if LW pieces are not arriving from upstream it is probably because they are being degraded along the way, as expected for small sized in-stream wood (Haga *et al.*, 2002; Lienkaemper and Swanson, 1987; Merten *et al.*, 2013).

Unfortunately, our ability to estimate the role of wood decay was weak because we did not measure it, instead using climatic variables as surrogates. Still, we inferred the direct effects

---

[24] the seasonal bed area which is flooded during the annual rainy season.

of wood decay through humidity reducing wood stock (WOOD2), since water is a limiting factor to decomposing organisms (Bärlocher and Boddy, 2016). On the other hand, temperature and precipitation tended to increase wood stock, likely being more related to input sources than decay. The indirect effects between climatic variables and wood provide us some relevant insights. The negative relationship between temperature and riparian forest results in higher temperature averages in deforested streams, which in turn have less wood as demonstrated by Leal *et al.* (2016) for the same Amazon streams. Higher precipitation averages result in higher bankfull discharge, but higher humidity levels result in lower bankfull discharge average. Streams located in more humid sites have denser riparian forest which reflects in higher wood load (WOOD1), but also in less stable pieces probably due to breakage caused by decay agents that reduce the wood stock. Fragmentation and leaching are particularly important mechanisms of wood decomposition in streams leading to significant mass loss (Jones *et al.*, 2019).

Analysing the results per biome, we found that Amazon and Cerrado differ in some aspects and that the interaction between biome and wood predictors is rarely important to explain wood load (WOOD1), but commonly important to explain wood stock (WOOD2). This means that the mechanisms influencing wood load (the wood sources) are basically the same in tropical streams independent of the biome, but the channel features that determine wood stock by storage and transport can vary considerably between biomes. Regarding wood load, the general pattern detected in the global model (the transport variables being the most important wood predictor and the riparian forest playing a secondary role) persisted independent of the biome. Nevertheless, the influence of riparian forest is greater in the Amazon than in Cerrado, probably as a result of naturally denser forest due to the climatic conditions and better conservation status which are due, in turn, to the lower rates of deforestation in the region (Article 1).

Wood stability based on the piece diameter and water depth (WSTAB_D) was the only predictor of wood load that differed between biomes, ceasing to be important to explain wood in Amazon. Amazon streams have greater and more variable values of WSTAB_D than those in the Cerrado, diminishing the effect of this predictor in explaining differences in wood load among streams. This difference in wood stability is caused not by the piece diameter differences between biomes, but by differences in bankfull dimensions, since Amazon streams had wider and shallower channels (Chapter 1). The reduced channel depth would provide greater stability to the wood in Amazon, but as these streams are also wide, a piece of wood will not remain trapped even in shallow channels, as they wide enough to decrease anchoring and allow the piece to be rolled down even during mild flood events.

Precipitation and wood load (WOOD1) were the only predictors that did not differ in their influence on wood stock (WOOD2) between the two biomes; they had a positive influence of similar magnitude in both Amazon and Cerrado streams. Discharge variation, which was a minor influence on wood stock in the global model, was not important when we considered biomes separately. Therefore, the expected influence of discharge variation in reducing wood stock through decay, because of repeated episodes of submersion and exposition of wood (Cadol and Wohl, 2010; Martius, 1997) was not detectable in our data. This may be due to the limitations of our variable since we calculated discharge variation from the ratio between low flow and bankfull discharge. This variable does not exactly correspond to the submersion and exposure episodes since wood pieces may be submerged even in floods smaller than the bankfull. To better measure the influence of these episodes in wood decay we would need flow records of frequency and duration of low and high flows to use as a better indirect (surrogate) variable than the one we used, but unfortunately this kind of data is not available to the study catchments. Alternatively, further studies should measure the discharge level in which most of the in-stream wood pieces are submerged, which would provide a precise measure of the frequency and duration of submersion and exposure episodes.

Humidity affected wood stock negatively and air temperature affected it positively in the Amazon, but not in Cerrado. This is understandable because both humidity and temperature are remarkably higher in the Amazon. Therefore, the high and constant humidity and temperature levels in the Amazon (Fisch *et al.*, 1998) as well as the high diversity of decomposing microorganisms (Bustamante and Martius, 1998; Lodge, 1995; López-Quintero *et al.*, 2012) might contribute to a faster wood decay compared to the Cerrado. The high temperatures associated with high humidity in the Amazon are responsible for the typical high primary productivity of this biome. These two climatic factors influenced wood volume both by providing greater quantity of pieces, and by supplying streams with large sized pieces of wood, which are harder to break down than small ones (Merten *et al.*, 2013).

Channel width negatively affected wood stock (WOOD2) in both Amazon and Cerrado streams (Table 4), confirming the universal pattern that larger streams tend to store less wood (Harmon *et al.*, 1986; Martin and Benda, 2001; Swanson, 2003). However, in Cerrado this relationship was stronger. The pattern with bankfull discharge was reversed, affecting wood stock negatively in streams of both biomes, but in this case, the relationship was stronger in Amazon. Stream power only affected wood stock, positively in the Amazon, but not in Cerrado. These variables are related to wood transport such their influence is exerted through mobilizing and trapping pieces, which can be limited by the channel characteristics. Amazon streams have low slope and stream power, predominantly glide flow, and less confined channels (Article 1). In the Cerrado, slope and stream power are much greater, but it is also important to consider the greater amounts of deforestation and land use change in this biome (Article 1). These human activities not only reduce the input of wood but can increase the frequency and magnitude of flood events (Kang *et al.*, 2001; Mahe *et al.*, 2005; Sriwongsitanon and Taesombat, 2011). This favours downstream wood output (Q_o) in the Cerrado, which explains why the relationship between channel width and wood stock was stronger and why there was no effect of stream power on the wood stock in this biome. It is apparent that most of the wood that enters into the reaches is transported downstream, nullifying the stream power effect. The effect of bankfull discharge in reducing wood stock in Amazon streams derived not only directly from downstream transport (Q_o), but also indirectly through on is effects on lateral output (L_o) and decay (D) which are potentially favoured by the shallower channel characteristics and wetter environmental conditions. Unconfined channels allow the overflow to easily occupy adjacent areas, so LW may be easier exported to the seasonally flooded riparian areas. Furthermore, forested floodplains along the Amazon streams are able to trap floating LW (Wohl, 2017), keeping them out of the water in the riparian zone floor, where there is a high density of decomposing organisms (Martius, 1997). Therefore, bankfull discharge is likely to be a negative influence on in-stream wood in the Amazon biome through three mechanisms instead of only one.

Wood stock was also influenced by wood stability based on piece length in both biomes. The longer the piece transported relative to channel width, the higher the wood volume per area (WOOD2) in both biomes. The strength of this influence is twice as strong in the Amazon streams because they are wider and shallower and also bordered by denser riparian forest than in the Cerrado (Article 1). Conversely, the influence of the wood piece diameter based on channel depth was significant only in Amazon, where it was a small negative influence in contrast with its strong positive influence on WOOD1 in both biomes. Thus, the way the wood volume was scaled determined its relationship to with WSTAB_D. This shows that when we consider the channel area instead of the reach length, the thicker the wood related to channel depth, the lower the wood volume. This can be pointing out a soft effect of decay on wood stability, since more stable pieces tend to remain trapped in the same place, providing better opportunities to the decomposing organisms, which already have friendly conditions in the floodplain of Amazon streams (Martius, 1997). Alternatively, this could be only a mathematical consequence, since WSTAB_D and WOOD2 both have channel width in their denominator, such their association just reveals that LW volume per area with equal WOOD1 increases as width (therefore also area) decreases.

5. Conclusions

Our results indicate that the wood budget in neotropical streams impacted by agricultural activities is dominated by transport out of the stream reach (Q_o) rather than transport into the reach (Q_i). Variation in the amount of instream wood among streams was more strongly influenced by variation in transport than by differences in the amount of recruitment. Specifically, transport of wood recruited from the local riparian forest along these streams is controlled primarily by channel dimensions and the size of wood pieces relative to the channel size. Basically, the amount of wood found in the streams is the result of the wood delivered by the local riparian forest and how much of this wood remains trapped. Wood decay may play an important role, but unfortunately our ability to detect its effect was limited, indicating that the use of surrogate wood decay variables is not ideal. To clearly show the decay effect on wood budget future studies should focus on measuring the decay rates (D). The most desirable scenario to fully understand the wood regime would directly measure all terms of the wood budget equation, which also includes the recruitment rates from the local riparian forest (L_i), the export to the riparian zone (L_o) and the rates of fluvial transport in (Q_i) and out (Q_o) the reach. However, this would never be possible in a study of a spatial scale as extensive as ours. The SEM analysis proved to be a powerful tool in disentangling such complex systems when applied to this large regional dataset. Local factors dominated the wood regime in Amazon and Cerrado streams, whereas regional factors only showed influence through climatic controls. However, the lack of influence of broad scale variables, such as the upstream forest in the catchment, may be only a result of an already disrupted wood regime, the contemporary wood regime, as Wohl *et al.* (2019) warned. Further research should focus on investigating how close or far Amazon and Cerrado river corridors are from the natural neotropical wood regime.

ACKNOWLEDGEMENTS

We are grateful for financial support from Companhia Energética de Minas Gerais (CEMIG) and Instituto Nacional de Ciência e Tecnologia - Biodiversidade e Uso da Terra na Amazônia (CNPq; 574008/2008-0), Empresa Brasileira de Pesquisa Agropecuária (Embrapa; SEG: 02.08.06.005.00), the UK government Darwin Initiative (17-023), The Nature Conservancy, Natural Environment Research Council (NERC; NE/F01614X/1 and NE/G000816/1), and Fulbright Brasil. Individual funding included a Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) scholarship in

Brazil and a Science without Borders Grant in Australia (PDSE-88881.361954/2019-01) to SOS. Our manuscript was subjected to review by the U.S. Environmental Protection Agency National Health and Environmental Effects Research Laboratory's Western Ecology Division and approved for publication. Approval does not signify that the contents reflect the views of the Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

REFERENCES

Bagnold RA. 1966. An Approach to the Sediment Transport Problem from General Physics. USGS Professional Paper : 42.

Barbosa RI, de Castilho CV, de Oliveira Perdiz R, Damasco G, Rodrigues R, Fearnside PM. 2017. Decomposition rates of coarse woody debris in undisturbed Amazonian seasonally flooded and unflooded forests in the Rio Negro-Rio Branco Basin in Roraima, Brazil. Forest Ecology and Management **397** : 1–9. DOI: 10.1016/j.foreco.2017.04.026 [online] Available from: http://dx.doi.org/10.1016/j.foreco.2017.04.026

Bärlocher F, Boddy L. 2016. Aquatic fungal ecology - How does it differ from terrestrial? Fungal Ecology **19** : 5–13. DOI: 10.1016/j.funeco.2015.09.001

Beckman ND, Wohl E. 2014. Effects of forest stand age on the characteristics of logjams in mountainous forest streams. Earth Surface Processes and Landforms **39** : 1421–1431. DOI: 10.1002/esp.3531

Benda LE, Bigelow P, Worsley TM. 2002. Recruitment of wood to streams in old-growth and second-growth redwood forests, northern California, U.S.A. Canadian Journal of Forest Research **32** : 1460–1477. DOI: 10.1139/x02-065

Benda LE, Poff NL, Miller D, Dunne T, Reeves G, George P, Pollock M. 2004. The Network Dynamics Hypothesis: How Channel Networks Structure Riverine Habitats. BioScience **54** : 413. DOI: 10.1641/0006-3568(2004)054[0413:tndhhc]2.0.co;2

Benda LE, Sias JC. 2003. A quantitative framework for evaluating the mass balance of in-stream organic debris. Forest Ecology and Management **172** : 1–16. DOI: 10.1016/S0378-1127(01)00576-X

Bilby RE, Bisson PA. 1998. Function and Distibution of Large Woody Debris. In River ecology and management: lessons from the Pacific Coastal Ecoregion, NAIMAN, R. J.; Bilby RE (ed). Springer: New York; 324–346.

Bilby RE, Wasserman LJ. 1989. Forest practices and riparian management in Washington State: Data based regulation development. In: Gresswell RE, Barton BA and Kershner JL (eds) Practical approaches to riparian resource management: an educational workshop. Billings: U.S. Bureau of Land Management.

Boddy L. 1983. Carbon dioxide release from decomposing wood: Effect of water content and temperature. Soil Biology and Biochemistry **15** : 501–510. DOI: 10.1016/0038-0717(83)90042-1

Bustamante NCR, Martius C. 1998. Nutritional preferences of wood-feeding termites inhabiting floodplain forest of the Amazon River, Brazil. Acta Amazonica **28** : 301–307.

Cadol D, Wohl E. 2010. Wood retention and transport in tropical, headwater streams, La Selva Biological Station, Costa Rica. Geomorphology **123** : 61–73. DOI: 10.1016/j.geomorph.2010.06.015

Cadol D, Wohl E, Goode JR, Jaeger KL. 2009. Wood distribution in neotropical forested headwater streams of La Selva, Costa Rica. Earth Surface Processes and Landforms **34** : 1198–1215. DOI: 10.1002/esp.1800 [online] Available from: http://doi.wiley.com/10.1002/esp.1800

Chao KJ, Phillips OL, Baker TR. 2008. Wood density and stocks of coarse woody debris in a northwestern Amazonian landscape. Canadian Journal of Forest Research **38** : 795–805. DOI: 10.1139/X07-163

Clark DB, Clark DA, Brown S, Oberbauer SF, Veldkamp E. 2002. Stocks and flows of coarse woody debris across a tropical rain forest nutrient and topography gradient. Forest Ecology and Management **164** : 237–248. DOI: 10.1016/S0378-1127(01)00597-7 [online] Available from: https://linkinghub.elsevier.com/retrieve/pii/S0378112701005977

Comiti F, Andreoli A, Lenzi MA, Mao L. 2006. Spatial density and characteristics of woody debris in five mountain rivers of the Dolomites (Italian Alps). Geomorphology **78** : 44–63. DOI: 10.1016/j.geomorph.2006.01.021

Comiti F, Lucía A, Rickenmann D. 2016. Large wood recruitment and transport during large floods: A review. Geomorphology **269** : 23–39. DOI: 10.1016/j.geomorph.2016.06.016 [online] Available from: http://dx.doi.org/10.1016/j.geomorph.2016.06.016

Costigan KH, Soltesz PJ, Jaeger KL. 2015. Large wood in central Appalachian headwater streams: Controls on and potential changes to wood loads from infestation of hemlock woolly adelgid. Earth Surface Processes and Landforms **40** : 1746–1763. DOI: 10.1002/esp.3751

Delaney M, Brown S, Lugo AE, Torres-Lezama A, Quintero NB. 1998. The quantity and turnover of dead wood in permanent forest plots in six life zones of Venezuela. Biotropica **30** : 2–11. DOI: 10.1111/j.1744-7429.1998.tb00364.x

Dixon SJ, Sear DA. 2014. The influence of geomorphology on large wood dynamics in a low gradient headwater stream. Water Resources Research **50** : 9194–9210. DOI: 10.1002/2014WR015947 [online] Available from: http://doi.wiley.com/10.1002/2014WR015947

FBDS - Fundação Brasileira para o Desenvolvimento Sustentável. 2009. Mapeamento em Alta Resolução dos Biomas Brasileiros. Rio de Janeiro, Brasil. Available from FBDS web page: http://geo.fbds.org.br/. Date accessed: 2021-10-29.

Ferraz SFB, Cassiano CC, Begotti RA, Tranquilin AR. 2012. Land use change analysis tools (LUCAT). II Congresso Brasileiro de Ecologia de Paisagens.

Fick SE, Hijmans RJ. 2017. WorldClim 2: new 1-km spatial resolution climate surfaces for global land areas. International Journal of Climatology **37** : 4302–4315. DOI: 10.1002/joc.5086

Fisch G, Marendo JA, Nobre CA. 1998. Uma revisão geral sobre o clima da Amazônia. Acta Amazonica **28** : 101–126. DOI: 10.1590/1809-43921998282126

Gardner TA *et al.* 2013. A social and ecological assessment of tropical land uses at multiple scales: the Sustainable Amazon Network. Philosophical Transactions of the Royal Society B: Biological Sciences **368** : 20120166–20120166. DOI: 10.1098/rstb.2012.0166 [online] Available from: http://rstb.royalsocietypublishing.org/cgi/doi/10.1098/rstb.2012.0166

Grace JB. 2008. Structural Equation Modeling for Observational Studies. Journal of Wildlife Management **72** : 14–22. DOI: 10.2193/2007-307 [online] Available from: http://www.bioone.org/doi/abs/10.2193/2007-307

Gurnell AM, Piégay H, Swanson FJ, Gregory S V. 2002. Large wood and fluvial processes. Freshwater Biology **47** : 601–619. DOI: 10.1046/j.1365-2427.2002.00916.x

Guyette RP, Dey DC, Stambaugh MC. 2008. The temporal distribution and carbon storage of large oak wood in streams and floodplain deposits. Ecosystems **11** : 643–653. DOI: 10.1007/s10021-008-9149-9

Haga H, Kumagai T, Otsuki K, Ogawa S. 2002. Transport and retention of coarse woody debris in mountain streams: An in situ field experiment of log transport and a field survey of coarse woody debris distribution. Water Resources Research **38** : 1-1-1–16. DOI: 10.1029/2001WR001123 [online] Available from: http://doi.wiley.com/10.1029/2001WR001123

Harmon ME, Franklin JF, Swanson FJ, Sollins P, Gregory S V, Lattin JD, Anderson NH, Cline SP, Aumen NG, Sedell JR. 1986. Ecology of Coarse Woody Debris in Temperate Ecosystems. Advances in Ecological Research **15** : 133–302.

Harmon ME, Whigham DF, Sexton J, Olmsted I. 1995. Decomposition and Mass of Woody Detritus in the Dry Tropical Forests of the Northeastern Yucatan Peninsula , Mexico. Biotropica **27** : 305–316.

Hughes RM, Peck D V. 2008. Acquiring data for large aquatic resource surveys: the art of compromise among science, logistics, and reality. Journal of the North American Benthological Society **27** : 837–859. DOI: 10.1899/08-028.1

Hyatt TL, Naiman RJ. 2001. The residence time of large woody debris in the Queets River, Washington, USA. Ecological Applications **11** : 191–202. DOI: 10.1890/1051-0761(2001)011[0191:TRTOLW]2.0.CO;2

Iroumé A, Andreoli A, Comiti F, Ulloa H, Huber A. 2010. Forest Ecology and Management Large wood abundance, distribution and mobilization in a third order Coastal mountain range river system, southern Chile. **260** : 480–490. DOI: 10.1016/j.foreco.2010.05.004

Jarvis A, Reuter, HI, Nelson, A, Guevara, E. 2008. Hole-filled SRTM for the globe Version 4. Available from the CGIAR- CSI SRTM 90m Database. http://srtm.csi.cgiar.org

Jones JM, Heath KD, Ferrer A, Brown SP, Canam T, Dalling JW. 2019. Wood decomposition in aquatic and terrestrial ecosystems in the tropics: contrasting biotic and abiotic processes. FEMS Microbiology Ecology **95** : 1–13. DOI: 10.1093/femsec/fiy223 [online] Available from: https://academic.oup.com/femsec/article/doi/10.1093/femsec/fiy223/5184448

Junqueira NT, Macedo DR, de Souza RCR, Hughes RM, Callisto M, Pompeu PS. 2016. Influence of environmental variables on stream fish fauna at multiple spatial scales. Neotropical Ichthyology **14** DOI: 10.1590/1982-0224-20150116

Kang S, Zhang L, Song X. 2001. Runoff and sediment loss responses to rainfall and land use in two agricultural catchments on the Loess Plateau of China. Hydrological Processes **15** : 977–988. DOI: 10.1002/hyp.191

Kaufmann PR, Faustini JM, Larsen DP, Shirazi MA. 2008. A roughness-corrected index of relative bed stability for regional stream surveys. Geomorphology **99** : 150–170. DOI: 10.1016/j.geomorph.2007.10.007

Kaufmann, PR, Larsen, DP, Faustini, JM. 2009 Bed stability and sedimentation associated with human disturbances in Pacific Northwest streams. Journal of the American Water Resources Association, **45**, 434–459.

Kaufmann PR, Levine P, Robison EG, Seeliger C, Peck D V. 1999. Quantifying Physical Habitat in . EPA/620/R-. U.S. Environmental Protection Agency: Washington, DC

Keeton WS, Kraft CE, Warren DR. 2007. Mature and old-growth riparian forests: Structure, dynamics, and effects on adirondack stream habitats. Ecological Applications **17** : 852–868. DOI: 10.1890/06-1172

Keller EA, Swanson FJ. 1979. Effects of large organic material on channel form and fluvial processes. Earth Surface Processes and Landforms **4** : 361–380.

Latterell JJ, Naiman RJ. 2007. Sources and dynamics of large logs in a temperate floodplain river. Ecological Applications **17** : 1127–1141. DOI: 10.1890/06-0963

Leal CG *et al.* 2016. Multi-scale assessment of human-induced changes to Amazonian instream habitats. Landscape Ecology **31** : 1725–1745. DOI: 10.1007/s10980-016-0358-x

Lefcheck JS. 2016. piecewiseSEM: Piecewise structural equation modelling in r for ecology, evolution, and systematics. Methods in Ecology and Evolution **7** : 573–579. DOI: 10.1111/2041-210X.12512

Lewis SL *et al.* 2004. Tropical forest tree mortality, recruitment and turnover rates: Calculation, interpretation and comparison when census intervals vary. Journal of Ecology **92** : 929–944. DOI: 10.1111/j.0022-0477.2004.00923.x

Lienkaemper GW, Swanson FJ. 1987. Dynamics of large woody debris in streams in old-growth Douglas-fir forests. Canadian Journal of Forest Research **17** : 150–156. DOI: 10.1139/x87-027

Liu W, Schaefer D, Qiao L, Liu X. 2013. What controls the variability of wood-decay rates? Forest Ecology and Management **310** : 623–631. DOI: 10.1016/j.foreco.2013.09.013 [online] Available from: http://dx.doi.org/10.1016/j.foreco.2013.09.013

Lodge DJ. 1995. A survey of patterns of diversity in non-lichenized fungi. Mitteilungen - Eidgenossischen forschungsanstalt fur Wald, Schnee und Landschaft **70** : 157–173.

López-Quintero CA, Straatsma G, Franco-Molano AE, Boekhout T. 2012. Macrofungal diversity in Colombian Amazon forests varies with regions and regimes of disturbance. Biodiversity and Conservation **21** : 2221–2243. DOI: 10.1007/s10531-012-0280-8

Di Luzio M, Srinivasan R, Arnold JG. 2004. A GIS-coupled hydrological model system for the watershed assessment of agricultural nonpoint and point sources of pollution. Transactions in GIS **8** : 113–136. DOI: 10.1111/j.1467-9671.2004.00170.x

Macedo, D.R., Pompeu, P.S., Morais, L., Castro, M.A., Alves, C.B.M., França, J.S., Sanches, B.O., Uchôa, J., Callisto, M. 2014. Sampling site selection, land use and cover, field reconnaissance, and sampling. Ecological conditions in hydropower basins (ed. by M. Callisto, R.M. Hughes, J.M. Lopes, and M.A. Castro), pp. 61–83. Companhia Energética de Minas Gerais, Belo Horizonte, Brazil.

Mackensen J, Bauhus J, Webber E. 2003. Decomposition rates of coarse woody debris - A review with particular emphasis on Australian tree species. Australian Journal of Botany **51** : 27–37. DOI: 10.1071/BT02014

Mahe G, Paturel JE, Servat E, Conway D, Dezetter A. 2005. The impact of land use change on soil water holding capacity and river flow modelling in the Nakambe River, Burkina-Faso. Journal of Hydrology **300** : 33–43. DOI: 10.1016/j.jhydrol.2004.04.028

Martin DJ, Benda LE. 2001. Patterns of Instream Wood Recruitment and Transport at the Watershed Scale. Transactions of the American Fisheries Society **130** : 940–958. DOI: 10.1577/1548-8659(2001)130<0940:poiwra>2.0.co;2

Martin DJ, Harden CP, Tran L, Pavlowsky RT. 2018. Investigating patterns of in-channel wood deposition locations in a low-gradient, variably-confined alluvial river system. Progress in Physical Geography **42** : 139–161. DOI: 10.1177/0309133318759613

Martius C. 1997. Decomposition of Wood. In The Central Amazon Floodplain: Ecology of a Pulsing System , Junk WJ (ed). Springer: Plön, Germany; 267–276.

McDade MH, Swanson FJ, McKee WA, Franklin JF, Van Sickle J. 1990. Source distances for coarse woody debris entering small streams in werstern Oregon and Washington. Canadian Journal of Fisheries and Aquatic Science **20** : 326–330.

Merten EC, Vaz PG, Decker-Fritz JA, Finlay JC, Stefan HG. 2013. Relative importance of breakage and decay as processes depleting large wood from streams. Geomorphology **190** : 40–47. DOI: 10.1016/j.geomorph.2013.02.006

Parente L, Nogueira S, Baumann L, Almeida C, Maurano L, Affonso AG, Ferreira L. 2021. Quality assessment of the PRODES Cerrado deforestation data. Remote Sensing Applications: Society and Environment **21** DOI: 10.1016/j.rsase.2020.100444

Paula FR De, Ferraz SFDB, Gerhard P, Vettorazzi CA, Ferreira A. 2011. Large woody debris input and its influence on channel structure in agricultural lands of Southeast Brazil. Environmental Management **48** : 750–763. DOI: 10.1007/s00267-011-9730-4

Paula FR, Gerhard P, Wenger SJ, Ferreira A, Vettorazzi CA, de Barros Ferraz SF. 2013. Influence of forest cover on in-stream large wood in an agricultural landscape of southeastern Brazil: A multi-scale analysis. Landscape Ecology **28** : 13–27. DOI: 10.1007/s10980-012-9809-1

Pereira EJ de AL, Ribeiro LC de S, Freitas LF da S, Pereira HB de B. 2020. Brazilian policy and agribusiness damage the Amazon rainforest. Land Use Policy **92** : 104491. DOI: 10.1016/j.landusepol.2020.104491 [online] Available from: https://doi.org/10.1016/j.landusepol.2020.104491

Ravazzolo D, Mao L, Garniga B, Picco L, Lenzi Mario A. 2015. Volume and Travel Distance of Wood Pieces in the Tagliamento River (Northeastern Italy). In Engineering Geology for Society and Territory - Volume 3 , . Springer International Publishing: Cham; 135–138. [online] Available from: http://link.springer.com/10.1007/978-3-319-09054-2_26

Robison EG, Beschta RL. 1990. Characteristics of coarse woody debris for several coastal streams of southeast Alaska, USA. Canadian Journal of Fisheries and Aquatic Sciences **47** : 1684–1693. DOI: 10.1139/f90-193

Ruiz-Villanueva V, Wyzga B, Hajdukiewicz H, Stoffel M. 2016. Exploring large wood retention and deposition in contrasting river morphologies linking numerical modelling and field observations. Earth Surface Processes and Landforms **41** : 446–459. DOI: 10.1002/esp.3832

Shipley B. 2000. Cause and Correlation in Biology: A User's Guide to Path Analysis, Structural Equations and Causal Inference . Cambridge University Press: Cambridge [online] Available from: https://www.cambridge.org/core/product/identifier/9780511605949/type/book

Van Sickle J, Gregory S V. 1990. Modeling inputs of large woody debris to streams from falling trees. Canadian Journal of Forest Research **20** : 1593–1601.

Silva Junior CHL, Pessôa ACM, Carvalho NS, Reis JBC, Anderson LO, Aragão LEOC. 2021. The Brazilian Amazon deforestation rate in 2020 is the greatest of the decade. Nature Ecology and Evolution **5** : 144–145. DOI: 10.1038/s41559-020-01368-x [online] Available from: http://dx.doi.org/10.1038/s41559-020-01368-x

Silva LFSG, de Castilho CV, de Oliveira Cavalcante C, Pimentel TP, Fearnside PM, Barbosa RI. 2016. Production and stock of coarse woody debris across a hydro-edaphic gradient of oligotrophic forests in the northern Brazilian Amazon. Forest Ecology and Management **364** : 1–9. DOI: 10.1016/j.foreco.2015.12.045

Sriwongsitanon N, Taesombat W. 2011. Effects of land cover on runoff coefficient. Journal of Hydrology **410** : 226–238. DOI: 10.1016/j.jhydrol.2011.09.021

Swanson FJ. 2003. Wood in Rivers: A Ladscape Perspective. American Fisheries Society Symposium **37** : 299–313.

Swanson FJ, Gregory S V., Iroumé A, Ruiz-Villanueva V, Wohl E. 2020. Reflections on the history of research on large wood in rivers. Earth Surface Processes and Landforms : esp.4814. DOI: 10.1002/esp.4814 [online] Available from: https://onlinelibrary.wiley.com/doi/abs/10.1002/esp.4814

Trigueiro WR, Nabout JC, Tessarolo G. 2020. Uncovering the spatial variability of recent deforestation drivers in the Brazilian Cerrado. Journal of Environmental Management **275** DOI: 10.1016/j.jenvman.2020.111243

USEPA. 2013. National Rivers and Streams Assessment 2013-2014: Field Operations Manual – Wadeable. . EPA-841-B-. Office of Water: Washington, DC [online] Available from: https://www.epa.gov/sites/production/files/2016-04/documents/nrsa1314_fom_wadeable_version1_20130501.pdf

Valeriano M de M, Rossetti D de F. 2012. Topodata: Brazilian full coverage refinement of SRTM data. Applied Geography **32** : 300–309. DOI: 10.1016/j.apgeog.2011.05.004 [online] Available from: http://dx.doi.org/10.1016/j.apgeog.2011.05.004

Wohl E *et al.* 2012a. The hydrology of the humid tropics. Nature Climate Change **2** : 655–662. DOI: 10.1038/nclimate1556 [online] Available from: http://dx.doi.org/10.1038/nclimate1556

Wohl E. 2013. Floodplains and wood. Earth-Science Reviews **123** : 194–212. DOI: 10.1016/j.earscirev.2013.04.009 [online] Available from: https://linkinghub.elsevier.com/retrieve/pii/S0012825213000834

Wohl E. 2017. Bridging the gaps: An overview of wood across time and space in diverse rivers. Geomorphology **279** : 3–26. DOI: 10.1016/j.geomorph.2016.04.014 [online] Available from: https://linkinghub.elsevier.com/retrieve/pii/S0169555X16302082

Wohl E *et al.* 2019. The natural wood regime in rivers. BioScience **69** : 259–273. DOI: 10.1093/biosci/biz013

Wohl E, Bolton S, Cadol D, Comiti F, Goode JR, Mao L. 2012b. A two end-member model of wood dynamics in headwater neotropical rivers. Journal of Hydrology **462**–**463** : 67–76. DOI: 10.1016/j.jhydrol.2011.01.061

Wohl E, Jaeger K. 2009a. A conceptual model for the longitudinal distribution of wood in mountain streams. Earth Surface Processes and Landforms **34** : 329–344. DOI: 10.1002/esp.1722 [online] Available from: http://doi.wiley.com/10.1002/esp.1730

Wohl E, Jaeger KL. 2009b. Geomorphic implications of hydroclimatic differences among step-pool channels. Journal of Hydrology **374** : 148–161. DOI: 10.1016/j.jhydrol.2009.06.008

Wohl E, Polvi LE, Cadol D. 2011. Wood distribution along streams draining old-growth floodplain forests in Congaree National Park, South Carolina, USA. Geomorphology **126** : 108–120. DOI: 10.1016/j.geomorph.2010.10.035

SUPLEMENTARY MATERIAL
(SUPPORTING ONLINE ONLY INFORMATION)

S1: All the possible pathways and the partial effects of each predictor on the wood variables.

HUMIDITY	
WOOD1	
Pathways	**Effect**
HUMID->RIP_FOR->WOOD1	0.182
HUMID->RIP_FOR->WSTAB_D->WOOD1	0.040
HUMID->RIP_FOR->WSTAB_L->WOOD1	0.125
HUMID->RIP_FOR->WSTAB_L->WSTAB_D->WOOD1	0.040
HUMID->WSTAB_L->WOOD1	-0.223
HUMID->WSTAB_L->WSTAB_D->WOOD1	-0.071
HUMID->QBF->WOOD1	-0.095
HUMID->QBF->STR_PWR->WOOD1	0.089
HUMID->QBF->STR_PWR->WSTAB_L->WOOD1	-0.048
HUMID->QBF->STR_PWR->WSTAB_L->WSTAB_D->WOOD1	-0.015
HUMID->QBF->WSTAB_L->WOOD1	0.096
HUMID->QBF->WSTAB_L->WSTAB_D->WOOD1	0.031
TOTAL	**0.150**
WOOD2	
Pathways	**Effect**
HUMID->WOOD2	-0.170
HUMID->CAT_FOR->Q_VAR->WOOD2	0.012
HUMID->RIP_FOR->WSTAB_D->WOOD2	-0.010
HUMID->RIP_FOR->WSTAB_L->WOOD2	0.040
HUMID->RIP_FOR->WSTAB_L->WSTAB_D->WOOD2	-0.010
HUMID->QBF->WOOD2	0.053
HUMID->QBF->STR_PWR->WOOD2	-0.022
HUMID->QBF->STR_PWR->WSTAB_D->WOOD2	0.006
HUMID->QBF->STR_PWR->WSTAB_L->WOOD2	-0.016
HUMID->QBF->STR_PWR->WSTAB_L->WSTAB_D->WOOD2	0.004
HUMID->QBF->Q_VAR->WOOD2	-0.002
HUMID->QBF->WSTAB_L->WOOD2	0.031
HUMID->QBF->WSTAB_L->WSTAB_D->WOOD2	-0.007
HUMID->RIP_FOR->WOOD1->WOOD2	0.160
HUMID->RIP_FOR->WSTAB_D->WOOD1->WOOD2	0.035
HUMID->RIP_FOR->WSTAB_L->WOOD1->WOOD2	0.110
HUMID->RIP_FOR->WSTAB_L->WSTAB_D->WOOD1->WOOD2	0.035
HUMID->WSTAB_L->WOOD1->WOOD2	-0.196
HUMID->WSTAB_L->WSTAB_D->WOOD1->WOOD2	-0.062
HUMID->QBF->WOOD1->WOOD2	-0.084
HUMID->QBF->STR_PWR->WOOD1->WOOD2	0.078
HUMID->QBF->STR_PWR->WSTAB_L->WOOD1->WOOD2	-0.043
HUMID->QBF->STR_PWR->WSTAB_L->WSTAB_D->WOOD1->WOOD2	-0.014
HUMID->QBF->WSTAB_L->WOOD1->WOOD2	0.085

HUMID->QBF->WSTAB_L->WSTAB_D->WOOD1->WOOD2	0.027
TOTAL	**0.043**

PRECIPITATION	
WOOD1	
Pathways	**Effect**
PRECIP->QBF->WOOD1	0.061
PRECIP->QBF->STR_PWR->WOOD1	-0.057
PRECIP->QBF->STR_PWR->WSTAB_L->WOOD1	0.031
PRECIP->QBF->STR_PWR->WSTAB_L->WSTAB_D->WOOD1	0.010
PRECIP->STR_PWR->WOOD1	0.019
PRECIP->STR_PWR->WSTAB_L->WOOD1	-0.010
PRECIP->STR_PWR->WSTAB_L->WSTAB_D->WOOD1	-0.003
PRECIP->WSTAB_L->WOOD1	0.143
PRECIP->WSTAB_L->WSTAB_D->WOOD1	0.045
TOTAL	**0.239**
WOOD2	
Pathways	**Effect**
PRECIP->WOOD2	0.050
PRECIP->CAT_FOR->Q_VAR->WOOD2	0.001
PRECIP->Q_VAR->WOOD2	-0.011
PRECIP->WSTAB-L->WOOD2	0.046
PRECIP->WSTAB-L->WSTAB_D->WOOD2	-0.011
PRECIP->QBF->WOOD2	-0.034
PRECIP->QBF->Q_VAR->WOOD2	0.001
PRECIP->QBF->STR_PWR->WOOD2	0.014
PRECIP->QBF->STR_PWR->WSTAB_L->WOOD2	0.010
PRECIP->QBF->STR_PWR->WSTAB_L->WSTAB_D->WOOD2	-0.002
PRECIP->QBF->WSTAB_L->WOOD2	-0.020
PRECIP->QBF->WSTAB_L->WSTAB_D->WOOD2	0.005
PRECIP->STR_PWR->WOOD2	-0.005
PRECIP->STR_PWR->WSTAB_L->WOOD2	0.007
PRECIP->STR_PWR->WSTAB_L->WSTAB_D->WOOD2	0.001
PRECIP->QBF->WOOD1->WOOD2	0.054
PRECIP->QBF->STR_PWR->WOOD1->WOOD2	-0.050
PRECIP->QBF->STR_PWR->WSTAB_L->WOOD1->WOOD2	0.027
PRECIP->QBF->STR_PWR->WSTAB_L->WSTAB_D->WOOD1->WOOD2	0.009
PRECIP->STR_PWR->WOOD1->WOOD2	0.017
PRECIP->STR_PWR->WSTAB_L->WOOD1->WOOD2	-0.009
PRECIP->STR_PWR->WSTAB_L->WSTAB_D->WOOD1->WOOD2	-0.003
PRECIP->WSTAB_L->WOOD1->WOOD2	0.126
PRECIP->WSTAB_L->WSTAB_D->WOOD1->WOOD2	0.040
TOTAL	**0.261**

TEMPERATURE
WOOD1

Pathways	**Effect**
TEMP->RIP_FOR->WOOD1	-0.108
TEMP->RIP_FOR->WSTAB_D->WOOD1	-0.023
TEMP->RIP_FOR->WSTAB_L->WOOD1	-0.074
TEMP->RIP_FOR->WSTAB_L->WSTAB_D->WOOD1	-0.024
TOTAL	**-0.230**
WOOD2	
Pathways	**Effect**
TEMP->WOOD2	0.100
TEMP->CAT_FOR->Q_VAR->WOOD2	-0.007
TEMP->RIP_FOR->WOOD1->WOOD2	-0.095
TEMP->RIP_FOR->WSTAB_D->WOOD1->WOOD2	-0.021
TEMP->RIP_FOR->WSTAB_L->WOOD1->WOOD2	-0.065
TEMP->RIP_FOR->WSTAB_L->WSTAB_D->WOOD1->WOOD2	-0.021
TOTAL	**-0.109**

FOREST COVER IN THE CATCHMENT	
WOOD1	
Pathways	**Effect**
-	
TOTAL	**0.000**
WOOD2	
Pathways	**Effect**
CAT_FOR->Q_VAR->WOOD2	0.006
TOTAL	**0.006**

RIPARIAN FOREST ON THE BANKS	
WOOD1	
Pathways	**Effect**
RIP_FOR->WOOD1	0.200
RIP_FOR->WSTAB_D->WOOD1	0.044
RIP_FOR->WSTAB_L->WOOD1	0.138
RIP_FOR->WSTAB_L->WSTAB_D->WOOD1	0.044
TOTAL	**0.425**
WOOD2	
Pathways	**Effect**
RIP_FOR->WSTAB_D->WOOD2	-0.011
RIP_FOR->WSTAB_L->WOOD2	0.044
RIP_FOR->WSTAB_L->WSTAB_D->WOOD2	-0.011
RIP_FOR->WOOD1->WOOD2	0.176
RIP_FOR->WSTAB_D->WOOD1->WOOD2	0.038
RIP_FOR->WSTAB_L->WOOD1->WOOD2	0.121
RIP_FOR->WSTAB_L->WSTAB_D->WOOD1->WOOD2	0.038
TOTAL	**0.397**

BANKFULL DISCHARGE	
WOOD1	
Pathways	**Effect**
QBF->WOOD1	0.340
QBF->STR_PWR->WOOD1	-0.317
QBF->STR_PWR->WSTAB_L->WOOD1	0.173
QBF->STR_PWR->WSTAB_L->WSTAB_D->WOOD1	0.055
QBF->WSTAB_L->WOOD1	-0.345
QBF->WSTAB_L->WSTAB_D->WOOD1	-0.109
TOTAL	**-0.203**
WOOD2	
Pathways	**Effect**
QBF->WOOD2	-0.190
QBF->Q_VAR->WOOD2	0.006
QBF->STR_PWR->WOOD2	0.079
QBF->STR_PWR->WSTAB_L->WOOD2	0.056
QBF->STR_PWR->WSTAB_L->WSTAB_D->WOOD2	-0.013
QBF->WSTAB_L->WOOD2	-0.111
QBF->WSTAB_L->WSTAB_D->WOOD2	0.026
QBF->WOOD1->WOOD2	0.299
QBF->STR_PWR->WOOD1->WOOD2	-0.279
QBF->STR_PWR->WSTAB_L->WOOD1->WOOD2	0.152
QBF->STR_PWR->WSTAB_L->WSTAB_D->WOOD1->WOOD2	0.048
QBF->WSTAB_L->WOOD1->WOOD2	-0.303
QBF->WSTAB_L->WSTAB_D->WOOD1->WOOD2	-0.096
TOTAL	**-0.324**

STREAM POWER	
WOOD1	
Pathways	**Effect**
STR_PWR->WOOD1	-0.320
STR_PWR->WSTAB_L->WOOD1	0.175
STR_PWR->WSTAB_L->WSTAB_D->WOOD1	0.056
TOTAL	**-0.090**
WOOD2	
Pathways	**Effect**
STR_PWR->WOOD2	0.080
STR_PWR->WSTAB_L->WOOD2	0.056
STR_PWR->WSTAB_L->WSTAB_D->WOOD2	-0.013
STR_PWR->WOOD1->WOOD2	-0.282
STR_PWR->WSTAB_L->WOOD1->WOOD2	0.154
STR_PWR->WSTAB_L->WSTAB_D->WOOD1->WOOD2	0.049
TOTAL	**0.044**

DISCHARGE VARIATION
WOOD1

Pathways	**Effect**
-	
TOTAL	**0.000**
WOOD2	
Pathways	**Effect**
Q_VAR->WOOD2	0.020
TOTAL	**0.020**

CHANNEL SLOPE	
WOOD1	
Pathways	**Effect**
CHAN_SLOPE->QBF->WOOD1	0.119
CHAN_SLOPE->QBF->STR_PWR->WOOD1	-0.111
CHAN_SLOPE->QBF->STR_PWR->WSTAB_L->WOOD1	0.061
CHAN_SLOPE->QBF->STR_PWR->WSTAB_L->WSTAB_D->WOOD1	0.019
CHAN_SLOPE->QBF->WSTAB_L->WOOD1	-0.121
CHAN_SLOPE->QBF->WSTAB_L->WSTAB_D->WOOD1	-0.038
CHAN_SLOPE->STR_PWR->WOOD1	-0.090
CHAN_SLOPE->STR_PWR->WSTAB_L->WOOD1	0.049
CHAN_SLOPE->STR_PWR->WSTAB_L->WSTAB_D->WOOD1	0.016
TOTAL	**-0.096**
WOOD2	
Pathways	**Effect**
CHAN_SLOPE->QBF->WOOD2	-0.067
CHAN_SLOPE->QBF->STR_PWR->WOOD2	0.028
CHAN_SLOPE->QBF->STR_PWR->WSTAB_L->WOOD2	0.019
CHAN_SLOPE->QBF->STR_PWR->WSTAB_L->WSTAB_D->WOOD2	-0.005
CHAN_SLOPE->QBF->WSTAB_L->WOOD2	-0.039
CHAN_SLOPE->QBF->WSTAB_L->WSTAB_D->WOOD2	0.009
CHAN_SLOPE->STR_PWR->WOOD2	0.022
CHAN_SLOPE->STR_PWR->WSTAB_L->WOOD2	0.016
CHAN_SLOPE->STR_PWR->WSTAB_L->WSTAB_D->WOOD2	-0.004
CHAN_SLOPE->Q_VAR->WOOD2	0.004
CHAN_SLOPE->QBF->WOOD1->WOOD2	0.105
CHAN_SLOPE->QBF->STR_PWR->WOOD1->WOOD2	-0.098
CHAN_SLOPE->QBF->STR_PWR->WSTAB_L->WOOD1->WOOD2	0.053
CHAN_SLOPE->QBF->STR_PWR->WSTAB_L->WSTAB_D->WOOD1->WOOD2	0.017
CHAN_SLOPE->QBF->WSTAB_L->WOOD1->WOOD2	-0.106
CHAN_SLOPE->QBF->WSTAB_L->WSTAB_D->WOOD1->WOOD2	-0.034
CHAN_SLOPE->STR_PWR->WOOD1->WOOD2	-0.079
CHAN_SLOPE->STR_PWR->WSTAB_L->WOOD1->WOOD2	0.043
CHAN_SLOPE->STR_PWR->WSTAB_L->WSTAB_D->WOOD1->WOOD2	0.014

TOTAL	**-0.099**

CHANNEL DEPTH	
WOOD1	
Pathways	**Effect**
CHAN_DEPTH->WOOD1	0.330
CHAN_DEPTH->QBF->WOOD1	0.224
CHAN_DEPTH->QBF->STR_PWR->WOOD1	-0.209
CHAN_DEPTH->QBF->STR_PWR->WSTAB_L->WOOD1	0.114
CHAN_DEPTH->QBF->STR_PWR->WSTAB_L->WSTAB_D->WOOD1	0.036
CHAN_DEPTH->QBF->WSTAB_L->WOOD1	-0.227
CHAN_DEPTH->QBF->WSTAB_L->WSTAB_D->WOOD1	-0.072
CHAN_DEPTH->STR_PWR->WOOD1	0.093
CHAN_DEPTH->STR_PWR->WSTAB_L->WOOD1	-0.051
CHAN_DEPTH->STR_PWR->WSTAB_L->WSTAB_D->WOOD1	-0.016
CHAN_DEPTH->WSTAB_L->WOOD1	0.175
CHAN_DEPTH->WSTAB_L->WSTAB_D->WOOD1	0.056
CHAN_DEPTH->WSTAB_D->WOOD1	-0.171
TOTAL	**0.282**
WOOD2	
Pathways	**Effect**
CHAN_DEPTH->QBF->WOOD2	-0.076
CHAN_DEPTH->QBF->STR_PWR->WOOD2	0.052
CHAN_DEPTH->QBF->STR_PWR->WSTAB_L->WOOD2	0.037
CHAN_DEPTH->QBF->STR_PWR->WSTAB_L->WSTAB_D->WOOD2	-0.009
CHAN_DEPTH->QBF->WSTAB_L->WOOD2	-0.073
CHAN_DEPTH->QBF->WSTAB_L->WSTAB_D->WOOD2	0.017
CHAN_DEPTH->STR_PWR->WOOD2	-0.023
CHAN_DEPTH->STR_PWR->WSTAB_L->WOOD2	-0.016
CHAN_DEPTH->STR_PWR->WSTAB_L->WSTAB_D->WOOD2	0.004
CHAN_DEPTH->WSTAB_L->WOOD2	0.056
CHAN_DEPTH->WSTAB_L->WSTAB_D->WOOD2	-0.013
CHAN_DEPTH->WSTAB_D->WOOD2	0.041
CHAN_DEPTH->QBF->WOOD1->WOOD2	0.197
CHAN_DEPTH->QBF->STR_PWR->WOOD1->WOOD2	-0.184
CHAN_DEPTH->QBF->STR_PWR->WSTAB_L->WOOD1->WOOD2	0.101
CHAN_DEPTH->QBF->STR_PWR->WSTAB_L->WSTAB_D->WOOD1-WOOD2	0.032
CHAN_DEPTH->QBF->WSTAB_L->WOOD1->WOOD2	-0.200
CHAN_DEPTH->QBF->WSTAB_L->WSTAB_D->WOOD1->WOOD2	-0.063
CHAN_DEPTH->STR_PWR->WOOD1->WOOD2	0.082
CHAN_DEPTH->STR_PWR->WSTAB_L->WOOD1->WOOD2	-0.045
CHAN_DEPTH->STR_PWR->WSTAB_L->WSTAB_D->WOOD1->WOOD2	-0.014
CHAN_DEPTH->WSTAB_L->WOOD1->WOOD2	0.154
CHAN_DEPTH->WSTAB_L->WSTAB_D->WOOD1->WOOD2	0.049

CHAN_DEPTH->WSTAB_D->WOOD1->WOOD2	-0.151
TOTAL	**-0.045**

CHANNEL WIDTH	
WOOD1	
Pathways	**Effect**
CHAN_WIDTH->WOOD1	0.150
CHAN_WIDTH->QBF->WOOD1	0.136
CHAN_WIDTH->QBF->STR_PWR->WOOD1	-0.127
CHAN_WIDTH->QBF->STR_PWR->WSTAB_L->WOOD1	0.069
CHAN_WIDTH->QBF->STR_PWR->WSTAB_L->WSTAB_D->WOOD1	0.022
CHAN_WIDTH->QBF->WSTAB_L->WOOD1	-0.138
CHAN_WIDTH->QBF->WSTAB_L->WSTAB_D->WOOD1	-0.044
CHAN_WIDTH->STR_PWR->WOOD1	0.038
CHAN_WIDTH->STR_PWR->WSTAB_L->WOOD1	-0.021
CHAN_WIDTH->STR_PWR->WSTAB_L->WSTAB_D->WOOD1	-0.007
CHAN_WIDTH->WSTAB_L->WOOD1	-0.133
CHAN_WIDTH->WSTAB_L->WSTAB_D->WOOD1	-0.042
CHAN_WIDTH->WSTAB_D->WOOD1	0.046
TOTAL	**-0.048**
WOOD2	
Pathways	**Effect**
CHAN_WIDTH->WOOD2	-0.110
CHAN_WIDTH->QBF->WOOD2	-0.076
CHAN_WIDTH->QBF->STR_PWR->WOOD2	0.032
CHAN_WIDTH->QBF->STR_PWR->WSTAB_L->WOOD2	0.022
CHAN_WIDTH->QBF->STR_PWR->WSTAB_L->WSTAB_D->WOOD2	-0.005
CHAN_WIDTH->QBF->WSTAB_L->WOOD2	-0.044
CHAN_WIDTH->QBF->WSTAB_L->WSTAB_D->WOOD2	0.011
CHAN_WIDTH->STR_PWR->WOOD2	-0.010
CHAN_WIDTH->STR_PWR->WSTAB_L->WOOD2	-0.007
CHAN_WIDTH->STR_PWR->WSTAB_L->WSTAB_D->WOOD2	0.002
CHAN_WIDTH->WSTAB_L->WOOD2	-0.043
CHAN_WIDTH->WSTAB_L->WSTAB_D->WOOD2	0.010
CHAN_WIDTH->WSTAB_D->WOOD2	0.041
CHAN_WIDTH->WOOD1->WOOD2	0.132
CHAN_WIDTH->QBF->WOOD1->WOOD2	0.120
CHAN_WIDTH->QBF->STR_PWR->WOOD1->WOOD2	-0.112
CHAN_WIDTH->QBF->STR_PWR->WSTAB_L->WOOD1->WOOD2	0.061
CHAN_WIDTH->QBF->STR_PWR->WSTAB_L->WSTAB_D->WOOD1->WOOD2	0.019
CHAN_WIDTH->QBF->WSTAB_L->WOOD1->WOOD2	-0.121
CHAN_WIDTH->QBF->WSTAB_L->WSTAB_D->WOOD1->WOOD2	-0.038
CHAN_WIDTH->STR_PWR->WOOD1->WOOD2	0.034
CHAN_WIDTH->STR_PWR->WSTAB_L->WOOD1->WOOD2	-0.018

CHAN_WIDTH->STR_PWR->WSTAB_L->WSTAB_D->WOOD1->WOOD2	-0.006
CHAN_WIDTH->WSTAB_L->WOOD1->WOOD2	-0.117
CHAN_WIDTH->WSTAB_L->WSTAB_D->WOOD1->WOOD2	-0.037
CHAN_WIDTH->WSTAB_D->WOOD1->WOOD2	0.041
TOTAL	**-0.223**

WOOD STABILITY FROM PIECE LENGTH - WSTAB_L	
WOOD1	
Pathways	**Effect**
WSTAB_L->WOOD1	0.530
WSTAB_L->WSTAB_D->WOOD1	0.168
TOTAL	**0.698**
WOOD2	
Pathways	**Effect**
WSTAB_L->WOOD2	0.170
WSTAB_L->WSTAB_D->WOOD2	-0.041
WSTAB_L->WOOD1->WOOD2	0.466
WSTAB_L->WSTAB_D->WOOD1->WOOD2	0.148
TOTAL	**0.744**

WOOD STABILITY FROM PIECE DIAMETER - WSTAB_D	
WOOD1	
Pathways	**Effect**
WSTAB_D->WOOD1	0.290
TOTAL	**0.290**
WOOD2	
Pathways	**Effect**
WSTAB_D->WOOD2	-0.070
WSTAB_D->WOOD1->WOOD2	0.255
TOTAL	**0.185**

WOOD LOAD - WOOD 1	
WOOD2	
Pathways	**Effect**
WOOD1->WOOD2	0.880
TOTAL	**0.880**

S2: The parameters estimated for the predictor variables in the SEM multigroup analysis per biome. The predictors that differed among themselves between biome are indicated by an asterisk. The significant relationship between predictors within biome is highlighted in bold.

Predictor	**Amazon**				**Cerrado**			
	Estim.	Std. error	p-value	Std. estim.	Estim.	Std. error	p-value	Std. estim.
	QBF							
CHAN_SLOPE	**24.867**	**2.669**	**<0.001**	**0.276**	**24.867**	**2.669**	**<0.001**	**0.415**
CHAN_WIDTH*	**0.019**	**0.002**	**<0.001**	**0.576**	**0.078**	**0.008**	**<0.001**	**0.445**
CHAN_DEPTH	**0.939**	**0.057**	**<0.001**	**0.598**	**0.939**	**0.939**	**<0.001**	**0.660**
HUMID	**-0.384**	**0.089**	**<0.001**	**-0.047**	**-0.384**	**0.089**	**<0.001**	**-0.072**
PRECIP*	-0.000	0.000	0.1277	-0.092	**0.001**	**0.000**	**<0.001**	**0.271**
	STR_PWR							
QBF	**1.460**	**0.041**	**<0.001**	**1.033**	**1.460**	**0.041**	**<0.001**	**1.013**
CHAN_SLOPE*	**44.901**	**4.411**	**<0.001**	**0.352**	**23.819**	**2.364**	**<0.001**	**0.275**
CHAN_WIDTH	**-0.010**	**0.002**	**<0.001**	**-0.210**	**-0.010**	**0.002**	**<0.001**	**-0.040**
CHAN_DEPTH	**-0.602**	**0.056**	**<0.001**	**-0.271**	**-0.602**	**0.056**	**<0.001**	**-0.293**
PRECIP	**-0.000**	**0.000**	**<0.001**	**-0.023**	**-0.002**	**0.000**	**<0.001**	**-0.037**
	Q_VAR							
CHAN_SLOPE	**28.921**	**6.314**	**<0.001**	**0.282**	**28.921**	**6.314**	**<0.001**	**0.233**
PRECIP*	0.000	0.000	0.538	0.048	**-0.003**	**0.001**	**<0.001**	**-0.355**
QBF	**0.606**	**0.093**	**<0.001**	**0.533**	**0.606**	**0.093**	**<0.001**	**0.292**
CAT_FOR*	-0.003	0.003	0.326	-0.076	**0.012**	**0.004**	**0.001**	**0.240**
	WSTAB_L							
RIP_FOR	**0.003**	**0.001**	**<0.001**	**0.298**	**0.003**	**0.001**	**<0.001**	**0.203**
CHAN_WIDTH	**-0.013**	**0.004**	**<0.001**	**-0.365**	**-0.013**	**0.004**	**<0.001**	**-0.084**
CHAN_DEPTH	**0.427**	**0.136**	**0.002**	**0.254**	**0.428**	**0.136**	**0.002**	**0.332**
HUMID	**-0.512**	**0.130**	**<0.001**	**-0.058**	**-0.512**	**0.130**	**<0.001**	**-0.105**
PRECIP	**0.001**	**0.000**	**0.004**	**0.091**	**0.001**	**0.000**	**0.004**	**0.176**
QBF	**-0.590**	**0.183**	**0.001**	**-0.551**	**-0.590**	**0.183**	**0.001**	**-0.652**
STR_PWR	**0.2075**	**0.097**	**0.033**	**0.274**	**0.207**	**0.097**	**0.033**	**0.330**
	WSTAB_D							
RIP_FOR	**0.000**	**0.000**	**<0.001**	**0.159**	**0.000**	**0.000**	**<0.001**	**0.152**
CHAN_DEPTH*	**-0.241**	**0.016**	**<0.001**	**-0.662**	**-0.115**	**0.008**	**<0.001**	**-0.581**
WSTAB_L*	**0.147**	**0.012**	**<0.001**	**0.678**	**0.106**	**0.007**	**<0.001**	**0.690**
CHAN_WIDTH*	**0.002**	**0.000**	**<0.001**	**0.260**	**0.007**	**0.001**	**<0.001**	**0.279**
	CAT_FOR							
HUMID	**180.160**	**12.769**	**<0.001**	**0.711**	**180.160**	**12.769**	**<0.001**	**0.818**
PRECIP*	0.044	0.024	0.073	0.232	**-0.088**	**0.010**	**<0.001**	**-0.568**
TEMP	**-19.952**	**2.176**	**<0.001**	**-0.274**	**-19.952**	**2.176**	**<0.001**	**-0.951**
	RIP_FOR							
HUMID*	**347.979**	**92.622**	**<0.001**	**0.346**	-46.318	74.933	0.537	-0.122
TEMP*	**-69.396**	**26.631**	**0.011**	**-0.240**	6.825	7.135	0.340	0.189

ARTIGO III - *Large wood retention, recruitment and mobilization in low order streams of Cerrado, Southeast Brazil*

Sarah de Oliveira Saraiva; Rafael Pereira Leitão; Paulo dos Santos Pompeu

(Manuscrito redigido na língua e formato indicado para revista - número de linhas foi retirado para melhor adequação ao formato da tese)

LARGE WOOD RETENTION, RECRUITMENT AND MOBILIZATION IN LOW ORDER STREAMS OF CERRADO, SOUTHEAST BRAZIL

SARAIVA, S. O.[1], LEITÃO[2], R. P., POMPEU, P. S[1].*

[1] Departamento de Ecologia e Conservação, Instituto de Ciências Naturais, Universidade Federal de Lavras, Lavras - MG, Brazil, 37.200-900.
[2] Departamento de Biologia Geral, Universidade Federal de Minas Gerais, Belo Horizonte, Brazil, 31270-901.
** Corresponding author*

Abstract

The delivery of wood to streams varies in space and time and may occur continuously or episodically. Once in the stream, wood may be retained or transported due to the balance between driving (water flow) and resisting forces (channel features and wood characteristics). Despite the scarcity of studies directly measuring wood mobility, a great variation of the annual transport rates and mean travelled distances worldwide was already detected. However, there is a knowledge gap in regard to tropical streams and even more to tropical non-forested environments. In the present study we aimed to document the large wood (LW) recruitment, retention, and mobilization over a period of one year in low order streams of Cerrado (the South American Savanna), by tagging and tracing LW pieces. We detected high rates of LW transport and recruitment in Cerrado streams, such the total wood amounts remained constant from one year to another. However, there were important differences between streams due to distinct channel morphologies and the occurrence of episodic events. The LW size slightly influenced the likelihood of a piece being transported long distances. Still, the LW length and diameter, original local and orientation were the most important factors to predict the LW travelled distance, which varied from zero to almost 100 m. Our findings bring unprecedented information about the mobility of wood in tropical non-forested streams of South America. To fulfill the knowledge gap, more research is needed, and further studies should include monitoring the channel and hydrology variables in longer term surveys. Extra effort should be taken to characterize the great diversity of tropical wood pieces, including their densities.

Keywords: wood mobility, travelled distance, transport rates, breakdown, LW dimensions.

1. Introduction

Wood is known to play an important role in the morphology and ecology of streams (Bisson *et al.*, 1987; Montgomery, 2003; Wohl, 2013). In-stream wood, markedly the large wood pieces (LW, classically defined as those longer than 1 m and thicker than 10 cm), alters channel width and depth. It also creates pools and rapids (Abbe and Montgomery, 1996; Bilby and Bisson, 1998; Paula *et al.*, 2011; Rosenfeld and Huato, 2003); promotes increased roughness and the variation in substrate sizes (Abbe and Montgomery, 1996; Faustini and

Jones, 2003; Kaufmann *et al.*, 2008); contributes to the appearance of islands and margin stabilization (Brooks *et al.*, 2001; Shields-Jr *et al.*, 2004); increases nutrient cycling, sediment retention and carbon storage (Beckman and Wohl, 2014; Guyette *et al.*, 2008; Harmon *et al.*, 1986; Sutfin *et al.*, 2016). Besides benefiting the aquatic biota through the structuration of the physical habitat (Kaufmann and Hughes, 2006; Leal *et al.*, 2016; Macedo *et al.*, 2016), wood still improves populations and communities (Angermeier and Karr, 1984; Herdrich *et al.*, 2018; Leitão *et al.*, 2018; Pettit *et al.*, 2013; Sterling and Warren, 2018), by providing spawning areas, shelter and cover (Bisson *et al.*, 1987; Bryant, 1983; Montgomery *et al.*, 1999; Power, 2003; Wright and Flecker, 2004). It also increases the availability of organic matter, nutrients and food (Bilby and Bisson, 1998; Frainer *et al.*, 2018).

Delivered by the riparian forest through individual or mass tree mortality, bank or floodplain erosion, windstorms or landslides, the recruitment of wood happens continuously or episodically, varying temporally and spatially along with the river network (Wohl, 2017). Wohl *et al.* (2012) proposed a two-end member model to explain wood dynamics in headwater neotropical streams. When the individual tree fall is the primary source of wood to streams, and the delivery rates are high enough to compensate the sinks, maintaining relatively unchanging wood loads through time, then we have the steady-state end-member model (Wohl *et al.*, 2012). Whereas, when the mass recruitment domains, such as after a landslide or windthrow, we have the episodic end-member model in which wood storage becomes spatially unbalanced, forming large accumulations of wood, the logjams (Wohl *et al.*, 2012). These structures also store a great amount of sediment, but as they are very transient (Wohl *et al.*, 2009), the episodic end-member persists only for short periods (Wohl *et al.*, 2012).

Once wood was delivered to the channel, it may be retained or transported. Worldwide studies have demonstrated that in-stream retention of large wood varies with position in the river network, bankfull channel width and depth, channel slope, and tree type (Ruiz-Villanueva *et al.*, 2016). In low order streams, the channel morphology significantly influences individual piece stability (Wohl, 2017), because they are commonly longer than the average channel width and thicker than the average flow depth (Bilby and Ward, 1989; Dixon and Sear, 2014; Lienkaemper and Swanson, 1987; Martin and Benda, 2001). Thus, LW pieces tend to stay trapped, resulting in higher amounts of wood stored in small streams (Abbe and Montgomery, 2003; Keller and Swanson, 1979). The water level also determines wood stability or mobilization, since the latter predominantly occurs above a discharge threshold where the piece may float and be entrained by the flow (Wohl, 2017). However, even submerged pieces smaller than the bankfull channel may still stay stable depending on their density and if branches and rootwads anchor them on the riverbed (Gurnell, 2003; Ruiz-Villanueva *et al.*, 2016; Welber *et al.*, 2013). Therefore, whether a LW piece will remain trapped or be entrained and where it will be deposit depends on the interaction between driving (water flow) and resisting forces (channel features and wood characteristics) (Braudrick and Grant, 2001, 2000).

Flume experiments, assuming a LW as a cylinder, have already shown that piece movement is a function of its orientation, density, diameter, and the presence of attached rootwads (Braudrick and Grant, 2001, 2000). The piece length does not significantly determine piece stability because buoyant forces dominate drag forces (Braudrick and Grant, 2000). However, flume experiments are limited by disregarding common trap characteristics of low order streams, as the riparian vegetation and other roughness elements, which increase wood stability in these environments (Braudrick and Grant, 2000). Therefore, the field results showing that longer pieces are more stable than shorter pieces are due to the fact that in small channels, long pieces may be suspended over the channel or have much of their length outside the channel, so that the flow of water does not reach, and consequently cannot move them (Braudrick and Grant, 2000).

In the face of the uncertainties about LW mobility in small streams, there is a need for direct observations. The most accurate way to do this is by tracing or tagging wood at least for fairly short distances (Ruiz-Villanueva *et al.*, 2016), by inserting identifiable tags (metal plates or radio frequency identification - RFID) and recapturing them later (Iroumé *et al.*, 2015, 2010; Mao *et al.*, 2008; Ravazzolo *et al.*, 2014; Tonon *et al.*, 2018; Warren and Kraft, 2008). Results of this type of field survey have shown that it is common to observe during a single event, travelled distances of a hundred meters to a few kilometres, and possible distances higher than 100 km (Ruiz-Villanueva *et al.*, 2016). However, the different conditions adopted in the experiments results in inherent variability in data making the comparison of results difficult (Ruiz-Villanueva *et al.*, 2016).

Not all of the LW tagging and tracing studies have measured the travelled distance. Many of them are restricted to accounting for the annual transport rates. The pioneer studies performed in U.S. and U.K. between the end of 80's beginning of 90's detected a transport rates varying from 2-36% (Benke and Wallace, 1990; Gregory *et al.*, 1985, 1991; Grette, 1995; Young *et al.*, 1994). Wohl and Goode (2008) observed a rate of 19.5% of LW mobilization per year and Warren and Kraft (2008) 25% still measuring a mean travelled distance of 5 m in U.S. rocky mountain streams. More recently, studies investigating wood mobility have expanded to other parts of the world. Haga *et al.* (2002) observed a mean transport rate of 92% m and a mean travelled distance of 840 m in two mountain streams of Japan. Rickli and Bucher (2006) measured a transport rate of 33-72% in Switzerland streams. In Latin America, annual transport rates in temperate forested streams of Chile and Argentina varied from 2.5 to 14.8% (Andreoli *et al.*, 2007; Iroumé *et al.*, 2015, 2010; Mao *et al.*, 2008). Regarding LW travelled distance Iroumé *et al.* (2010) detected a maximum of 481 m and an average of 117.4 m. In the first study performed in a tropical rainforest, Cadol and Wohl (2010) observed a mean annual transport rate of 9-39% in headwater streams of Costa Rica. Investigations of LW mobility in non-forested environments is even more scarce (but see Galia *et al.*, 2019; Jacobson *et al.*, 1999). To our knowledge, there is no studies performed in the streams of Cerrado, the south American Savanna, despite they having evergreen riparian forests along its streams (the gallery forests or sometimes the less dense palm 'veredas' of Mauritia flexuosa L.) (Furley, 1999). After describing and quantifying the in-stream wood stock in Brazilian Cerrado streams in the first chapter and investigating its main predictors in the second chapter, we aimed to document its recruitment, retention, and mobilization over one year. To do so, we returned to eight Cerrado streams and individually measured and tagged the found LW, tracing them after one rainy season.

2. Methods

2.1. Study area

We surveyed eight freshwater wadeable streams (one site per stream) located in different catchments of three regions of Cerrado in the centre of Brazil. Four streams are located in Paranaíba River basin, two in Grande River basin and the other two in São Francisco River basin. These rivers present large dams in their main channels, such the study streams are located in their influence area. Therefore, we called each region by the name of the dam: São Simão, Volta Grande and Três Marias, respectively (Figure 1, 2). All of them have a history of human disturbances, and most of the native vegetation has been removed and replaced by croplands and pastures (Table 1). The LW found in these streams comes from the narrow string of riparian forest still remnant along with them. The study sites had their physical habitat and aquatic fauna assessed in previous studies (Carvalho *et al.*, 2017a, 2017b; Castro *et al.*, 2018; Fagundes *et al.*, 2015; Silva *et al.*, 2016) and the LW stock and regime investigated in the previous articles. Here, as we restricted the number of sites investigated, we deep in LW study and understanding, by applying a specific methodology to quantify and characterize in-stream wood such we measured each piece individually.

Table III-1 - Land use in the study catchments upstream the study sites.

Site	River basin	% Riparian forest	% Native cover	% Pasture	% Croplands	% Eucalyptus	% Urban
SS0129	Paranaíba	22.62	14.39	71.91	13.70	0.00	0.00
SS0133	Paranaíba	63.39	14.39	85.06	0.54	0.00	0.00
SS0149	Paranaíba	43.67	12.84	87.16	0.00	0.00	0.00
SS1000	Paranaíba	52.07	13.11	86.10	0.79	0.00	0.00
TM0082	São Francisco	27.17	25.35	68.16	0.00	6.48	0.02
TM0133	São Francisco	28.85	19.70	80.11	0.00	0.16	0.03
VG0034	Grande	25.67	12.11	35.07	52.83	0.00	0.00
VG0177	Grande	61.71	7.44	64.03	28.53	0.00	0.00

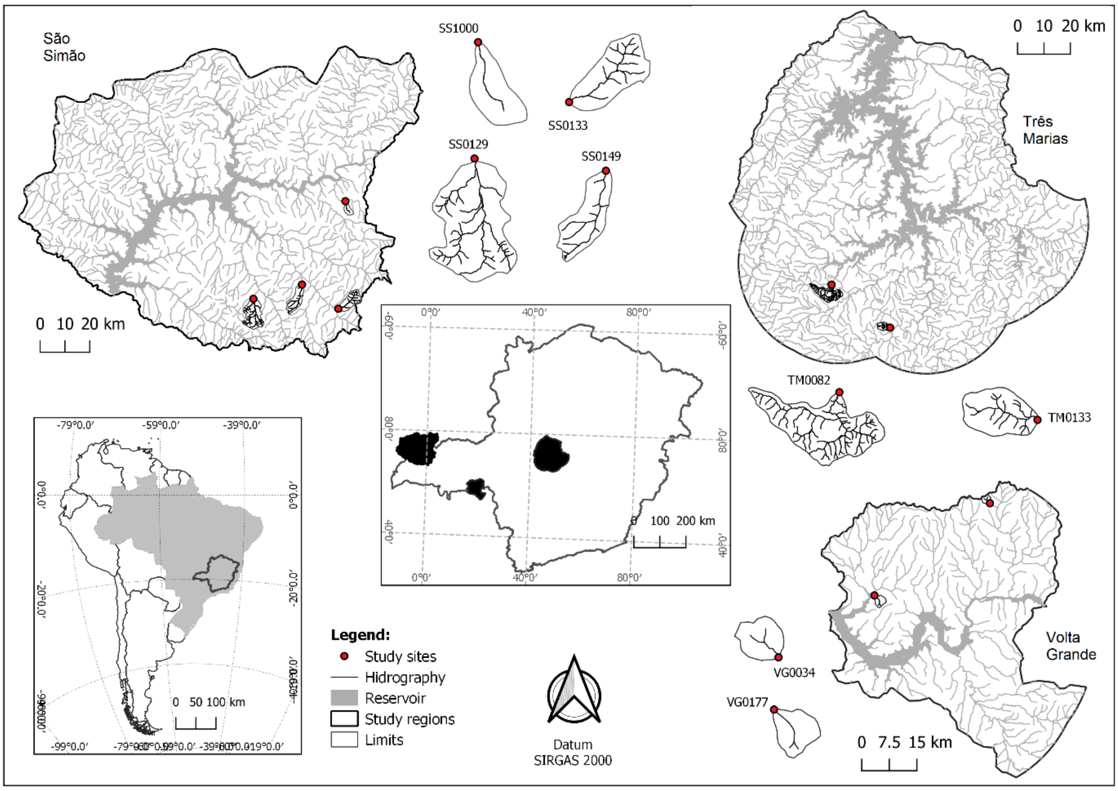


Figure III-1 - Location map of the study sample sites in the three study basins in Brazilian Savanna.

Figure III-2 - Pictures of the eight study streams.

2.2. Data collection

In May 2019, at the beginning of the dry season, we sampled large wood pieces (LW) in a segment of 150 m length in each of the eight study streams. The surveyed segment was divided into 10 sections of 15 meters. We counted, measured, tagged, and recorded the geographic coordinates of each LW found within the bankfull channel, which have dimensions greater than 10 cm in diameter and 1 m in length.

We measured the length of LW pieces using a tape and the diameter using a tree calliper, taking two measures at each end. We also accounted the logjams (accumulation with two or more wood pieces in contact with each other), but in some of the bigger ones it was not possible to measure all the individual LW, but it was assumed that less than 10 elements in total were not included in the survey. For partially buried LW, the length and diameter measurements were of the exposed part of the element. All of the measured LW pieces were tagged with a metal plate, in which we identified the piece by numbering. The respective section where each one was originally found was also recorded and the geographic coordinates were taken with a global positioning system (GPS) equipment (Garmin 76CSx with high-sensitivity receiver) in order to investigate log mobility and travel distance.

Besides measuring LW, we also recorded its local, position, and orientation relative to the channel and its type, decay state, and size class. We considered two possible places for the local determination: inside or outside the channel. There were four possible options for the position: centre of the channel, on the left or right margin, and crossed. We classified pieces as parallel, perpendicular, or oblique to the streamflow for the piece orientation. The types of LW included bridge, left and right ramp, stuck, buried, free and standing piece, and element of a logjam. The state of decay was determined by visual estimation and the LW were classified as low (intact bark, with or without branches, texture intact, round shape, original colour), medium (with bark remains, no branches, surface with some abrasion, still round shape, original to darkened colour) or high (no bark, no branches, corroded surface with holes, oval to irregular shape, dark colour). These decay classes were adapted from Maser *et al.* (1988) similarly as Iroumé *et al.* (2010) did, such “low” corresponds to Maser’s classes I and II, “medium” to Class III and “high” to classes IV and V. The difference is that we did not account the alive trees. Lastly, to classify pieces according to size, we adopted the USEPA classification, framing pieces in one of five size classes (T[25] = tiny, S[26] = small, M[27] = medium, L[28] = large, X[29] = extra-large) (USEPA, 2013).

The study reaches were resurveyed, repeating all the procedures above, at the following dry season, in July 2020, to evaluate LW mobility and recruitment. All tagged LW was recounted and remeasured within the study segment whether they were mobilized or not. The newly recruited pieces were also tagged, measured, positioned, and classified. At the end of the original reach, we walked another 50 m downstream reach looking for tagged pieces that might have been mobilized since the last survey.

2.3. Data analysis

The volume of each wood piece was calculated from its diameter and length assuming a solid cylindrical shape and applying the Smalian cubing method, given by the formula below:

Equation 1:

$$V = \frac{S_1 + S_2}{2} \, . \, L$$

where V = volume in m³; S1 and S2 = sectional areas in m² obtained at the extremities of wood piece and L = piece length in m.

---

[25] T = Diam 0,1 - 0,3 m / Length 1,5 - 5 m;

[26] S = Diam > 0,3 - 0,6 Length 1,5 - 5 m; Diam > 0,6 - 0,8 m Length 1,5 - 5 m; Diam 0,1 - 0,3 m Length > 5 - 15 m;

[27] M = Diam > 0,3 - 0,6 / Length 5 - 15 m; Diam > 0,1 - 0,3 m / Length > 15 m; Diam > 0,8 m / Length > 1,5 - 5 m;

[28] L = Diam > 0,3 - 0,6 / Length > 15 m; Diam > 0,6 - 0,8 m / Length > 5 - 15 m; Diam > 0,6 - 0,8 m / Length > 15 m; Diam > 0,8 / Length > 5 - 15 m;

[29] X = Diam > 0,8 m / Length > 15 m.

Large wood amounts were expressed as pieces/100m (abundance) and m³/100m² (volume) using the channel bankfull width and the reach length to calculate streambed area. We also calculated the relative length and diameter of the pieces by dividing them by the channel width and length, respectively.

From the geographic coordinates taken for each LW piece during the field surveys, we calculated the travelled distance in meters from the first year to the next. To do so, we calculated the difference in LW position between 2019 and 2020 using the Universal Transverse Mercator (UTM) plane grid system, and thus, multiplied it by the mean channel sinuosity[30] (Equation 2).

Equation 2:

$$\Delta D = \sqrt{(Y_1 - Y_2)^2 + (X_1 - X_2)^2} \times S$$

where ΔD is the travelled distance, Y_1 and X_1 are respectively the longitudinal and latitudinal coordinates taken in 2019, Y_2 and X_2 is respectively the longitudinal and latitudinal coordinates taken in 2019 and S is the mean channel sinuosity.

The surveyed data were organized in graphs and tables to present LW information accounting for the amount and features of pieces detected in the first and second field surveys. To study wood mobility, we performed an analysis of variance (ANOVA) followed by contrast analysis to test differences among streams. Generalised linear models (GLM) were performed in the R software to examine relationships between the LW mobility and its characteristics (length, diameter, relative length, relative diameter, volume, type[31], local, decay stage and orientation). First, to assess the LW characteristics that best predict the likelihood of a piece be transported out of the study reaches, we used the LW situation as explanatory variable setting 1 to the pieces that were transported (not recovered in 2020 survey) and zero to the pieces that remained in the study reach (recovered in 2020). As the explanatory variable was binary, we applied the binomial family to the ‘glm’ function (the equivalent of the logistic regression). Secondly, we used the LW travelled distance as a response variable applying the gaussian family to the ‘glm’ function (equivalent of the multiple regression). In both cases, to select the

---

[30] The channel sinuosity data were available from previous in-stream habitat assessments performed in the study streams.

[31] We altered LW type classification in the GLM analyses, renaming and aggregating some categories. Free pieces = unattached, right + left ramp = ramp, stuck + standing + fallen tree = attached. Buried, bridge and log jams were kept unaltered.

best models to explain wood mobility, we applied the dredge function (MuMIn package) in the GLM runs specifying the parameter delta < 2 and adding the r^2 statistics. Statistical analyses were considered statistically significant if $p \leq 0.05$

3. Results

A total of 444 LW pieces were found in the surveyed stream reaches, totalizing 61.13 m^3 of wood, from which 312 pieces and 48.50 m^3 were sampled in 2019, and in 2020 were added 132 pieces and 12.63 m^3 (Table 2). We accounted for an average of 27.25 pieces/100 m and 1.67 m^3/100 m^2 in 2019 campaign and 26.5 pieces/100 m and 0.85 m^3/100 m^2 in 2020. There was a great variation among streams, and the ones which presented the greatest and the smallest wood stock (SS00129 and SS00133 respectively) were located in the same region (Sao Simão) (Figure 3). Almost 60% (183 pieces and 28.02 m^3) of the in-stream wood first sampled in the 2019 survey was resampled in 2020, but there was a great variability per stream, such as the stream with the lowest resample rate achieved half of this percentual (Table 2). Only three of the recovered pieces were found in the 50 m extra downstream reach sampled in 2020, all the other 180 pieces were found in the original reach. In 2020 we detected a recruitment rate of new LW of 42% of the total when considering the number of pieces and 31% when considering the LW volume. Again, the variability was great among streams, with recruitment ranging from 20-70% of the pieces and 3-66% of the volume. Considering only the pieces resampled in the 2020 survey, we detected volume, length, and diameter loss in all streams (Table 3). In total were lost 8.17 m^3 (-22.88%) of wood in volume, 128.41 m (-15.55%) in length and 181.08 cm (-6.20%) in diameter. Only one stream had wood gain (SS0129), even though only related to the diameter (Supplementary 1).

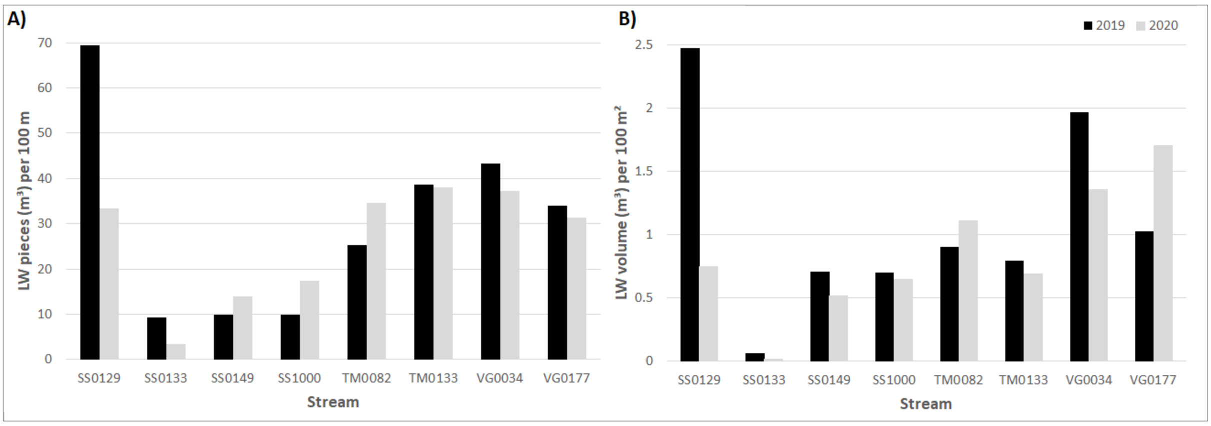


Figure III-3 - (A) LW abundance per channel length (pieces/100m); (B) LW volume per channel area (m^3/100m^2) in 2019 and 2020 field campaigns.

Table III-2 - Numbers and volumes of LW surveyed on 2019 and 2020 field campaigns and the respective rate of resampling and recruitment.

Stream	**LW PIECES**							**LW VOLUME (m^3)**						
	2019	***2020***			*%*	*%*	*%*	***2019***	***2020***			*%*	*%*	*%*
	Total	*old*	*new*	*Total*	*retained* [1]	*mobilized* [2]	*recruited* [3]	*Total*	*old*	*new*	*Total*	*retained* [1]	*mobilized* [2]	*recruited* [3]
SS0129	52	30	20	50	57.69%	42.31%	40.00%	10.58	5.55	0.85	6.40	52.44%	47.56%	13.30%
SS0133	20	7	1	8	35.00%	65.00%	12.50%	1.73	0.47	0.02	0.48	26.96%	73.04%	3.12%
SS0149	15	6	15	21	40.00%	60.00%	71.43%	7.14	3.48	1.70	5.18	48.75%	51.25%	32.84%
SS1000	14	8	17	25	57.14%	42.86%	68.00%	1.84	0.66	0.91	1.57	36.03%	63.97%	57.75%
TM0082	38	22	30	52	57.89%	42.11%	57.69%	5.89	3.65	3.62	7.27	61.92%	38.08%	49.86%
TM0133	57	44	12	56	77.19%	22.81%	21.43%	5.13	4.24	0.23	4.47	82.66%	17.34%	5.14%
VG0034	65	40	16	56	61.54%	38.46%	28.57%	11.91	7.60	0.60	8.19	63.79%	36.21%	7.28%
VG0177	51	26	21	47	50.98%	49.02%	44.68%	4.28	2.39	4.70	7.09	55.69%	44.31%	66.34%
TOTAL	***312***	***183***	***132***	***315***	***58.65%***	***41.32%***	***41.90%***	***48.50***	***28.02***	***12.63***	***40.65***	***57.78%***	***42.22%***	***31.06%***

Notes: [1] *percentage of pieces/volume retained relative to 2019 survey.*
[2] *percentage of pieces/volume transported out of the reach relative to 2019 survey.*
[3] *percentage of pieces/volume recruited into the reach relative to 2020 survey.*

Table III-3 - Total loss of volume, length, and diameter of wood per stream between 2019 and 2020.

Stream	**Volume (m^3)**				**Length (m)**				**Diameter (cm)**			
	Total		**Loss**		**Total**		**Loss**		**Total**		**Loss**	
	2019	***2020***	***m^3***	***%***	***2019***	***2020***	***m***	***%***	***2019***	***2020***	***cm***	***%***
SS0129	6.40	5.42	-0.98	-15.38%	144.81	121.60	-23.21	-16.03%	410.07	423.26	13.20	3.22%
SS0133	0.17	0.12	-0.06	-32.72%	7.70	6.70	-1.00	-12.99%	48.65	40.98	-7.68	-15.78%
SS0149	6.07	3.48	-2.59	-42.65%	68.24	47.10	-21.14	-30.98%	162.83	122.15	-40.68	-24.98%
SS1000	1.56	0.66	-0.89	-57.42%	29.88	25.15	-4.73	-15.83%	191.75	133.68	-58.08	-30.29%
TM0082	5.06	3.65	-1.42	-27.99%	102.21	80.73	-21.48	-21.02%	435.85	397.05	-38.80	-8.90%
TM0133	4.60	4.20	-0.40	-8.74%	172.59	151.52	-21.07	-12.21%	616.70	601.88	-14.83	-2.40%
VG0034	9.12	7.60	-1.52	-16.69%	195.52	169.44	-26.08	-13.34%	692.53	676.33	-16.20	-2.34%
VG0177	2.60	2.39	-0.21	-8.13%	98.71	92.58	-6.13	-6.21%	346.70	333.38	-13.33	-3.84%
TOTAL AVERAGE	***35.69***	***27.52***	***-8.17***	***-22.88%***	***825.73***	***697.32***	***-128.41***	***-15.55%***	***2919.12***	***2738.04***	***-181.08***	***-6.20%***

When analysing the LW qualitative variables, we did not detect remarkable differences from one year to another. Regarding wood decomposition (Figure 4a), we detected a similar amount of LW in high, medium, and low stages of decay, accounting for approximately one-third of each of these categories. In relation to size class (Figure 4b), most of the LW are small-sized, belonging to the tiny (T = 69% in 2019 and T = 73% in 2020) and small (S = 22% in 2019 and S = 19% in 2020) size classes. Similar amounts of wood were found inside and outside the channel (Figure 4c), and most of the LW was positioned on the channel margins (right + left margin = 69% in 2019 and 74% in 2020) (Figure 4f). Most of the LW pieces were perpendicular or parallel oriented to the channel, but there were also pieces oblique to the channel and still standing, but not alive, trees (Figure 4e). The most common type of LW was the free pieces (37%), followed by stuck (8% in 2019 and 17% in 2020) and buried (13% in 2019 and 12% in 2020) pieces and standing trees (11% in 2019 and 2020) (Figure 4d). The other LW types (logjams included) did not reach 10% of the LW surveyed in both field campaigns.

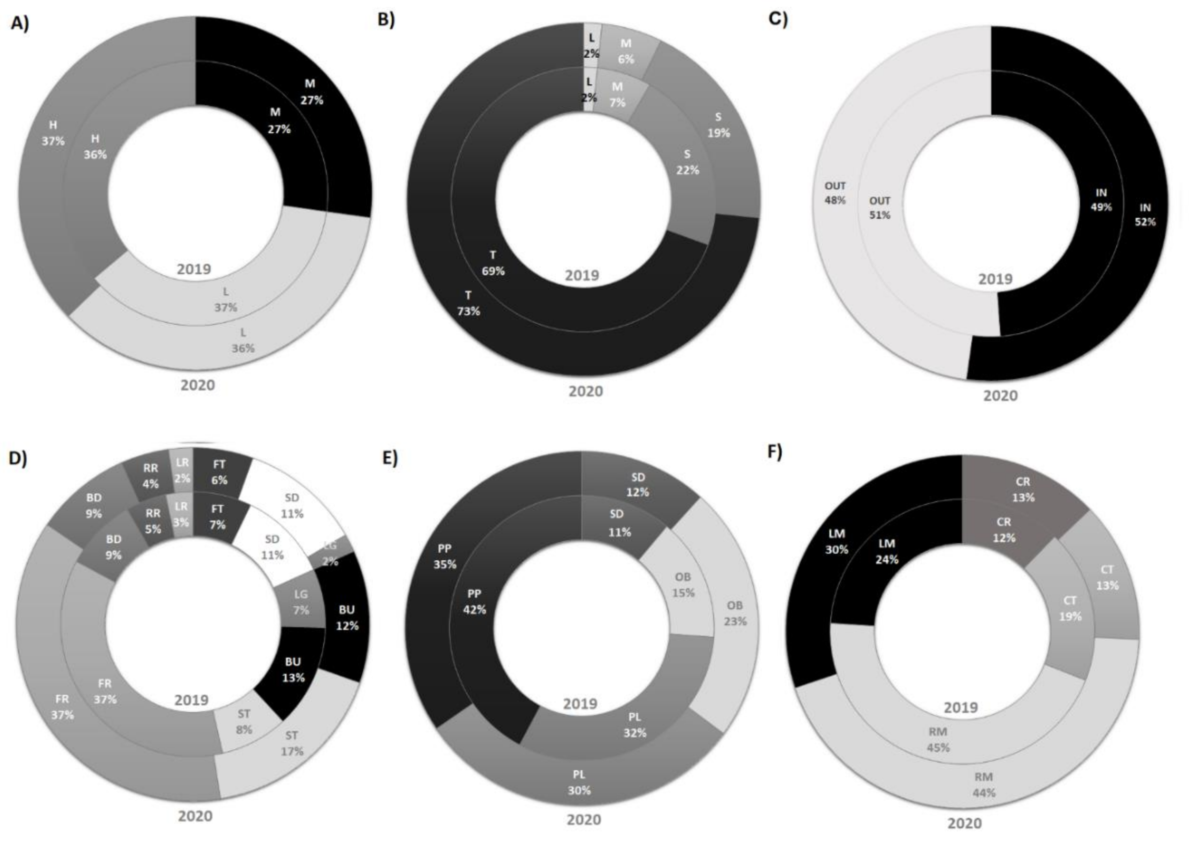


Figure III-4 - The percentages of LW according to its (A) decay state, (B) size class, (C) local, (D) type, (E) orientation and (F) position on 2019 (inner ring) and 2020 (outer ring) campaigns. In A: H = high, M = medium, L = low. In B: T = tiny, S = small, M = medium, L = large. In C: IN = inside the channel, OUT = outside the channel. In D: BD = Bridge, RR = right ramp, LR = left ramp, FT = fallen tree, SD

= standing tree, LG = logjam, BU = buried log, ST = stuck log, FR = free log. In E: PP = perpendicular, SD = standing, OB = oblique, PL = parallel. In F: RM = right margin, LM = left margin, CT = centre, CR = crossed.

Regarding to wood mobility, when considering the LW first tagged in 2019 (312 pieces) and accounting the ones not found in 2020 (129 pieces), we detected that the LW length, diameter, relative length, volume, local and decay affected the odds of a LW being transported (Figure 5). From the nine logistic regression models selected with delta < 2 (Table 4), the best one according to r^2 statistics (n. 294, $r^2 = 0.038$) pointed out the LW length, diameter, volume, and decay state as the most important variables. Despite its low explanatory power, this model was significantly different from the null model (X^2 test: $p = 0.03$). When performing the same analysis for streams separately (for the streams that had 30 or more LW pieces resampled in 2020, that is, SS0129, TM0133 and VG0034) we obtained models with better but still low explanatory power (Table 5). Only the best models selected for TM0133 stream (n. 309, 279, 313, 283, $r^2 = 0.15$) differed from the null model.

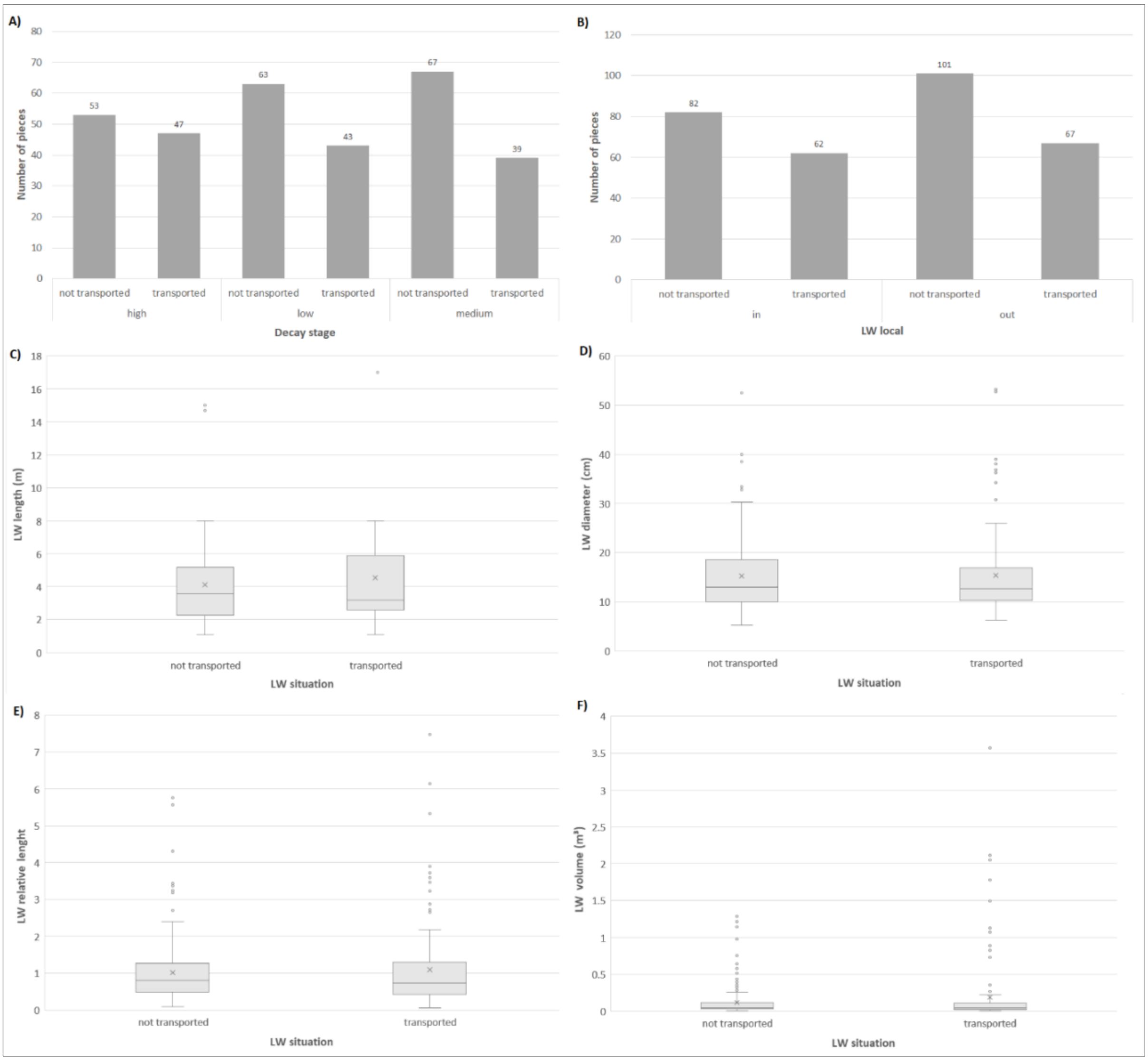


Figure III-5 - Graphs of the LW characteristics that affected the odds of a LW be transported or not according to logistic regression model for all streams. (A) Decay stage; (B) original local in the channel; (C) LW length; (D) LW diameter; (E) LW relative length; (F) LW volume (m³). In the boxplots the line represents the median, the x the mean, the box is the first (25%) and the third (75%) quartiles, the whiskers extend to the most extreme data point which is no more than 1.5 times the length of the box away from the box, the dots are the outliers defined by the '1.5 rule'.

Table III-4 - Model selection table for all streams (global model) and for three streams individually considering only GLM's (logistic regression) with delta < 2.00. The variables that contributed for the model explanation have a coefficient value in the case of the continuous variables or a plus sign in the case of the categorical variables. The best models according to the r^2 statistics which differed from the null model ($p<0.05$) are highlighted in bold.

Model	**Inter-cept**	**length**	**diam**	**rel. length**	**rel. diam**	**vol**	**type**	**local**	**decay**	**orient**	**R^2**	**df**	**logLik**	**AICc**	**delta**	**weight**
Global model																
293	0.55	-0.09	-0.06			2.50					0.0288	4	-207.01	422.15	0.00	0.062
289	0.10		-0.04			1.50					0.0220	3	-208.10	422.27	0.12	0.059
297	0.38		-0.05	-0.19		2.17					0.0264	4	-207.39	422.92	0.77	0.043
290	0.45		-0.05			1.67			+		0.0327	5	-206.38	422.95	0.80	0.042
294	**0.81**	**-0.08**	**-0.06**			**2.54**			**+**		**0.0377**	**6**	**-205.56**	**423.40**	**1.25**	**0.033**
257	-0.44					0.63					0.0105	2	-209.91	423.87	1.71	0.026
298	0.69		-0.06	-0.17		2.27			+		0.0362	6	-205.82	423.91	1.76	0.026
305	0.17		-0.04			1.50		+			0.0229	4	-207.96	424.04	1.89	0.024
309	0.59	-0.09	-0.06			2.47		+			0.0292	5	-206.94	424.07	1.92	0.024
SS0129 model																
257	-0.52					1.38					0.0485	2	-34.13	72.51	0.00	0.039
1	-0.31										0.0000	1	-35.43	72.93	0.42	0.031
301	1.37	$-4.05e^{+08}$	-0.13	$2.31e^{+09}$		5.92					0.1624	5	-30.82	72.94	0.43	0.031
271	1.37	$-4.05e^{+08}$		$2.31e^{+09}$	-0.17	5.92					0.1624	5	-30.82	72.94	0.43	0.031
258	0.18					2.27			+		0.1181	4	-32.16	73.17	0.66	0.028
259	0.43				-0.10	3.17					0.0765	3	-33.36	73.21	0.70	0.027
289	0.43		-0.08			3.17					0.0765	3	-33.36	73.21	0.70	0.027
269	-0.39	$-3.30e^{+08}$		$1.88e^{+09}$		2.00					0.1108	4	-32.37	73.60	1.09	0.023
270	0.17	$-4.05e^{+08}$		$2.31e^{+09}$		2.29			+		0.1890	6	-29.98	73.83	1.31	0.020
13	-0.67	$-3.00e^{+08}$		$1.71e^{+09}$							0.0604	3	-33.81	74.11	1.60	0.017
261	-0.32	-0.06				1.83					0.0535	3	-34.00	74.49	1.98	0.014
265	-0.32			-0.36		1.83					0.0535	3	-34.00	74.49	1.98	0.014
TM0133 model																
293	-11.10	1.31	0.67			-67.38					0.1454	4	-26.13	61.02	0.00	0.063
263	-11.10	1.31			1.32	-67.38					0.1454	4	-26.13	61.02	0.00	0.063
297	-11.10		0.67	5.64		-67.38					0.1454	4	-26.13	61.02	0.00	0.063
267	-11.10			5.64	1.32	-67.38					0.1454	4	-26.13	61.02	0.00	0.063
309	**-11.47**	**1.40**	**0.72**			**-72.73**		**+**			**0.1557**	**5**	**-25.78**	**62.74**	**1.72**	**0.026**

279	**-11.47**	**1.40**			**1.42**	**-72.73**	**+**	**0.1557**	**5**	**-25.78**	**62.74**	**1.72**	**0.026**
313	**-11.47**		**0.72**	**6.05**		**-72.73**	**+**	**0.1557**	**5**	**-25.78**	**62.74**	**1.72**	**0.026**
283	**-11.47**			**6.05**	**1.42**	**-72.73**	**+**	**0.1557**	**5**	**-25.78**	**62.74**	**1.72**	**0.026**
295	-10.82	1.29	2.74e^{+08}		-5.39e^{+08}	-66.31		0.1516	5	-25.92	63.02	1.99	0.023
299	-10.82		2.74e^{+08}	5.56	-5.39e^{+08}	-66.31		0.1516	5	-25.92	63.02	1.99	0.023
VG0034 model													
1	-0.47							0.0000	1	-43.31	88.68	0.00	0.218
3	-0.13						+	0.0241	2	-42.51	89.22	0.54	0.166
5	0.37		-0.06					0.0205	2	-42.63	89.46	0.78	0.147
2	0.37				-0.04			0.0205	2	-42.63	89.46	0.78	0.147
7	0.64		-0.06				+	0.0414	3	-41.94	90.26	1.58	0.099
4	0.64				-0.04		+	0.0414	3	-41.94	90.26	1.58	0.099
6	0.44		-1.24e^{+08}		7.80e^{+07}			0.0332	3	-42.21	90.81	2.13	0.075
8	0.73		-1.29e^{+08}		8.16e^{+07}		+	0.0546	4	-41.48	91.64	2.96	0.050

The LW travelled distance calculated for the pieces recovered in 2020 ranged from 0.43 to 102.95 m, with an average of 14.33 m of displacement in the downstream direction. The streams with the lowest LW displacement values (SS0133 and SS0149, significantly lower in the ANOVA and contrast analysis) were the ones with less wood recovered (Figure 6, Supplementary S2). None of the linear regressions performed between the travelled distance and the continuous variables were significant ($p > 0.05$). However, when we performed the multiple regressions for all streams (global model) with the continuous and categorical explanatory variables together, we selected seven models with delta < 2.00, in which LW length, diameter, relative length, volume, local and orientation were important to explain the LW travelled distance (Table 5, Figure 7). According to r^2 statistics (n. 29, $r^2 = 0.08$), the best model included the LW length, local and orientation as the most important variables. Importantly, wood orientation was included in all selected models. As were observed in the logistic regressions models, the explanatory power of the multiple regressions was also low, but slightly higher, and still different from the null model. When performing the same analysis separated for streams (the same as before: SS0129, TM0133 and VG0034), we had an increase in the explanatory power of the models (Table 5). Except by TM0133 stream, whose selected models did not differ from the null model, we could explain an important fraction of the variation of the LW travelled distance. The best model for SS0129 stream (n. 13 or 73, $r^2 = 0.26$) included the LW length or relative length and the local to explain 26% of the travelled distance variation (Figure 8). The best model for VG0034 stream (n. 147 or 177, $r^2 = 0.56$) included the LW diameter or relative diameter and type and orientation to explain 56% of the travelled distance variation (Figure 9).

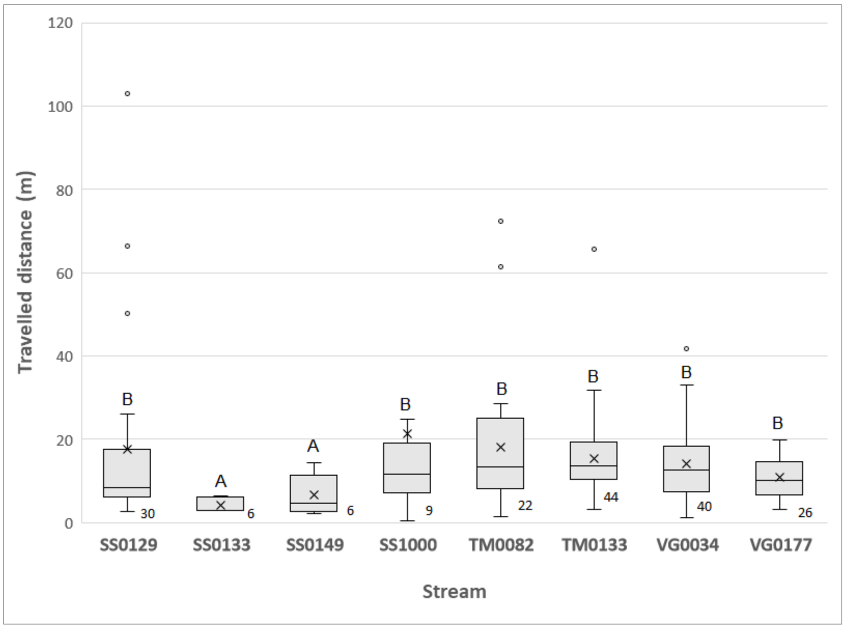


Figure III-6 - Boxplots of LW travelled distance in each stream from 2019 to 2020 field campaign. In the boxplots the line represents the median, the x the mean, the box is the first (25%) and the third (75%) quartiles, the whiskers extend to the most extreme data point which is no more than 1.5 times the length of the box away from the box, the dots are the outliers defined by the '1.5 rule'. The numbers near the boxes indicate the number of mobilized pieces. The letters above the whiskers indicate the result of the contrast analysis such that streams with the same letter did not differ in the average travelled distance.

Table III-5 - Model selection table for all streams (global model) and for three streams individually considering only GLM's with delta < 2.00. The variables that contributed for the model explanation have a coefficient value in the case of the continuous variables or a plus sign in the case of the categorical variables. The best models according to the r² statistics which differed from the null model ($p<0.05$) are highlighted in bold.

Model	**Intercept**	**length**	**diam**	**rel. length**	**rel. diam**	**vol**	**type**	**local**	**decay**	**orient**	**R²**	**df**	**logLik**	**AICc**	**delta**	**weight**
								Global model								
17	1.21									+	0.0739	5	-59.76	129.86	0.00	0.073
21	1.27	-0.01								+	0.0828	6	-58.88	130.24	0.39	0.060
273	1.23					-0.06				+	0.0805	6	-59.11	130.70	0.84	0.048
81	1.24			-0.02						+	0.0768	6	-59.47	131.43	1.57	0.033
19	1.25		-0.003							+	0.0764	6	-59.51	131.51	1.65	0.032
25	1.20							+		+	0.0764	6	-59.52	131.51	1.65	0.032
29	**1.26**	**-0.01**						**+**		**+**	**0.0866**	**7**	**-58.51**	**131.66**	**1.80**	**0.030**
								SS0129 model								
13	**1.3557**	**-0.04**						**+**			**0.2660**	**4**	**-10.17**	**29.95**	**0.00**	**0.095**
73	**1.3557**			**-0.22**				**+**			**0.2660**	**4**	**-10.17**	**29.95**	**0.00**	**0.095**
41	1.3578				-2.12			+			0.2355	4	-10.78	31.17	1.22	0.051
11	1.3578		-0.02					+			0.2355	4	-10.78	31.17	1.22	0.051
								TM0133 model								
1	1.12										0.0000	2	-4.30	12.91	0.00	0.111
9	1.07							+			0.0122	3	-4.04	14.69	1.79	0.045
257	1.11					0.09					0.0111	3	-4.06	14.74	1.83	0.044
5	1.08	0.01									0.0099	3	-4.09	14.79	1.89	0.043
65	1.08			0.04							0.0099	3	-4.09	14.79	1.89	0.043
								VG0034 model								
147	**-2.70**		**0.46**				**+**			**+**	**0.5624**	**10**	**-126.42**	**280.42**	**0.00**	**0.142**
177	**-2.70**				**28.99**		**+**			**+**	**0.5624**	**10**	**-126.42**	**280.42**	**0.00**	**0.142**

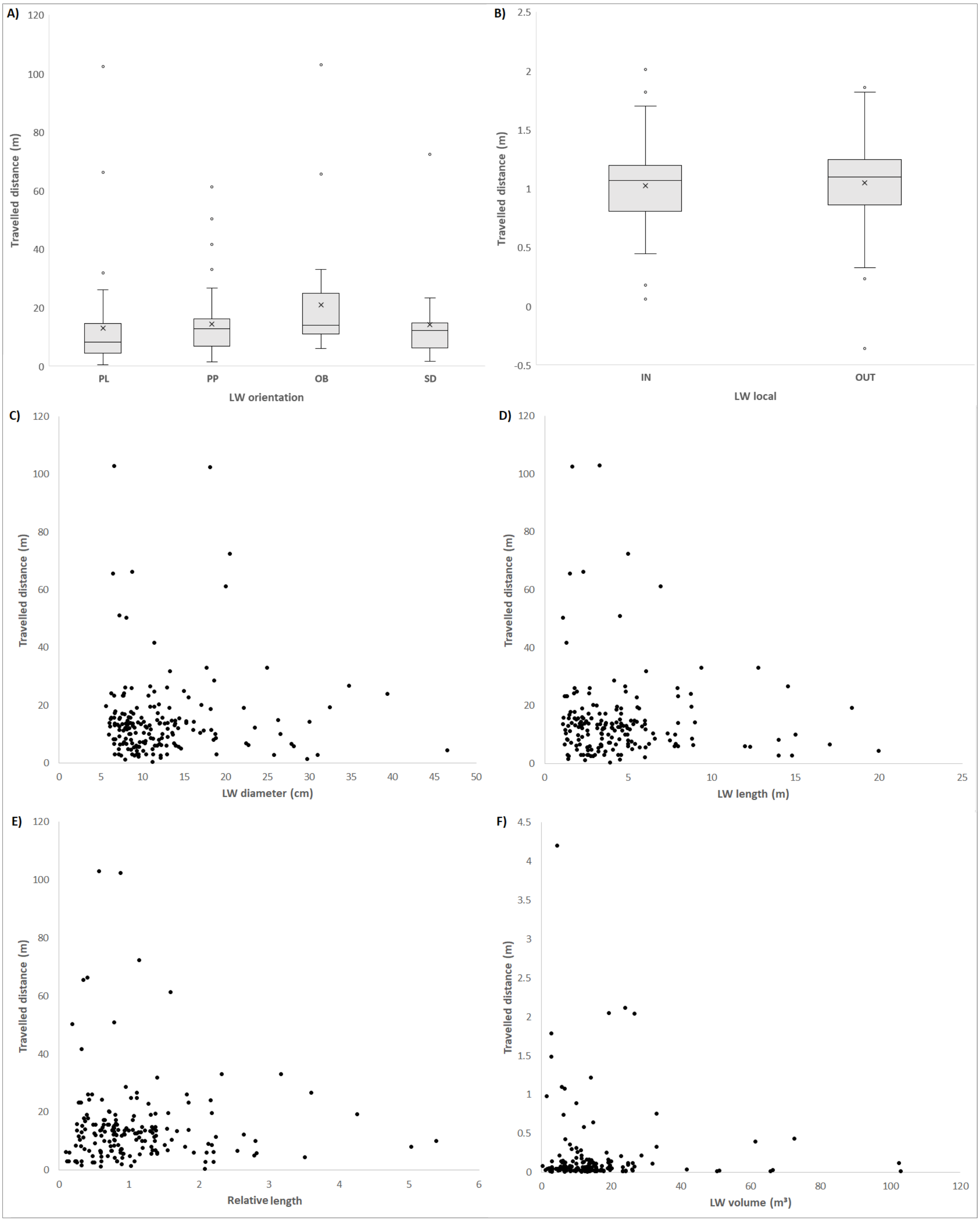


Figure III-7 - Graphs of the LW travelled distance against the most important variables to explain it in the global model: (A) LW orientation; (B) LW original local; (C) LW diameter; (D) LW length; (E) relative length; (F) LW volume. Legend: PL = parallel, PP = perpendicular, OB = oblique, SD = standing. In the boxplots the line represents the median, the x the mean, the box is the first (25%) and the third (75%) quartiles, the whiskers extend to the most extreme data point which is no more than 1.5 times the length of the box away from the box, the dots are the outliers defined by the '1.5 rule'.

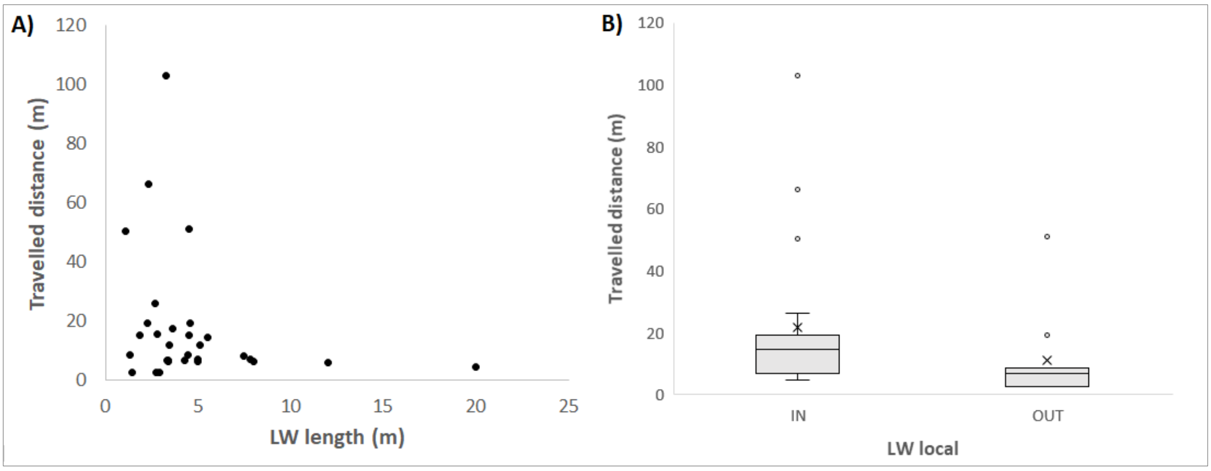


Figure III-8 - Graphs of the LW travelled distance against the most important variables to explain it for SS0129 stream. (A) LW length; (B) LW original local.

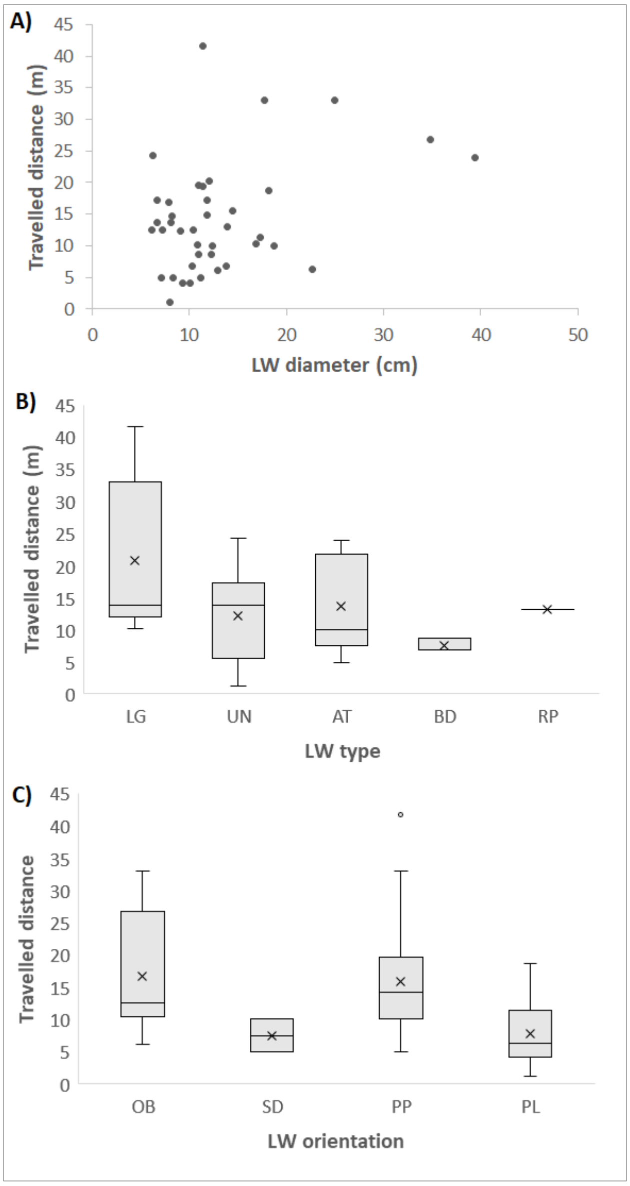


Figure III-9 - Graphs of the LW travelled distance against the most important variables to explain it for VG0034 stream. (A) LW diameter; (B) LW type; (C) LW orientation. Legend: LG = logjam, UN

= unattached, A= attached, BD = bridge, RP = ramp, PL = parallel, PP = perpendicular, OB = oblique, SD = standing.

4. Discussion

In general, Cerrado streams presented high rates of LW transport and recruitment, and such wood amounts remained constant from one year to another. However, important differences were detected between streams, likely due to the distinct channel morphology and hydrology, as well as the occurrence of episodic events. The breakage of pieces was detected as a more important process than decay in depleting wood from streams, but there were no differences in the quantity of pieces across the decay classes. Most of the pieces in the study streams were small-sized, single free elements (logjams are rare) and positioned preferentially on the channel margins. The LW size slightly influenced the likelihood of a piece being transported long distances, but the LW dimensions (length and diameter), original local, and orientation were the most important factors to predict the LW travelled distance. The explanatory power of predictors variables become stronger when analysing the travelled distance separated per stream.

About 60% of the LW pieces tagged in the dry season of 2019, were found again in the 2020 survey, even after experiencing a rainy season. However, a substantial portion of them (~40%) were not found, such we assumed that they were downstream transported for long distances (more than 50 m downstream of the end of the survey reach). Replacing the LW transported out of the reaches, new pieces were recruited in a similar proportion of the lost ones (~ 40%), such the average total amount of in-stream wood (number of pieces and volume per channel unit) were almost constant when comparing both surveys. This is in accordance with what was found by Cadol and Wohl (2010) when studying headwater streams in a tropical rainforest in Costa Rica. They observed the in-stream wood load in a steady state, with abundance fluctuating around a mean along a short period of time. Thus, a high recruitment rate ensures that tropical streams keep an important wood stock, despite the high transport and decay rates. This is an evidence that the wood load dynamics in the study streams are dominated by the steady-state end-member proposed by Wohl *et al.* (2012).

However, as we observed differences in wood stock among streams, the general steady state in such a short time did not necessarily apply to streams individually. The stream features, local variables and episodic events may significantly affect wood retention, mobility and recruitment (Wohl, 2017; Wohl *et al.*, 2012). Therefore, a high flow event, a landslide, a blowdown or even the fall of one big tree may significantly change the wood stock of a reach from one year to another. In the sampled stream where we detected the second higher wood stock (SS0129), we realized that a storm occurred in the day before the sampling. It was responsible for delivering a huge tree (T50, see its dimensions in the supplementary material S1), which brought with it a great amount of smaller wood pieces, much of them also classified as LW. If we had arrived a day before, the wood stock measured in this specific stream would be completely different, with obvious consequences to the second-year survey as well. Therefore, the remarkable difference in wood stock between this stream and the other was clearly affected by this episodic event directing the wood load regime to the episodic end-member proposed by Wohl *et al.* (2012).

Regarding wood retention, we observed that 35-77% of the wood pieces and 27-82% of the wood volume remained within the study reaches in a year. These retention rates are not very different from what Cadol and Wohl (2010) detected (0.55-0.91 for wood pieces and 0.67-0.99 for volume) but is lower than the rates commonly seen in temperate streams (Iroumé *et al.*, 2015, 2010; Mao *et al.*, 2008; Wohl and Goode, 2008). Indeed, the fluvial transport of wood is recognized to be more pronounced in tropical streams (Cadol *et al.*, 2009; Wohl *et al.*, 2017) due to the high magnitude and frequency of high peak events (Wohl and Jaeger, 2009). Such transport can be even more intensified in disturbed catchments that have the native vegetation cover replaced for urban or agricultural uses (Kang *et al.*, 2001; Mahe *et al.*, 2005; Sriwongsitanon and Taesombat, 2011). As this is the case of our study catchments, which had approximately 90-75% of their area converted to agricultural uses, we were expecting higher transport rates than in tropical conserved catchments as the Costa Rica study. Monitoring hydrological variables such as the discharge and water level allied to an extended time of study should provide better answers for these questions.

Considering only the pieces recovered, we detected an important loss of volume (-8.17 m^3, -22.88%), length (-128.41 m, -15.55%), and diameter (-181.08 cm, -6.20%) from one year to another in all streams. Only one stream (SS0129) had a little average gain of diameter (13.2 cm, 3.22%). The wood loss indicates the effect of the decomposition by decaying and breaking LW pieces, while the exposition of LW parts can explain the gain of wood before buried. When analysing LW pieces individually, is possible to separate breakage and decay processes. The LW pieces lost almost 15% of their volume, 12% of their length and 3% of their diameter (Supplementary S1). As the loss of length is higher than the diameter loss, it is clear that breakage is a more important decomposition process than degradation. Studies assessing the relative importance of breakage and decay as processes depleting large wood are scarce.

Iroumé *et al.* (2017) did not find differences between breakage and decay rates when analysing the LW in the Chilean stream. Nevertheless, Merten *et al.* (2013) found a similar result as ours when studying USA streams. Their results showed that mass losses related to breakage were 7.3% while those related to decay were 1.9%. The proportion of each decomposition process detected by Merten *et al.* (2013) was similar to ours, but their total loss of wood was lower. According to them, breakage was more likely for pieces that were thin in diameter, long, deeply submerged, braced, buried, and travelled long distances and decay more likely for denser pieces, that travelled a long distance, were not deeply submerged, lacked bark, were thin in diameter, were steeply pitched, were long, and were not buried. As our in-stream wood is relatively smaller sized than those typically found in USA (first article results) and tends to travel more, it is easy to understand the higher rates of breakage detected here compared to there. The also higher decay might be related to tropical conditions (higher temperature and moisture) more prone to the decomposition processes.

We observed nine types of LW in our streams. The most common one was the free pieces, followed by stuck, buried and still standing LW. The other LW types (bridges, ramps and logjams) were rare corresponding to less than 10% each one. We can compare our results with those from Iroumé *et al.* (2015) when classifying LW in Chilean streams, although they have adopted slightly different categories. The proportion of free pieces (named “single pieces” in their classification) was exactly the same as ours (37%), but the proportion of logjams was quite different: while we had only 7%, they detected 63.1% of logjams or small accumulations. The rarity of logjams reinforces the prevalence of the steady-state end-member model. As logjams in tropical streams may be very transient, lasting two years or less (Wohl *et al.*, 2009), it is not surprising that besides being rare, logjams have also diminished to only 2% in the second-year survey. The change in the proportion of LW types from one year to another is related their propensity to be entrained or not. Attached pieces tend to stay double times stabler than unattached ones (Cadol and Wohl, 2010). That is why we did not detect changes in the proportion of bridges and standing trees, which can be considered attached LW types. Conversely, the lack of change in the proportion of free logs might reflect that new pieces must have been recruited in the same proportion that they were lost. The increase in the proportion of stuck pieces supports the assumption of new recruitment, but in this case, they remained trapped, instead of being entrained.

We did not detect remarkable differences in the distribution and characteristics of LW from one year to another. The proportion of pieces in each decay class was practically constant, the same for LW size classes. The pieces sampled were equally classified as low, medium and high decomposed pieces in both field surveys. In relation to the pieces size, we confirmed the information brought in the first article that most of the LW is small sized and constantly replaced with rare large pieces appearing occasionally. As one might expect, most of the LW tend to be positioned on the channel margins obviously because is where the stream flow deposit it, while in the channel centre they are readily transported. Following the same line of reasoning, it is easy to understand why most of the LW is paralleled or perpendicularly oriented. In the first case, they have been entrained by the flow and in the second case, they might be new recruited pieces or are anchored on the banks, thus resisting mobilization. Also, in regard to LW orientation, our data are in similar proportions as those observed by Iroumé *et al.* (2015), with approximately 20% oblique, 30% parallel and 40% perpendicular positioned.

Despite being different from the null model, the logistic regression models were weak to predict the factors affecting the LW odds of being transported. In general, they pointed out that length, relative length, diameter, volume, local and decay are important, with the first two affecting negatively and volume positively. We would expect that larger pieces would be more resistant to transportation and more decayed pieces would be more easily broken and, thus, entrained (Wohl, 2017). However, this is not a straightforward relationship, as many factors may influence it. Cadol and Wohl (2010) observed a strong and negative effect of the LW length on wood mobilization, with the chances of a piece being transported halved for every doubling of relative log length. Alternatively, Dixon and Sear (2014) found a low predictive power of LW length and diameter on wood mobility and explained this result due to the differences in wood density and buoyancy between conifers and broadleaves trees. They also pointed out the importance of the complexity of the log, since single straight pieces tend to be entrained easily than complex branching pieces which are readily trapped. These arguments may be applied to explain the low, but still existing effect of length, diameter and volume detected in our data. Similar reasoning can be used to understand the weak effect of decay on the LW transport likelihood. When analysing exactly this relationship, Cadol and Wohl (2010) did not found a significative correlation. In face of this, they argued that a winnowing process may have contributed to a similar mobility of pieces in different decay classes, as the stability provided by the position of piece (pieces in low energy positions of the channel have lower odds of being entrained by the flow) may overcome the loss of structural integrity through decay. Thus, the effect of decay classes in our likelihood transport models may have been diluted by this winnowing process.

The travelled distance of the remaining pieces ranged from almost zero to more than 100 m. However, due to the limited accuracy of the handheld GPS equipment, with a mean error of ≤ 2 m under a forest canopy (Hasegawa and Yoshimura, 2003), it is difficult to evaluate whether low travelled distance values correspond to real displacements of LW or to an error of measure. Being more conservative and setting 5 m as the threshold to consider that a LW have been mobilized, then we have only 26 stable pieces from the 132 first sampled in 2019 (8.3%). The other 286 pieces (91.6%) must have effectively travelled from their initial location. The factors affecting the LW travelled distance are in accordance with the expected, since the main factors controlling a log movement are the ones related to piece and channel dimensions (Ruiz-Villanueva *et al.*, 2016). Wood mobilization is favoured when pieces are shorter than the channel width or thinner than the channel depth (Bilby and Ward, 1989; Lienkaemper and Swanson, 1987). However, the relative importance of these relationships changes depending on the channel planform (Braudrick and Grant, 2001) and if pieces are anchored in the river bed through root wads or branches (Abbe and Montgomery, 1996; Welber *et al.*, 2013). These caveats may be behind the weak power of prediction of the global model. In the individual models we could eliminate the likely differences of channel morphology between streams such we had an important increase of the explanatory power.

The positive relationships for LW diameter detected in the separated models for VG0034 stream can be understood because the LW size may also affect the piece movement by increasing its mobility. Larger pieces have higher mass and, therefore, higher momentum, which allows them to overcome frictional resistance offered by obstructions (Ruiz-Villanueva *et al.*, 2016). Still, depending on the wood density, the initial motion and transport of wood pieces during the water level elevation may be favoured independently of their dimensions (Gurnell, 2003). According to a pioneer and remarkable flume experiment performed by Braudrick and Grant (2000), log entrainment is primarily a function of the piece angle relative to flow direction (orientation), the density of the log, the piece diameter and the presence of rootwads. A thicker LW perpendicular oriented will tend to move, because of the increased force of the stream flow against the surface area of a large diameter log. So, if a thick LW is not properly anchored, thus it will tend to be downstream mobilized. Braudrick and Grant (2000) still highlight that density differences between pieces of different diameters may also dilute the effect of diameter as a strong predictor of the travelled distance.

As the main finding of their experiment, Braudrick and Grant (2000) concluded that the two most important factors in the entrainment of wood are the piece orientation and the presence or absence of root wads. Pieces perpendicular and oblique oriented move more than parallel oriented pieces, because they are submitted to a higher push due to a larger surface area exposed to the water flow. This is in accordance with what we found, since LW oblique oriented travelled more than the other orientations (Figure 6a, 8c). In the case of the standing LW (dead trees that have not fallen yet), besides having a reduced exposed surface area to the flow, they are still rooted, being physically able to resist to the entrainment forces. As we have not classified pieces according to the presence or absence of root wads and branches, neither have measured the wood density of the tagged wood, then the lack of these two important factors in controlling LW mobilization in our global predictive models might have weakened their power to explain the LW travelled distance. In the individual models for VG0034 stream we could explain major part of the travelled distance variation through the LW diameter (or relative diameter), type and orientation. Although we have not accounted for the presence of branches and root wads, the LW type provide us some insights about this. As bridges correspond to fallen trees that crossed the channel, they tend to be anchored in the banks by their branches or root wads, which justify the verified lowest travelled distance mean. On the other hand, the logjams presented the greatest and more variable values. Once more, we verify the transiency of this type of accumulation in tropical streams (Wohl *et al.*, 2009), and the distance travelled by the elements of a new collapsed logjam will vary according to their dimensions in interaction with the channel features.

5. Conclusion

For the first time, LW retention, recruitment and mobilization processes were investigated in Cerrado streams of southeast Brazil, complementing the contributions of the first two articles regarding wood stock quantification and wood controls investigation, respectively. We presented here the annual rates of LW transport and replacement, as well as the description of pieces characteristics and distribution in the channel. We also made initial indications of the relative importance of decomposition processes and the factors controlling wood mobility in Cerrado streams. However, non-accounted variables such wood density and LW complexity, besides the natural heterogeneity among stream environments and the hydrological conditions during the study period may have limited our ability to explain wood entrainment or retention. Although these processes are still not well understood, we believe our findings are the first step in a long way of the in-stream tropical wood research. Further studies should deep in the monitoring of channel and hydrology variables along with measurements of wood pieces in longer term investigations. Special effort should be dedicated in describing and characterizing the great structural complexity and biodiversity of tropical wood pieces. The investigation of wood densities is imperative, in face of the high number of tree species components of the tropical riparian forests and the importance of this variable in affecting wood mobility.

Acknowledgements:

We are grateful for financial support from Minas Gerais Energy Company (CEMIG) through PROECOS P&D Aneel-Cemig GT-599 Project. Individual funding included the Coordination for the Improvement of Higher Education Personnel (CAPES) scholarship in Brazil and a Science without Borders Grant in Australia (PDSE-88881.361954/2019-01) to SOS. PSP was awarded a researched productivity grant (CNPq 30402/2014-3) and a Minas Gerais scholarship grant (FAPEMIG PPM 608-15). Authors thank João Pedro Corrêa Gomes, Aline Junqueira Grossi and Flávio Canavezi for field surveys assistance. We thank the Editor and two anonymous reviewers for the constructive comments and suggestions, which significantly improved the manuscript.

References

Abbe, T.B., Montgomery, D.R., 2003. Patterns and processes of wood debris accumulation in the Queets river basin, Washington. Geomorphology 51, 81–107. https://doi.org/10.1016/S0169-555X(02)00326-4

Abbe, T.B., Montgomery, D.R., 1996. Large woody debris jams, channel hydraulics and habitat formation in large rivers. Regul. Rivers Res. Manag. 12, 201–221. https://doi.org/10.1002/(SICI)1099-1646(199603)12:2/3<201:AID-RRR390>3.0.CO;2-A

Andreoli, A., Comiti, F., Lenzi, M.A., 2007. Characteristics, distribution and geomorphic role of large woody debris in a mountain stream of the Chilean Andes. Earth Surf. Process. Landforms 32, 1675–1692. https://doi.org/10.1002/esp.1593

Angermeier, P.L., Karr, R., 1984. Relationships between Woody Debris and. Trans. Am. Fish. Soc. 113, 716–726. https://doi.org/10.1577/1548-8659(1984)113<716:RBWDAF>2.0.CO;2

Beckman, N.D., Wohl, E., 2014. Carbon storage in mountainous headwater streams: The role of old-growth forest and logjams. Water Resour. Res. 50, 2376–2393. https://doi.org/10.1002/2013WR014167.Received

Benke, A.C., Wallace, J.B., 1990. Wood Dynamics in Coasta ackwater Streams. Can. J. Fish. Aquat. Sci. 47, 92–99.

Bilby, R.E., Bisson, P.A., 1998. Function and Distibution of Large Woody Debris, in: Naiman, R. J.; Bilby, R.E. (Ed.), River Ecology and Management: Lessons from the Pacific Coastal Ecoregion. Springer, New York, pp. 324–346.

Bilby, R.E., Ward, J.W., 1989. Changes in Characteristics and Function of Woody Debris with Increasing Size of Streams in Western Washington. Trans. Am. Fish. Soc. 118, 368–378. https://doi.org/10.1577/1548-8659(1989)118<0368

Bisson, P.A., Bilby, R.E., Bryant, M.D., Dolloff, C.A., Grette, G.B., House, R.A., Murphy, M.L., Koski, V., Sedell, J.R., 1987. Large Woody Debris in Forested Streams in the Pacific Northwest: Past, Present, and Future, in: Salo, E.O., Cundy, T.W. (Eds.), Streamside Management: Forestry and Fisheries Interactions. University of Washington, Seattle, pp. 144–190.

Braudrick, C.A., Grant, G.E., 2001. Transport and deposition of large woody debris in streams: a flume experiment. Geomorphology 41, 263–283.

Braudrick, C.A., Grant, G.E., 2000. When do logs move in rivers? Water Resour. Res. 36, 571–583. https://doi.org/10.1029/1999WR900290

Brooks, A.P., Abbe, T.B., Jansen, J.D., Taylor, M., Gippel, C.J., 2001. Putting the wood back into our rivers: an experiment in river rehabilitation, in: Rutherfurd, I., Sheldon, F., Brierley, G., Kenyon, C. (Eds.), Proceedings of the 3rd Australian Stream Management Conference. Cooperative Research Centre for Catchment Hydrology, Clayton, Australia, pp. 73–80.

Bryant, M.D., 1983. The Role and Management of Woody Debris in West Coast Salmonid Nursery Streams. North Am. J. Fish. Manag. 3, 322–330. https://doi.org/10.1577/1548-8659(1983)3<322:tramow>2.0.co;2

Cadol, D., Wohl, E., 2010. Wood retention and transport in tropical, headwater streams, La Selva Biological Station, Costa Rica. Geomorphology 123, 61–73. https://doi.org/10.1016/j.geomorph.2010.06.015

Cadol, D., Wohl, E., Goode, J.R., Jaeger, K.L., 2009. Wood distribution in neotropical forested headwater streams of La Selva, Costa Rica. Earth Surf. Process. Landforms 34, 1198–1215. https://doi.org/10.1002/esp.1800

Carvalho, D.R., Castro, D.M.P., Callisto, M., Moreira, M.Z., Pompeu, P.S., 2017a. The trophic structure of fish communities from streams in the Brazilian Cerrado under different land uses: an approach using stable isotopes. Hydrobiologia 795, 199–217. https://doi.org/10.1007/s10750-017-3130-6

Carvalho, D.R., Leal, C.G., Junqueira, N.T., de Castro, M.A., Fagundes, D.C., Alves, C.B.M., Hughes, R.M., Pompeu, P.S., 2017b. A fish-based multimetric index for Brazilian savanna streams. Ecol. Indic. 77, 386–396. https://doi.org/10.1016/j.ecolind.2017.02.032

Castro, D.M.P. de, Dolédec, S., Callisto, M., 2018. Land cover disturbance homogenizes aquatic insect functional structure in neotropical savanna streams. Ecol. Indic. 84, 573–582. https://doi.org/10.1016/j.ecolind.2017.09.030

Dixon, S.J., Sear, D.A., 2014. The influence of geomorphology on large wood dynamics in a low gradient headwater stream. Water Resour. Res. 50, 9194–9210. https://doi.org/10.1002/2014WR015947

Fagundes, D.C., Leal, C.G., de Carvalho, D.R., Junqueira, N.T., Langeani, F., Pompeu, P. dos S., 2015. The stream fish fauna from three regions of the Upper Paraná River basin. Biota Neotrop. 15, 1–8. https://doi.org/10.1590/1676-06032015018714

Faustini, J.M., Jones, J.A., 2003. Influence of large woody debris on channel morphology and dynamics in steep, boulder-rich mountain streams, western Cascades, Oregon. Geomorphology 51, 187–205. https://doi.org/10.1016/S0169-555X(02)00336-7

Frainer, A., Polvi, L.E., Jansson, R., McKie, B.G., 2018. Enhanced ecosystem functioning following stream restoration: The roles of habitat heterogeneity and invertebrate species traits. J. Appl. Ecol. 55, 377–385. https://doi.org/10.1111/1365-2664.12932

Furley, P.A., 1999. The nature and diversity of neotropical savanna vegetation with particular reference to the Brazilian cerrados. Glob. Ecol. Biogeogr. 8, 223–241. https://doi.org/10.1046/j.1365-2699.1999.00142.x

Galia, T., Horáček, M., Macurová, T., Škarpich, V., 2019. Drivers of Low Instream Large Wood Retention and Imprints of Wood Mobility in Mountain Nonperennial Streams of a Mediterranean Semiarid Environment. Water Resour. Res. 55, 7843–7859. https://doi.org/10.1029/2019WR025094

Gregory, K.J., Gurnell, A.M., Hill, C.T., 1985. The permanence of debris dams related to river channel processes. Hydrol. Sci. J. 30, 371–381. https://doi.org/10.1080/02626668509491000

Gregory, S. V., Swanson, F.J., McKee, W.A., Cummins, K.W., 1991. An Ecosystem Perspective of Riparian Zones. Bioscience 41, 540–551. https://doi.org/10.2307/1311607

Grette, G. B., 1985. The role of large organic debris in juvenile salmonid rearing habitat in small streams. Master’s thesis, Univ. of Washington, Seattle, Washington, 105 pp.

Gurnell, A. M., 2003. Wood storage and mobility, in The Ecology and Management ofWood in World Rivers, vol. 37, edited by S. V. Gregory, K. L. Boyer, and A. M. Gurnell, Am. Fish. Soc. Symp., Bethesda, Maryland.

Guyette, R.P., Dey, D.C., Stambaugh, M.C., 2008. The temporal distribution and carbon storage of large oak wood in streams and floodplain deposits. Ecosystems 11, 643–653. https://doi.org/10.1007/s10021-008-9149-9

Haga, H., Kumagai, T., Otsuki, K., Ogawa, S., 2002. Transport and retention of coarse woody debris in mountain streams: An in situ field experiment of log transport and a field survey of coarse woody debris distribution. Water Resour. Res. 38, 1-1-1–16. https://doi.org/10.1029/2001WR001123

Harmon, M.E., Franklin, J.F., Swanson, F.J., Sollins, P., Gregory, S. V, Lattin, J.D., Anderson, N.H., Cline, S.P., Aumen, N.G., Sedell, J.R., 1986. Ecology of Coarse Woody Debris in Temperate Ecosystems. Adv. Ecol. Res. 15, 133–302.

Hasegawa, H., Yoshimura, T., 2003. Application of dual-frequency GPS receivers for static surveying under tree canopies. J. For. Res. 8, 103–110. https://doi.org/10.1007/s103100300012

Herdrich, A.T., Winkelman, D.L., Venarsky, M.P., Walters, D.M., Wohl, E., 2018. The loss of large wood affects rocky mountain trout populations. Ecol. Freshw. Fish 27, 1023–1036. https://doi.org/10.1111/eff.12412

Iroumé, A., Andreoli, A., Comiti, F., Ulloa, H., Huber, A., 2010. Large wood abundance, distribution and mobilization in a third order Coastal mountain range river system, southern Chile. For. Ecol. Manage. 260, 480–490. https://doi.org/10.1016/j.foreco.2010.05.004

Iroumé, A., Mao, L., Andreoli, A., Ulloa, H., Ardiles, M.P., 2015. Large wood mobility processes in low-order Chilean river channels. Geomorphology 228, 681–693. https://doi.org/10.1016/j.geomorph.2014.10.025

Iroumé, A., Ruiz-Villanueva, V., Picco, L., 2017. Breakdown of instream wood in low order forested streams of the Southern Chilean mountain ranges. For. Ecol. Manage. 401, 17–32. https://doi.org/10.1016/j.foreco.2017.06.058

Jacobson, P.J., Jacobson, K.M., Angermeier, P.L., Cherry, D.S., 1999. Transport, retention, and ecological significance of woody debris within a large ephemeral river. J. North Am. Benthol. Soc. 18, 429–444.

Kang, S., Zhang, L., Song, X., 2001. Runoff and sediment loss responses to rainfall and land use in two agricultural catchments on the Loess Plateau of China. Hydrol. Process. 15, 977–988. https://doi.org/10.1002/hyp.191

Kaufmann, P.R., Faustini, J.M., Larsen, D.P., Shirazi, M.A., 2008. A roughness-corrected index of relative bed stability for regional stream surveys. Geomorphology 99, 150–170. https://doi.org/10.1016/j.geomorph.2007.10.007

Kaufmann, P.R., Hughes, R.M., 2006. Geomorphic and anthropogenic influences on fish and amphibians in pacific northwest coastal streams. Am. Fish. Soc. Symp. 2006, 429–455.

Keller, E.A., Swanson, F.J., 1979. Effects of large organic material on channel form and fluvial processes. Earth Surf. Process. Landforms 4, 361–380.

Leal, C.G., Pompeu, P.S., Gardner, T.A., Leitão, R.P., Hughes, R.M., Kaufmann, P.R., Zuanon, J., de Paula, F.R., Ferraz, S.F.B., Thomson, J.R., Mac Nally, R., Ferreira, J., Barlow, J., 2016. Multi-scale assessment of human-induced changes to Amazonian instream habitats. Landsc. Ecol. 31, 1725–1745. https://doi.org/10.1007/s10980-016-0358-x

Leitão, R.P., Zuanon, J., Mouillot, D., Leal, C.G., Hughes, R.M., Kaufmann, P.R., Villéger, S., Pompeu, P.S., Kasper, D., de Paula, F.R., Ferraz, S.F.B., Gardner, T.A., 2018. Disentangling the pathways of land use impacts on the functional structure of fish assemblages in Amazon streams. Ecography (Cop.). 41, 219–232. https://doi.org/10.1111/ecog.02845

Lienkaemper, G.W., Swanson, F.J., 1987. Dynamics of large woody debris in streams in old-growth Douglas-fir forests. Can. J. For. Res. 17, 150–156. https://doi.org/10.1139/x87-027

Macedo, D.R., Hughes, R.M., Ferreira, W.R., Firmiano, K.R., Silva, D.R.O., Ligeiro, R., Kaufmann, P.R., Callisto, M., 2016. Development of a benthic macroinvertebrate multimetric index (MMI) for Neotropical Savanna headwater streams. Ecol. Indic. 64, 132–141. https://doi.org/10.1016/j.ecolind.2015.12.019

Mahe, G., Paturel, J.E., Servat, E., Conway, D., Dezetter, A., 2005. The impact of land use change on soil water holding capacity and river flow modelling in the Nakambe River, Burkina-Faso. J. Hydrol. 300, 33–43. https://doi.org/10.1016/j.jhydrol.2004.04.028

Mao, L., Burns, S., Comiti, F., Andreoli, A., Urciuolo, A., Gaviño-Novillo, M., Iturraspe, R., Lenzi, M.A., 2008. LW jams in a mountain stream of Tierra del Fuego: Piece movement and hydro-morphological effects analysis | Acumulaciones de detritos leñosos en un cauce de montaña de Tierra del Fuego: Análisis de la movilidad y de los efectos hidromorfológicos. Bosque 29, 197–211.

Martin, D.J., Benda, L.E., 2001. Patterns of Instream Wood Recruitment and Transport at the Watershed Scale. Trans. Am. Fish. Soc. 130, 940–958. https://doi.org/10.1577/1548-8659(2001)130<0940:poiwra>2.0.co;2

Maser, C., Tarrant, R.F., Trappe, J.M., Franklin, J.F., 1988. From the Forest to the Sea: A Story of Fallen Trees. Gen. Tech. Rep. PNW-GTR-229. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, OR, p. 153.

Merten, E.C., Vaz, P.G., Decker-Fritz, J.A., Finlay, J.C., Stefan, H.G., 2013. Relative importance of breakage and decay as processes depleting large wood from streams. Geomorphology 190, 40–47. https://doi.org/10.1016/j.geomorph.2013.02.006

Montgomery, D.R., 2003. Geomorphic Effects of Wood in Rivers. Am. Fish. Soc. Symp. 37, 21–47.

Montgomery, D.R., Beamer, E.M., Pess, G.R., Quinn, T.P., 1999. Channel type and salmonid spawning distribution and abundance. Can. J. Fish. Aquat. Sci. 56, 377–387. https://doi.org/10.1139/f98-181

Paula, F.R. De, Ferraz, S.F.D.B., Gerhard, P., Vettorazzi, C.A., Ferreira, A., 2011. Large woody debris input and its influence on channel structure in agricultural lands of Southeast Brazil. Environ. Manage. 48, 750–763. https://doi.org/10.1007/s00267-011-9730-4

Pettit, N.E., Warfe, D.M., Kennard, M.J., Pusey, B.J., Davies, P.M., Douglas, M.M., 2013. Dynamics of in-stream wood and its importance as fish habitat in a large tropical floodplain river. River Res. Appl. 29, 864–875. https://doi.org/10.1002/rra.2580

Power, M.E., 2003. Life cycles, limiting factors, and behavioral ecology of four Loricariid catfishes in a Panamanian stream, in: Arratia, G., Kapoor, B.G., Chardon, M., Diogo, R. (Eds.), Catfishes. Science Publishers, Enfield, pp. 581–600.

Ravazzolo, D., Mao, L., Picco, L., Lenzi, M.A., 2014. Tracking log displacement during floods in the Tagliamento River using RFID and GPS tracker devices. Geomorphology 228, 226–233. https://doi.org/10.1016/j.geomorph.2014.09.012

Rickli, C., Bucher, H., 2006. Einfluss ufernaher Bestockungen auf das Schwemmholzvorkommen in Wildbächen, Projektbericht zuhanden des Bundesamts für Umwelt BAFU.

Rosenfeld, J.S., Huato, L., 2003. Relationship between Large Woody Debris Characteristics and Pool Formation in Small Coastal British Columbia Streams. North Am. J. Fish. Manag. 23, 928–938. https://doi.org/10.1577/M02-110

Ruiz-Villanueva, V., Piégay, H., Gurnell, A.M., Marston, R.A., Stoffel, M., 2016. Recent advances quantifying the large wood dynamics in river basins: New methods and remaining challenges. Rev. Geophys. 611–652. https://doi.org/10.1002/2015RG000514.Received

Shields-Jr, F.D., Asce, M., Morin, N., Cooper, C.M., 2004. Large Woody Debris Structures for Sand-Bed Channels. J. Hydraul. Eng. 130, 208–217.

Silva, D.R.O., Ligeiro, R., Hughes, R.M., Callisto, M., 2016. The role of physical habitat and sampling effort on estimates of benthic macroinvertebrate taxonomic richness at basin and site scales. Environ. Monit. Assess. 188, 1–12. https://doi.org/10.1007/s10661-016-5326-z

Sriwongsitanon, N., Taesombat, W., 2011. Effects of land cover on runoff coefficient. J. Hydrol. 410, 226–238. https://doi.org/10.1016/j.jhydrol.2011.09.021

Sterling, K.A., Warren, M.L., 2018. Effects of introduced small wood in a degraded stream on fish community and functional diversity. Southeast. Nat. 17, 74–94. https://doi.org/10.1656/058.017.0106

Sutfin, N.A., Wohl, E.E., Dwire, K.A., 2016. Banking carbon : a review of organic carbon storage and physical factors influencing retention in floodplains and riparian ecosystems 60, 38–60. https://doi.org/10.1002/esp.3857

Tonon, A., Picco, L., Rainato, R., 2018. Test of methodology for developing a large wood budget: A 1-year example from a regulated gravel bed river following ordinary floods. Catena 165, 115–124. https://doi.org/10.1016/j.catena.2018.01.035

USEPA, 2013. National Rivers and Streams Assessment 2013-2014: Field Operations Manual – Wadeable., EPA-841-B-. ed. Office of Water, Washington, DC.

Warren, D.R., Kraft, C.E., 2008. Dynamics of large wood in an eastern U.S. mountain stream. For. Ecol. Manage. 256, 808–814. https://doi.org/10.1016/j.foreco.2008.05.038

Welber, M., Bertoldi, W., Tubino, M., 2013. Wood dispersal in braided streams: Results from physical modeling. Water Resour. Res. 49, 7388–7400. https://doi.org/10.1002/2013WR014046

Wohl, E., 2017. Bridging the gaps: An overview of wood across time and space in diverse rivers. Geomorphology 279, 3–26. https://doi.org/10.1016/j.geomorph.2016.04.014

Wohl, E., 2013. Floodplains and wood. Earth-Science Rev. https://doi.org/10.1016/j.earscirev.2013.04.009

Wohl, E., Bolton, S., Cadol, D., Comiti, F., Goode, J.R., Mao, L., 2012. A two end-member model of wood dynamics in headwater neotropical rivers. J. Hydrol. 462–463, 67–76. https://doi.org/10.1016/j.jhydrol.2011.01.061

Wohl, E., Goode, J.R., 2008. Wood dynamics in headwater streams of the Colorado Rocky Mountains. Water Resour. Res. 44, 1–14. https://doi.org/10.1029/2007WR006522

Wohl, E., Jaeger, K.L., 2009. Geomorphic implications of hydroclimatic differences among step-pool channels. J. Hydrol. 374, 148–161. https://doi.org/10.1016/j.jhydrol.2009.06.008

Wohl, E., Lininger, K.B., Fox, M., Baillie, B.R., Erskine, W.D., 2017. Instream large wood loads across bioclimatic regions. For. Ecol. Manage. 404, 370–380. https://doi.org/10.1016/j.foreco.2017.09.013

Wohl, E., Ogden, F.L., Goode, J., 2009. Episodic wood loading in a mountainous neotropical watershed. Geomorphology 111, 149–159. https://doi.org/10.1016/j.geomorph.2009.04.013

Wright, J.P., Flecker, A.S., 2004. Deforesting the riverscape : the effects of wood on fish diversity in a Venezuelan piedmont stream 120, 439–447. https://doi.org/10.1016/j.biocon.2004.02.022

Young, M.K., Haire, D., Bozek, M.A., 1994. The Effect and Extent of Railroad Tie Drives in Streams of Southeastern Wyoming. West. J. Appl. For. 9, 125–130.

Supplementary Material

S1: Piece volume, length and diameter change for each LW piece measured in 2019 survey and resampled in 2020**.**

Stream	**LW piece**	**Volume (m^3)**				**Length (m)**				**Diameter (cm)**			
		Total		**Loss**		**Total**		**Loss**		**Total**		**Loss**	
		2019	***2020***	***m^3***	***%***	***2019***	***2020***	***m***	***%***	***2019***	***2020***	***cm***	***%***
SS0129	T33	0.04	0.03	-0.01	-25.03%	2.70	2.50	-0.20	-7.41%	12.73	10.35	-2.38	-18.70%
SS0129	T34	0.13	0.14	0.01	7.49%	3.38	3.38	0.00	0.00%	21.54	22.24	0.70	3.25%
SS0129	T36	0.13	0.13	0.00	0.00%	8.00	8.00	0.00	0.00%	11.50	11.50	0.00	0.00%
SS0129	T37	0.06	0.06	0.00	1.00%	5.00	5.20	0.20	4.00%	12.00	11.63	-0.38	-3.13%
SS0129	T40	0.05	0.06	0.01	19.03%	2.75	3.20	0.45	16.36%	13.30	15.38	2.08	15.60%
SS0129	T45	0.04	0.05	0.01	26.13%	2.89	2.90	0.01	0.35%	13.35	14.50	1.15	8.61%
SS0129	T46	0.01	0.01	0.00	-35.67%	1.45	1.60	0.15	10.34%	10.15	7.48	-2.68	-26.35%
SS0129	T50	4.21	3.57	-0.63	-15.00%	20.00	17.00	-3.00	-15.00%	39.00	39.00	0.00	0.00%
SS0129	T51	0.07	0.08	0.01	12.20%	12.00	4.60	-7.40	-61.67%	7.75	14.48	6.73	86.77%
SS0129	T52	0.06	0.05	-0.01	-19.05%	3.46	3.70	0.24	6.94%	15.00	12.95	-2.05	-13.67%
SS0129	T53	0.03	0.03	0.00	0.84%	5.10	4.50	-0.60	-11.76%	7.60	8.65	1.05	13.82%
SS0129	T54	0.02	0.03	0.00	13.68%	3.62	3.40	-0.22	-6.08%	8.20	9.20	1.00	12.20%
SS0129	T55	0.02	0.01	-0.02	-61.16%	4.47	3.70	-0.77	-17.23%	7.25	5.43	-1.83	-25.17%
SS0129	T56	0.05	0.06	0.01	23.52%	1.35	1.42	0.07	5.19%	20.65	22.30	1.65	7.99%
SS0129	T57	0.02	0.03	0.01	42.88%	4.50	1.50	-3.00	-66.67%	7.50	15.63	8.13	108.33%
SS0129	T58	0.01	0.01	0.00	20.80%	1.88	1.70	-0.18	-9.57%	8.45	10.05	1.60	18.93%
SS0129	T62	0.01	0.02	0.01	88.62%	1.09	1.20	0.11	10.09%	12.05	15.43	3.38	28.01%
SS0129	T63	0.08	0.02	-0.06	-77.37%	4.26	3.80	-0.46	-10.80%	14.95	7.63	-7.33	-49.00%
SS0129	T64	0.03	0.03	0.00	8.77%	3.34	3.20	-0.14	-4.19%	9.55	10.08	0.52	5.50%
SS0129	T65	0.02	0.01	-0.01	-55.21%	3.28	3.30	0.02	0.61%	7.50	5.23	-2.28	-30.33%
SS0129	T67	0.23	0.23	0.00	0.00%	8.00	8.00	0.00	0.00%	15.85	15.85	0.00	0.00%
SS0129	T69	0.42	0.31	-0.12	-27.45%	7.83	7.30	-0.53	-6.77%	20.00	18.25	-1.75	-8.75%
SS0129	T70	0.05	0.05	0.00	9.25%	5.00	5.50	0.50	10.00%	10.75	10.75	0.00	0.00%
SS0129	T73	0.03	0.01	-0.02	-59.52%	2.32	1.10	-1.22	-52.59%	13.10	12.20	-0.90	-6.87%
SS0129	T75	0.02	0.02	0.00	-22.51%	4.50	2.40	-2.10	-46.67%	6.55	8.75	2.20	33.59%
SS0129	T76	0.08	0.07	-0.01	-9.76%	7.50	6.10	-1.40	-18.67%	9.75	12.15	2.40	24.62%
SS0129	T79	0.13	0.14	0.01	8.39%	4.59	5.40	0.81	17.65%	18.65	18.05	-0.60	-3.22%
SS0129	T80	0.16	0.06	-0.10	-63.70%	2.25	1.00	-1.25	-55.56%	25.75	27.13	1.38	5.34%
SS0129	T81	0.15	0.06	-0.08	-56.52%	5.50	2.60	-2.90	-52.73%	16.50	15.80	-0.70	-4.24%

SS0129	T82	0.04	0.04	0.00	6.20%	2.80	2.40	-0.40	-14.29%	13.15	15.25	2.10	15.97%
SS0129 total		***6.40***	***5.42***	***-0.98***	***-15.38%***	***144.81***	***121.60***	***-23.21***	***-16.03%***	***410.07***	***423.26***	***13.20***	***3.22%***
SS0133	T87	0.05	0.02	-0.02	-48.48%	2.70	2.10	-0.60	-22.22%	13.35	11.25	-2.10	-15.73%
SS0133	T89	0.07	0.06	0.00	-3.16%	1.90	2.10	0.20	10.53%	20.80	19.48	-1.33	-6.37%
SS0133	T94	0.06	0.03	-0.03	-52.70%	3.10	2.50	-0.60	-19.35%	14.50	10.25	-4.25	-29.31%
SS0133 total		***0.17***	***0.12***	***-0.06***	***-32.72%***	***7.70***	***6.70***	***-1.00***	***-12.99%***	***48.65***	***40.98***	***-7.68***	***-15.78%***
SS0149	T20	1.78	1.28	-0.50	-28.00%	14.80	14.70	-0.10	-0.68%	38.10	33.15	-4.95	-12.99%
SS0149	T21	1.88	1.89	0.01	0.32%	14.00	12.90	-1.10	-7.86%	41.08	43.08	2.00	4.87%
SS0149	T23	0.06	0.04	-0.02	-34.40%	7.37	6.00	-1.37	-18.59%	9.00	7.38	-1.63	-18.06%
SS0149	T24	1.08	0.01	-1.06	-98.77%	17.07	1.30	-15.77	-92.38%	24.65	11.35	-13.30	-53.96%
SS0149	T25	0.05	0.04	-0.01	-27.63%	6.00	6.30	0.30	5.00%	10.00	7.25	-2.75	-27.50%
SS0149	T29	1.22	0.22	-1.00	-82.05%	9.00	5.90	-3.10	-34.44%	40.00	19.95	-20.05	-50.13%
SS0149 total		***6.07***	***3.48***	***-2.59***	***-42.65%***	***68.24***	***47.10***	***-21.14***	***-30.98%***	***162.83***	***122.15***	***-40.68***	***-24.98%***
SS1000	T1	0.08	0.04	-0.04	-54.41%	3.90	2.65	-1.25	-32.05%	16.25	11.58	-4.68	-28.77%
SS1000	T2	0.18	0.19	0.01	2.75%	4.19	4.10	-0.09	-2.15%	23.00	23.05	0.05	0.22%
SS1000	T3	0.22	0.08	-0.14	-63.25%	2.55	2.50	-0.05	-1.96%	33.00	20.13	-12.88	-39.02%
SS1000	T4	0.22	0.14	-0.08	-35.63%	5.22	4.70	-0.52	-9.96%	23.00	18.95	-4.05	-17.61%
SS1000	T6	0.03	0.01	-0.02	-55.69%	3.15	1.70	-1.45	-46.03%	10.75	9.63	-1.13	-10.47%
SS1000	T7	0.58	0.04	-0.54	-92.73%	4.95	4.30	-0.65	-13.13%	38.50	10.88	-27.63	-71.75%
SS1000	T8	0.15	0.09	-0.06	-40.53%	4.00	3.00	-1.00	-25.00%	21.50	18.78	-2.73	-12.67%
SS1000	T9	0.10	0.08	-0.02	-24.29%	1.92	2.20	0.28	14.58%	25.75	20.70	-5.05	-19.61%
SS1000 total		***1.56***	***0.66***	***-0.89***	***-57.42%***	***29.88***	***25.15***	***-4.73***	***-15.83%***	***191.75***	***133.68***	***-58.08***	***-30.29%***
TM0082	T278	0.13	0.16	0.03	20.70%	6.05	6.00	-0.05	-0.83%	16.00	17.55	1.55	9.69%
TM0082	T285	0.12	0.02	-0.10	-81.84%	6.00	3.40	-2.60	-43.33%	14.65	7.68	-6.98	-47.61%
TM0082	T286	0.13	0.09	-0.03	-25.24%	3.40	3.00	-0.40	-11.76%	21.60	19.78	-1.83	-8.45%
TM0082	T287	0.03	0.02	-0.01	-26.06%	2.63	2.30	-0.33	-12.55%	11.75	10.75	-1.00	-8.51%
TM0082	T289	0.98	0.83	-0.15	-15.18%	4.50	3.70	-0.80	-17.78%	52.50	53.25	0.75	1.43%
TM0082	T290	0.05	0.05	0.01	16.83%	1.40	1.35	-0.05	-3.57%	20.15	22.40	2.25	11.17%
TM0082	T291	0.05	0.04	-0.01	-13.76%	3.90	2.98	-0.92	-23.59%	12.15	13.38	1.23	10.08%
TM0082	T292	0.12	0.05	-0.08	-62.77%	7.95	2.15	-5.80	-72.96%	13.00	16.28	3.28	25.19%
TM0082	T296	0.30	0.25	-0.06	-18.85%	6.58	6.00	-0.58	-8.81%	22.75	21.08	-1.68	-7.36%
TM0082	T298	0.12	0.07	-0.05	-40.15%	4.86	3.00	-1.86	-38.27%	17.80	17.50	-0.30	-1.69%
TM0082	T299	0.01	0.01	0.00	-12.73%	1.37	1.35	-0.02	-1.46%	10.85	10.10	-0.75	-6.91%
TM0082	T300	0.06	0.05	-0.01	-24.03%	5.20	3.70	-1.50	-28.85%	11.75	12.08	0.32	2.77%
TM0082	T301	1.10	1.10	0.00	0.00%	12.30	12.30	0.00	0.00%	31.25	31.25	0.00	0.00%

TM0082	T302	0.05	0.04	-0.01	-26.24%	5.83	4.20	-1.63	-27.96%	10.70	10.30	-0.40	-3.74%
TM0082	T304	0.07	0.03	-0.04	-60.77%	3.67	3.60	-0.07	-1.91%	14.40	9.25	-5.15	-35.76%
TM0082	T305	0.02	0.03	0.01	32.21%	1.80	1.30	-0.50	-27.78%	11.50	15.90	4.40	38.26%
TM0082	T306	0.01	0.01	0.00	-1.93%	1.24	1.30	0.06	4.84%	9.60	9.20	-0.40	-4.17%
TM0082	T307	0.64	0.16	-0.49	-75.56%	5.18	5.90	0.72	13.90%	38.90	14.23	-24.68	-63.43%
TM0082	T309	0.02	0.01	-0.01	-55.75%	2.25	2.30	0.05	2.22%	10.95	6.75	-4.20	-38.36%
TM0082	T311	0.40	0.23	-0.16	-40.65%	6.95	3.30	-3.65	-52.52%	26.00	29.50	3.50	13.46%
TM0082	T312	0.22	0.12	-0.10	-45.25%	4.15	3.60	-0.55	-13.25%	24.60	20.25	-4.35	-17.68%
TM0082	T315	0.43	0.28	-0.15	-34.88%	5.00	4.00	-1.00	-20.00%	33.00	28.63	-4.38	-13.26%
TM0082 total		***5.06***	***3.65***	***-1.42***	***-27.99%***	***102.21***	***80.73***	***-21.48***	***-21.02%***	***435.85***	***397.05***	***-38.80***	***-8.90%***
TM0133	T222	0.03	0.01	-0.02	-56.06%	3.43	1.40	-2.03	-59.18%	10.35	11.28	0.93	8.94%
TM0133	T228	0.02	0.02	0.00	-13.48%	1.61	1.50	-0.11	-6.83%	13.15	11.70	-1.45	-11.03%
TM0133	T229	0.07	0.08	0.00	3.28%	4.89	4.89	0.00	0.00%	13.30	13.45	0.15	1.13%
TM0133	T230	0.01	0.01	0.00	0.78%	1.41	1.30	-0.11	-7.80%	9.55	10.20	0.65	6.81%
TM0133	T231	0.17	0.17	0.00	0.56%	6.00	6.00	0.00	0.00%	18.70	18.75	0.05	0.27%
TM0133	T232	0.04	0.03	0.00	-13.01%	4.56	3.90	-0.66	-14.47%	9.70	9.40	-0.30	-3.09%
TM0133	T233	0.05	0.06	0.01	18.93%	5.31	4.20	-1.11	-20.90%	10.70	12.50	1.80	16.82%
TM0133	T234	0.12	0.12	0.00	0.00%	8.00	8.00	0.00	0.00%	12.50	12.50	0.00	0.00%
TM0133	T236	0.06	0.06	0.00	0.00%	4.00	4.00	0.00	0.00%	13.50	13.50	0.00	0.00%
TM0133	T237	0.06	0.06	0.00	2.44%	3.58	3.60	0.02	0.56%	13.60	13.23	-0.37	-2.76%
TM0133	T238	0.01	0.01	0.00	12.57%	1.39	1.46	0.07	5.04%	9.50	9.73	0.23	2.37%
TM0133	T239	0.05	0.04	-0.01	-12.73%	2.62	2.62	0.00	0.00%	14.85	14.00	-0.85	-5.72%
TM0133	T240	0.11	0.13	0.01	9.84%	3.31	3.50	0.19	5.74%	20.55	20.93	0.38	1.82%
TM0133	T241	0.04	0.05	0.00	11.42%	1.10	1.15	0.05	4.55%	21.65	22.35	0.70	3.23%
TM0133	T242	0.14	0.06	-0.08	-57.19%	5.70	7.00	1.30	22.81%	16.50	8.75	-7.75	-46.97%
TM0133	T244	0.03	0.03	0.00	-7.29%	4.05	2.00	-2.05	-50.62%	9.80	13.65	3.85	39.29%
TM0133	T245	0.02	0.02	0.00	-11.31%	1.20	1.10	-0.10	-8.33%	13.85	13.55	-0.30	-2.17%
TM0133	T246	0.01	0.01	-0.01	-49.13%	1.30	1.09	-0.21	-16.15%	11.50	9.15	-2.35	-20.43%
TM0133	T247	0.07	0.03	-0.04	-54.55%	8.00	3.60	-4.40	-55.00%	9.70	10.43	0.73	7.47%
TM0133	T248	0.01	0.01	0.00	1.94%	1.34	1.28	-0.06	-4.48%	11.45	11.70	0.25	2.18%
TM0133	T249	0.14	0.06	-0.07	-53.80%	3.12	1.11	-2.01	-64.42%	22.00	26.63	4.63	21.02%
TM0133	T250	0.11	0.01	-0.10	-91.24%	6.07	1.40	-4.67	-76.94%	14.05	9.53	-4.53	-32.21%
TM0133	T251	0.03	0.04	0.01	27.07%	3.56	4.10	0.54	15.17%	9.70	10.08	0.38	3.87%
TM0133	T252	0.02	0.03	0.01	44.76%	2.24	2.30	0.06	2.68%	10.80	13.23	2.43	22.45%
TM0133	T253	0.05	0.02	-0.03	-61.12%	3.80	3.80	0.00	0.00%	12.90	7.58	-5.33	-41.28%

TM0133	T255	0.04	0.05	0.01	26.09%	6.05	6.05	0.00	0.00%	8.80	9.13	0.32	3.69%
TM0133	T256	0.08	0.03	-0.04	-56.69%	6.80	5.09	-1.71	-25.15%	11.75	8.18	-3.58	-30.43%
TM0133	T257	0.01	0.00	-0.01	-65.31%	1.50	1.00	-0.50	-33.33%	10.25	7.40	-2.85	-27.80%
TM0133	T259	0.02	0.06	0.04	180.43%	1.58	1.80	0.22	13.92%	13.35	20.03	6.68	50.00%
TM0133	T260	0.05	0.07	0.02	33.47%	3.84	3.68	-0.16	-4.17%	12.65	15.15	2.50	19.76%
TM0133	T263	0.14	0.14	0.00	-0.13%	4.56	4.80	0.24	5.26%	17.50	16.25	-1.25	-7.14%
TM0133	T265	0.01	0.01	0.00	-1.54%	1.54	1.60	0.06	3.90%	10.00	9.68	-0.32	-3.25%
TM0133	T266	0.04	0.03	-0.02	-39.42%	2.60	2.00	-0.60	-23.08%	14.35	12.73	-1.63	-11.32%
TM0133	T267	0.03	0.03	0.00	-0.59%	2.65	2.80	0.15	5.66%	10.90	9.68	-1.23	-11.24%
TM0133	T268	0.02	0.02	0.00	-5.49%	1.50	1.58	0.08	5.33%	13.00	12.35	-0.65	-5.00%
TM0133	T269	0.02	0.01	-0.01	-49.22%	1.80	1.10	-0.70	-38.89%	11.45	10.58	-0.88	-7.64%
TM0133	T270	0.05	0.01	-0.04	-79.93%	5.65	2.12	-3.53	-62.48%	10.50	7.75	-2.75	-26.19%
TM0133	T271	0.04	0.05	0.01	23.72%	3.40	3.50	0.10	2.94%	11.95	13.20	1.25	10.46%
TM0133	T272	0.05	0.04	-0.01	-28.45%	1.28	1.00	-0.28	-21.88%	21.95	21.25	-0.70	-3.19%
TM0133	T273	0.04	0.04	0.00	2.40%	4.05	4.80	0.75	18.52%	10.70	9.35	-1.35	-12.62%
TM0133	T274	0.08	0.08	0.00	4.04%	4.80	4.90	0.10	2.08%	14.00	14.20	0.20	1.43%
TM0133	T275	0.21	0.21	0.00	0.00%	5.50	5.50	0.00	0.00%	21.75	21.75	0.00	0.00%
TM0133	T276	2.05	2.05	0.00	0.00%	18.40	18.40	0.00	0.00%	36.25	36.25	0.00	0.00%
TM0133	T277	0.13	0.11	-0.03	-19.64%	3.50	3.50	0.00	0.00%	21.75	19.25	-2.50	-11.49%
TM0133 total		***4.60***	***4.20***	***-0.40***	***-8.74%***	***172.59***	***151.52***	***-21.07***	***-12.21%***	***616.70***	***601.88***	***-14.83***	***-2.40%***
VG0034	T158	0.07	0.06	-0.01	-19.49%	4.50	2.60	-1.90	-42.22%	13.65	16.38	2.73	19.96%
VG0034	T160	0.05	0.09	0.05	96.87%	2.60	4.60	2.00	76.92%	14.50	15.65	1.15	7.93%
VG0034	T161	0.76	0.66	-0.10	-12.97%	12.80	9.90	-2.90	-22.66%	24.25	24.88	0.63	2.58%
VG0034	T162	0.02	0.01	-0.01	-41.44%	4.40	2.60	-1.80	-40.91%	6.25	6.30	0.05	0.80%
VG0034	T163	0.01	0.01	-0.01	-37.61%	2.05	1.70	-0.35	-17.07%	9.35	7.75	-1.60	-17.11%
VG0034	T164	0.33	0.32	0.00	-1.43%	9.38	6.80	-2.58	-27.51%	20.25	24.50	4.25	20.99%
VG0034	T165	2.04	1.05	-0.99	-48.41%	14.55	12.80	-1.75	-12.03%	39.25	27.25	-12.00	-30.57%
VG0034	T168	0.26	0.25	-0.01	-2.70%	6.50	5.80	-0.70	-10.77%	21.90	22.95	1.05	4.79%
VG0034	T169	0.04	0.07	0.04	99.31%	1.29	1.36	0.07	5.43%	19.00	24.63	5.63	29.61%
VG0034	T171	0.08	0.05	-0.03	-39.41%	5.37	2.90	-2.47	-46.00%	12.60	14.50	1.90	15.08%
VG0034	T173	0.26	0.19	-0.06	-25.09%	4.31	2.80	-1.51	-35.03%	27.00	29.05	2.05	7.59%
VG0034	T176	0.07	0.09	0.02	24.57%	5.56	5.56	0.00	0.00%	11.40	12.50	1.10	9.65%
VG0034	T181	0.05	0.06	0.01	20.04%	2.89	2.90	0.01	0.35%	13.35	15.00	1.65	12.36%
VG0034	T182	0.09	0.09	-0.01	-6.87%	8.80	9.95	1.15	13.07%	11.50	10.13	-1.38	-11.96%
VG0034	T183	0.01	0.01	-0.01	-49.91%	2.38	2.10	-0.28	-11.76%	8.30	6.50	-1.80	-21.69%

VG0034	T184	0.03	0.04	0.00	5.10%	4.02	3.10	-0.92	-22.89%	10.10	11.75	1.65	16.34%
VG0034	T187	0.13	0.06	-0.07	-55.91%	5.40	5.50	0.10	1.85%	16.55	11.45	-5.10	-30.82%
VG0034	T188	0.09	0.13	0.05	53.79%	6.25	5.76	-0.49	-7.84%	13.15	16.33	3.18	24.14%
VG0034	T189	0.01	0.01	0.00	2.64%	1.75	1.80	0.05	2.86%	9.60	9.63	0.02	0.26%
VG0034	T192	0.74	0.73	-0.01	-1.13%	8.90	8.75	-0.15	-1.69%	32.25	30.83	-1.43	-4.42%
VG0034	T194	2.11	2.11	0.00	0.00%	8.74	8.74	0.00	0.00%	52.75	52.75	0.00	0.00%
VG0034	T196	0.08	0.11	0.03	42.10%	8.81	9.00	0.19	2.16%	10.10	11.88	1.78	17.57%
VG0034	T197	0.17	0.12	-0.04	-26.51%	4.73	4.10	-0.63	-13.32%	21.10	19.50	-1.60	-7.58%
VG0034	T198	0.28	0.22	-0.06	-20.45%	4.63	4.64	0.01	0.22%	27.75	24.78	-2.98	-10.72%
VG0034	T199	0.07	0.01	-0.06	-79.69%	3.42	3.23	-0.19	-5.56%	15.35	7.08	-8.28	-53.91%
VG0034	T200	0.04	0.02	-0.02	-42.88%	1.93	1.90	-0.03	-1.55%	16.00	12.45	-3.55	-22.19%
VG0034	T201	0.02	0.01	-0.01	-36.61%	4.10	3.80	-0.30	-7.32%	7.60	6.25	-1.35	-17.76%
VG0034	T202	0.03	0.02	-0.01	-22.98%	2.81	2.80	-0.01	-0.36%	11.40	9.45	-1.95	-17.11%
VG0034	T204	0.04	0.05	0.00	6.91%	3.65	2.30	-1.35	-36.99%	11.75	15.88	4.13	35.11%
VG0034	T205	0.05	0.04	0.00	-2.20%	3.21	3.00	-0.21	-6.54%	12.75	13.58	0.82	6.47%
VG0034	T206	0.02	0.01	-0.01	-42.42%	1.49	1.05	-0.44	-29.53%	14.05	12.65	-1.40	-9.96%
VG0034	T209	0.03	0.03	-0.01	-18.74%	2.40	2.60	0.20	8.33%	13.25	11.45	-1.80	-13.58%
VG0034	T210	0.03	0.04	0.01	21.28%	2.50	2.80	0.30	12.00%	12.45	12.75	0.30	2.41%
VG0034	T211	0.08	0.05	-0.04	-44.11%	2.63	1.00	-1.63	-61.98%	19.75	23.83	4.08	20.63%
VG0034	T212	0.02	0.01	-0.01	-44.03%	3.29	1.30	-1.99	-60.49%	9.50	10.70	1.20	12.63%
VG0034	T215	0.04	0.01	-0.03	-83.64%	3.15	1.30	-1.85	-58.73%	12.65	7.93	-4.73	-37.35%
VG0034	T216	0.28	0.28	0.00	-0.28%	4.80	4.80	0.00	0.00%	25.13	25.05	-0.07	-0.30%
VG0034	T217	0.31	0.28	-0.03	-9.65%	4.94	4.50	-0.44	-8.91%	28.00	27.63	-0.38	-1.34%
VG0034	T218	0.15	0.05	-0.10	-68.66%	7.78	4.50	-3.28	-42.16%	15.25	11.30	-3.95	-25.90%
VG0034	T219	0.11	0.12	0.01	11.77%	2.81	2.80	-0.01	-0.36%	21.75	21.55	-0.20	-0.92%
VG0034 total		***9.12***	***7.60***	***-1.52***	***-16.69%***	***195.52***	***169.44***	***-26.08***	***-13.34%***	***692.53***	***676.33***	***-16.20***	***-2.34%***
VG00177	T105	0.19	0.06	-0.13	-70.27%	7.80	5.88	-1.92	-24.62%	17.25	10.70	-6.55	-37.97%
VG00177	T117	1.17	1.14	-0.02	-1.84%	15.00	15.00	0.00	0.00%	25.88	24.50	-1.38	-5.31%
VG00177	T118	0.05	0.05	0.01	11.04%	5.00	4.50	-0.50	-10.00%	10.63	11.93	1.30	12.24%
VG00177	T119	0.01	0.02	0.01	93.32%	1.20	2.00	0.80	66.67%	9.75	10.08	0.32	3.33%
VG00177	T120	0.16	0.16	0.00	-0.37%	4.30	5.00	0.70	16.28%	20.25	19.45	-0.80	-3.95%
VG00177	T124	0.05	0.04	-0.01	-27.53%	3.62	3.40	-0.22	-6.08%	13.00	10.80	-2.20	-16.92%
VG00177	T126	0.02	0.01	-0.01	-39.44%	2.00	1.50	-0.50	-25.00%	10.00	8.95	-1.05	-10.50%
VG00177	T128	0.01	0.02	0.01	58.63%	1.99	2.40	0.41	20.60%	9.50	10.90	1.40	14.74%
VG00177	T129	0.02	0.02	0.00	20.79%	1.46	1.40	-0.06	-4.11%	12.55	14.08	1.53	12.15%

VG00177	T130	0.03	0.04	0.01	23.59%	3.20	3.10	-0.10	-3.13%	10.75	11.80	1.05	9.77%
VG00177	T131	0.08	0.04	-0.04	-47.29%	2.56	2.40	-0.16	-6.25%	19.35	14.60	-4.75	-24.55%
VG00177	T132	0.05	0.04	0.00	-8.86%	2.54	2.30	-0.24	-9.45%	15.35	15.40	0.05	0.33%
VG00177	T133	0.02	0.02	0.00	5.66%	1.83	2.00	0.17	9.29%	11.95	11.75	-0.20	-1.67%
VG00177	T134	0.03	0.03	-0.01	-16.92%	2.20	2.20	0.00	0.00%	13.35	12.10	-1.25	-9.36%
VG00177	T135	0.05	0.07	0.02	33.02%	2.18	2.30	0.12	5.50%	16.85	18.98	2.13	12.61%
VG00177	T136	0.03	0.02	-0.01	-38.34%	4.33	3.50	-0.83	-19.17%	9.05	7.80	-1.25	-13.81%
VG00177	T137	0.02	0.01	-0.01	-45.37%	2.05	1.90	-0.15	-7.32%	11.50	8.48	-3.03	-26.30%
VG00177	T138	0.03	0.03	0.00	-7.27%	3.00	2.70	-0.30	-10.00%	11.00	11.08	0.07	0.68%
VG00177	T139	0.02	0.02	0.00	-16.74%	2.30	2.00	-0.30	-13.04%	11.75	11.50	-0.25	-2.13%
VG00177	T143	0.04	0.02	-0.02	-49.43%	3.80	2.90	-0.90	-23.68%	11.75	9.60	-2.15	-18.30%
VG00177	T146	0.03	0.03	0.00	7.40%	2.25	2.00	-0.25	-11.11%	12.00	13.38	1.38	11.46%
VG00177	T147	0.36	0.34	-0.02	-4.29%	14.00	13.40	-0.60	-4.29%	17.00	17.00	0.00	0.00%
VG00177	T148	0.01	0.02	0.00	27.95%	2.12	1.80	-0.32	-15.09%	9.00	11.10	2.10	23.33%
VG00177	T151	0.02	0.01	-0.01	-56.50%	2.10	1.30	-0.80	-38.10%	12.00	10.00	-2.00	-16.67%
VG00177	T154	0.09	0.12	0.03	29.34%	4.10	4.10	0.00	0.00%	15.50	17.25	1.75	11.29%
VG00177	T155	0.01	0.01	0.00	-1.73%	1.78	1.60	-0.18	-10.11%	9.75	10.20	0.45	4.62%
VG0177 total		***2.60***	***2.39***	***-0.21***	***-8.13%***	***98.71***	***92.58***	***-6.13***	***-6.21%***	***346.70***	***333.38***	***-13.33***	***-3.84%***
Grand Total		**35.58**	**27.50**	**-8.07**	**-22.70%**	**819.66**	**694.82**	**-124.84**	**-15.23%**	**2905.07**	**2728.69**	**-176.38**	**-6.07%**
Average		**0.20**	**0.15**	**-0.05**	**-14.38%**	**4.59**	**3.88**	**-0.70**	**-12.19%**	**16.28**	**15.30**	**-0.98**	**-3.17%**

S2: LW pieces mobilized from 2019 to 2020 field campaign.

Stram	**LW pieces**	**Travelled distance (m)**			
		Average	***Minimum***	***Maximum***	***Std. deviation***
SS0129	30	17.69	2.56	102.95	22.17
SS0133	7	4.03	2.95	6.29	1.68
SS0149	6	6.49	2.13	14.22	4.93
SS1000	8	11.03	0.43	24.87	7.08
TM0082	22	18.09	1.51	72.46	17.55
TM0133	44	15.41	3.09	65.64	10.24
VG0034	40	14.19	1.15	41.67	8.74
VG0177	26	10.83	3.01	19.73	4.56
TOTAL	183	**14.33**	**0.43**	**102.95**	**13.16**