INSTITUTO NACIONAL DE PESQUISAS DA AMAZÔNIA – INPA

PROGRAMA DE PÓS-GRADUAÇÃO EM CIÊNCIAS DE FLORESTAS TROPICAIS

Variação espaço-temporal do estoque e sequestro de carbono na biomassa lenhosa ao longo de um gradiente hidroedáfico em florestas alagáveis de igapó no Parque Nacional do Jaú, Amazônia Central.

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Manaus, AM

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CNPq/FAPEAM
CNPq/PELD-MAUA

Dissertação apresentada ao Programa de Pós-Graduação em Ciências de Florestas Tropicais, do Instituto Nacional de Pesquisas da Amazônia, como parte dos requisitos para obtenção do título de Mestre em Ciências de Florestas Tropicais, área de concentração Manejo Florestal.

Manaus, AM

2018

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Sinopse:

Florestas alagáveis desempenham um papel importante nos ciclos biogeoquímicos. Entretanto, pouco se conhece a respeito da quantidade de carbono que estas florestas são capazes de estocar e sequestrar. Com isso, o presente estudo objetiva estimar estoques de carbono na biomassa lenhosa por meio de modelos alométricos e o sequestro de carbono aplicando analises de anéis de crescimento em florestas de igapó do Parque Nacional do Jaú e elucidar a ecologia desses ecossistemas.

Palavras-chaves: Florestas de igapó. Biomassa lenhosa. Anéis de crescimento. Gradientes de inundação.

C824v Correa, Jailane Brandão

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vi, 62 f. : il. color.

Dissertação (Mestrado) - INPA, Manaus, 2018.

Orientador: Jochen Schöngart.

Programa: Ciências de Florestas Tropicais.

Agradecimentos

A fase de mestrado para todo e qualquer aluno de pós-graduação, configura-se em um momento onde surge, paulatinamente, uma série de desafios a serem vencidos dia após dia. Uns conseguem conduzir suas pesquisas exitosamente, alcançando de forma merecida o resultado de seus esforços. Outros, mediante sua realidade de vida e acontecimentos inesperados estão sujeitos a enfrentar dificuldades ao longo de sua jornada. Persistir e confiar no Senhor, além de bíblico, é um lema que todos nós devemos levar para toda a vida: “Posso todas as coisas em Cristo que me fortalece" (Filipenses 4:13).

Gostaria de agradecer algumas pessoas que me acompanharam e foram fundamentais para a realização de mais este sonho. Por isso, expresso aqui, através de palavras sinceras a importância que elas tiveram, e ainda têm, nesta conquista e a minha sincera gratidão. Primeiramente, agradeço a Deus pela oportunidade e pela Sua infinita misericórdia. Acordar todos os dias e saber que existe um Deus que reconhece o quanto sou frágil, e mesmo assim me ama e me abençoa face às falhas e erros cometidos. Quero deixar minha gratidão e carinho ao meu esposo, Marcel Leão, companheiro, melhor amigo, colega de profissão e agora parceiro para vida: Te amo. Aos meus pais, Jaime e Elane; a minha irmã Juliane, minha avó Edwirges, pela compreensão, ao serem privados em muitos momentos da minha companhia e atenção, e pelo profundo apoio, me estimulando nos momentos mais difíceis. Obrigada pelo esforço que fizeram para que eu pudesse superar cada obstáculo em meu caminho e chegar aqui. À vocês, minha família, sou eternamente grata por tudo que sou, por tudo que consegui conquistar até aqui.

Agradeço imensamente ainda ao meu orientador, Dr. Jochen Schöngart, pelos ensinamentos e paciência ao longo da pesquisa: certamente para mim, com toda a certeza foi uma grande satisfação tê-lo como meu orientador. Ao grupo MAUA pela oportunidade em participar e fazer parte de suas excursões, as quais geram conhecimentos e oportunidades únicas para vida dos alunos que mergulham nesse mundo das áreas úmidas amazônicas. Além dos pesquisadores que muito colaboraram na revisão do meu plano, e também aos membros da banca que engrandeceram esse trabalho com suas valiosas contribuições. Não posso deixar de agradecer ao INPA, que me deu toda a estrutura e o incentivo necessário para vencer essa etapa, cada funcionário que ajudou e fez parte dessa história.

Resumo

Florestas alagáveis subsidiam a regulação de inundações e o ciclo global de carbono (C). Por sua vez, resultados mais precisos do efeito da inundação sazonal e o armazenamento de C sob as taxas de biomassa lenhosa e o modo como essa condição pode controlar a produtividade florestal, ainda são inconclusivos e escassos. Diante disso, o presente estudo objetivou relacionar o estoque e sequestro de carbono na biomassa lenhosa de florestas alagáveis de igapós de água preta com fatores hidroedáficos no Parque Nacional do Jaú, Amazônia Central. O estudo foi realizado no Parque Nacional do Jaú, na região de floresta de igapó. As espécies amostradas que atenderam ao critério DAP> 10 cm dentro das seis parcelas de monitoramento, foram incluídas no inventário florestal distribuídas ao longo de um gradiente hidroedáfico em condições topográficas distintas (baixo, médio e alto igapó) em uma área total de 6 ha. Estimou-se a produtividade da biomassa, combinando dados de anéis de crescimento, fatores hidroedáticos e equações alométricas com base no diâmetro, altura e densidade da madeira. O presente estudo mostrou que o ecossistema de Jaú igapó apresentou relação entre variáveis ambientais e crescimento das árvores. Modelos idade-diâmetro e idade-biomassa, indicaram correlações significativas. O alto igapó apresentou maior ocorrência de árvores mais velhas, as quais acumularam mais biomassa lenhosa ao longo de toda a sua vida quando comparada às árvores das topografias que sofrem períodos mais longos de inundação. O gradiente de inundação mostrou ter estreita correlação com a produtividade da floresta.

Palavras-chaves: Florestas de igapó. Biomassa lenhosa. Anéis de crescimento. Gradientes de inundação.

Abstract

Floodplain forests provide a relevant function in flood regulation and the global carbon (C) cycle. An accurate conclusion about seasonal inundation effect and soil conditions in the biomass rates and C-storage is still scanty. Basin-wide variations in forest biomass, age trees, growth increasing and stem turn over rates are closely related to edaphic as well as climatic conditions. However, informations based on flooding gradients that can probably control the forest productivity remain to be accurately determined. Therefore, the present study was undertaken to correlate carbon sequestration and stocking rates in the woody biomass from igapós forests from black water along to hydroedaphical gradient. The study was performed at Jaú National Park in igapó forest region. The sampled species had achieved DBH>10 cm criterion among six monitoring plots, were included at forest inventory spread along hydroedaphical gradient on distinct topographical conditions (high, moderate and low flooded forest) in a total area of 6 ha. It was estimated stand-age, wood biomass productivity combining tree-ring data, hydroedaphical factors and allometric equations based on diameter, height and wood density. The present study showed Jaú igapó ecosystem presented an evident relation among environmental variables and tree growing. Age-diameter and age-biomass modeling, both relations, indicated significant correlations. Low flooded gradient level presented expressive results. Although the highest occurence of older trees individuals in the low-flooded forest, this topographical level accumulates more coarse biomass over their lifetime than trees in the topographies that undergo a longest duration flooding. The flooding gradient was shown to have a close correlation with forest productivity.

Keywords: Igapós forests. Coarse biomass. Tree rings. Inundation gradients.

SUMÁRIO

INTRODUÇÃO

Os ecossistemas florestais e seus solos são importantes sumidouros de carbono (Fischlin et al., 2007) e, portanto, influenciam no ciclo de carbono global. Estimativas apontam que esses ambientes armazenam mais carbono do que toda a atmosfera (Basu, 2009). Esforços crescentes e contínuos têm surgido para estimar os estoques de carbono em ecossistemas florestais em difererentes regiões e relacioná-los com as atividades antrópicas que influenciam na alteração do ciclo do carbono (Laurance, 1999).

Regiões entre os trópicos apresentam as maiores taxas de produtividade florestal da superfície terrestre, baseado nos relatos de Phillips et al., (1998), com destaque para as florestas tropicais, as quais apresentam uma estimativa média de aproximadamente 30% a 50% da produtividade terrestre global e em torno de 40% representa o estoque terrestre global de carbono, onde grande parte desse carbono armazenado se encontra na forma de biomassa (Grace et al., 2001). As florestas mais produtivas na bacia amazônica estão na parte ocidental, nas proximidades da Cordilheira Andina, sendo as intermediárias nas áreas dos escudos das Guianas e as menos produtivas nas áreas central e oriental da Amazônia (Malhi et al., 2004).

Dentre os diferentes ecossistemas amazônicos existentes, as florestas alagáveis fornecem serviços ecossistêmicos de extrema importância, pois garantem a conservação da biodiversidade regional, contribuem para qualidade das águas superficiais, representam uma importante fonte de recursos usados para sobrevivência do ser humano, além de atuarem na regulação de enchentes (Malmqvist, 2002). Os ecossistemas sujeitos à inundação desempenham função essencial no ciclo global do carbono (C), devido ao seu importante papel no manejo de sumidouros de C em relação a outros ecossistemas terrestres (Cartisano et al., 2013). Esses ambientes naturais são diretamente influenciados por um regime de inundação sazonal (pulso de inundação) responsável pela variabilidade espacial no armazenamento de C e, consequentemente, na produtividade de florestas inundadas (Junk, 1989).

A própria humanidade tem modificado o ciclo ecológico desses ecossistemas naturais, influenciando diretamente na redução das taxas de produtividade florestal.

Em decorrência dos crescentes fenômenos naturais extremos em resposta aos desequilíbrios ocasionados pela atuação antropogênica, infelizmente muitos ecossistemas naturais estão sendo progressivamente destruídos, e somente pequenas áreas de sua extensão original sobrevivem (Laurance, 2011), permitindo, contudo, que essa permanência esteja ameaçada ao longo do tempo.

Ecossistemas mais frágeis com cobertura de florestas remanescentes, apresentam elevada susceptibilidade à perda e à degradação de seus hábitats após impactos. Essa informação é corroborada por estudos que mostraram que a taxa de mortalidade de árvores e a perda de área basal é maior em florestas sazonalmente inundáveis do que em florestas de terra firme (Resende, 2014).

Estudos realizados por Flores et al., (2014) mostraram sinais de grandes incêndios ocorridos no médio Rio Negro, a partir de imagens de satélites da década de 90. Pelas análises das imagens e trabalhos de campo, chegou-se à conclusão que florestas inundáveis de águas negras apresentam características que apontam baixa resistência dos indivíduos arbóreos que ocorrem nessas regiões e, consequentemente, apresentam baixa resiliência e recuperam-se lentamente.

Dentre as florestas alagáveis existentes na Amazônia, Prance (1980) denominou florestas de igapó aquelas que ocorrem nas margens dos cursos de águas pretas ou claras, podendo ser alagadas durante o período de cheia dos rios. As águas negras, em geral, são ácidas e pobres em nutrientes (Melack & Hess, 2010; Furch & Junk, 1997) e sua vegetação, adaptada às inundações (Prance, 1980; Junk, 1989), pode desenvolver um denso tapete de raízes finas entremeando a serrapilheira, o que contribui para o aumento da inflamabilidade (Uhl & Kauffman, 1990; Dos Santos & Nelson, 2013).

Esses ambientes alagáveis, embora inundados sazonalmente, enfrentam uma fase seca (Junk, 1989), com escassez de chuvas e baixa coluna de água, período no qual as espécies arbóreas intensificam seu crescimento (Worbes, 1989; Schöngart et al., 2002). Em períodos de fortes secas, esse crescimento é afetado pelos impactos naturais extremos, os quais provocam efeitos negativos diversos, principalmente em ambientes não perturbados. Em vista disso, há evidências de que nos últimos séculos, florestas de igapós foram impactadas, resultando em uma expressiva redução de grandes áreas florestais, em decorrência do desencadeamento de eventos ambientais severos, os quais se alastraram e se intensificaram ao longo de toda a bacia Amazônica. Contudo, essas regiões foram sujeitas a períodos de transição e regimes de distúrbios severos, os quais apontam para mudanças no ciclo hidrológico, conforme investigado por Gloor et al. (2013); em virtude dos impactos ocasionados por secas, dentre eles, o El Niño que se intensificou e provocou o declínio bem como a dizimação de extensas áreas florestadas, além da acentuada vulnerabilidade que essas florestas têm em relação ao fogo (Nelson 2001; Flores et al., 2014, 2017; Resende, 2014), particularmente, nos anos de El Niño de 2015/16 (Jimenez-Munoz et al., 2016). O manejo inadequado dessas áreas também favorece para sua fragilidade. Esse modelo insustentável pode ocasionar superexploração e subutilização do potencial madeireiro devido à baixa produtividade que as florestas de igapó apresentam (Worbes 1997; Fonseca et al., 2009; Schöngart 2010; Scabin et al., 2012; Rosa et al., 2017). Além disso, essas atividades não consideram que as variações nas taxas de crescimento entre as espécies, entre os hábitats ao longo dos anos (Schöngart, 2003; Brienen & Zuidema, 2006) inviabilizam o manejo desses ambientes.

A manifestação desses impactos, à exemplo da perda maciça de ecossistemas florestais decorrentes de hidrelétricas instaladas na Amazônia, as quais alagam extensas áreas, resultaram em inúmeras “ilhas de florestas”, como é o caso de Balbina no Rio Uatumã. Em consequência, essa construção humana, provocou elevada mortalidade de árvores nas planícies de igapó, principalmente nas baixas topografias à jusante da hidrelétrica de Balbina, que provavelmente resultou em variações significativas nas taxas de biomassa florestal (Assahira et al., 2017). As mudanças podem ter interferido na dinâmica de crescimento das árvores que ocorrem nessas regiões, ou seja, o estágio sucessional dos indivíduos possivelmente pode ter sofrido alterações, influenciando diretamente na idade das árvores.

Assim, estimativas de estoque de carbono nas florestas de igapó estão sendo cada vez mais afetadas devido às mudanças ambientais globais. Uma caracterização mais precisa da biomassa que essas florestas são capazes de estocar, é de extrema importância a fim de determinar a sua efetiva contribuição nas taxas de estoque de carbono globais. Esse balanço de carbono incide nas taxas de produtividade florestal, as quais permitem descrever o comportamento das espécies arbóreas (Andrade e Higuchi, 2009), tendo em vista questões ambientais associadas às condições de inundação e solo com reflexo de seus efeitos ao longo do tempo.

Atualmente, em meio às discussões sobre as mudanças climáticas é de suma importância quantificar com detalhamento a biomassa das florestas, especialmente as florestas tropicais, para o entendimento do ciclo do carbono global. A eficiência do estoque de biomassa lenhosa indica a qualidade das condições ambientais como clima, hidrologia, estrutura do solo e da vegetação e disponibilidade de nutrientes (Chave et al., 2004).

Desse modo, as estimativas obtidas no presente estudo, serão importantes para a tomada de decisões futuras quanto ao uso dos recursos florestais. Sendo assim, o incentivo REDD+ (Redução de emissões decorrentes do desmatamento e degradação florestal) e o papel da conservação, manejo sustentável de florestas configuram-se como estratégias de mitigação das mudanças no clima adotada pelos países em desenvolvimento com a finalidade de contribuir para a conservação da biodiversidade e dos recursos hídricos, e para a melhoria das condições da vida das populações tradicionais.

Diante desse panorama, a pesquisa teve como objetivo relacionar o estoque e sequestro de carbono em biomassa lenhosa de florestas inundadas de água preta, com fatores hidroedáficos no Parque Nacional do Jaú, Amazônia Central.

A partir dessa ótica para sustentar a investigação foram elencadas as seguintes hipóteses: (1) Devido às mudanças no uso da terra e variações climáticas, a altura de inundação pode ser um indicador que influencia nas estimativas de estoque de carbono na floresta de igapó do Jaú? (2) Em razão da baixa resistência e resiliência dos igapós, existe diferença em termos de taxas anuais de crescimento e idade dos indivíduos arbóreos ao longo de um gradiente hidroedáfico? (3) Variáveis edáficas e altura de inundação podem afetar substancialmente a produtividade em biomassa lenhosa ao longo do gradiente?

OBJETIVOS

Objetivo geral

O objetivo geral deste estudo foi relacionar o estoque e sequestro de carbono na biomassa lenhosa de florestas alagáveis de igapó de água preta com fatores hidroedáficos no Parque Nacional do Jaú, Amazônia Central.

Objetivos específicos

I) Relacionar o estoque de carbono na biomassa lenhosa com fatores hidroedáficos considerando as diferentes topografias das florestas alagáveis de igapó de água preta no Parque Nacional do Jaú.

II) Estimar a idade, as taxas anuais de incremento radial das espécies arbóreas amostradas nas diferentes cotas de inundação;

III) Relacionar a produtividade em biomassa lenhosa com a altura da inundação e fatores edáficos em florestas alagáveis de igapó de água preta.

Chapter 1

Corrêa, J.B., Schöngart, J. 2017. Spatial-temporal variation of carbon stock in the woody biomass along a hydroedaphical gradient in Igapó floodplain forests in Jaú National Park, Central Amazonia. Acta Amazônica.

Spatial-temporal variation of carbon stock in the woody biomass along a hydroedaphical gradient in Igapó floodplain forests in Jaú National Park, Central Amazonia.

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Abstract

Floodplain forests provide a relevant function in flood regulation and the global carbon (C) cycle. An accurate conclusion about seasonal inundation effect and soil conditions in the biomass rates and C-storage is still scanty. Basin-wide variations in forest biomass, age trees, growth increasing and stem turn over rates are closely related to edaphic as well as climatic conditions. However, informations based on flooding gradients that can probably control the forest productivity remain to be accurately determined. Therefore, the present study was undertaken to correlate carbon sequestration and stocking rates in the woody biomass of igapó forests from black water along to hydroedaphical gradient. The study was performed at Jaú National Park in igapó forest region. It was inventoried 300 trees among six monitoring plots along hydroedaphical gradient on distinct topographical conditions with a quantitative of 103, 104 and 93 from high, moderate and low flooded forest respectively in a total area of 6 ha. It was estimated stand-age, wood biomass productivity combining tree-ring data, hydroedaphical factors and allometric equations based on diameter, height and wood density. The present study showed Jaú igapó ecosystem presented an evident relation among environmental variables and tree growing. Age-diameter and age-biomass modeling, both relations, indicated significant correlations. Low flooded gradient level presented a highest occurence of older tree individuals, and also accumulates more woody biomass over their lifetime than trees in the topographies that undergo a longest duration flooding and where are yougest trees individuals. Areas where flooding periods are shorter have indicated that they are more productive in woody biomass. Low flooded igapó forest, presented high ecological potential reaching higher increments over 200 years. Furthermore, the relation between age x biomass rates determined that the carbon stock and the annual sequestration for this topography was approximately double the estimates reached compared to the remainder of the hydroedaphical gradient.

Keywords: *Stand productivity rates. Flooding height. Forest age.*

Introduction

Floodplain forests provide relevant ecosystem services, among other functions such as a greater reservoir of biodiversity, supply of resources used by humans, act in the flood regulation (Malmqvist, 2002). Furthermore, mainly these wetlands play an essential function in the global carbon (C) cycle due to their important role in C sink management relative to other terrestrial ecosystems.

Unfortunately, humanity has been modifying much intensely of the Earth's surface and its natural ecosystems. Although this functioning has been relatively regular and natural for biodiversity cycle process, it has accelerated sharply over the last centuries. Today, the loss and degradation of natural habitat area because mainly anthropogenic actions resulted in the intensification of extreme natural phenomena. Many natural ecosystems are being progressively razed, bulldozed, and felled by axes or chainsaws, until only small scraps of their original extensive survival (Laurance, 2011).

Amongst the less studied amazonian ecosystems, black-water igapós forests have been presenting a clear unbalanced in their ecological structure. These environments, although seasonally flooded, deal with an intensification dry season every year (Junk, 1989). This dry period enhances the tree species grow gradually (Worbes, 1989; Schöngart et al., 2002) and if there is an unbalanced from trees growing process could be impaired.

Igapós forests have been hit hard: a huge area that covers canopy forests have been reduced over the past centuries. Shortly, these regions have been undergone several impacts historically, such as: Intensification of the hydrological cycle (Gloor et al., 2013, 2015), impacts of severe droughts in El Niño years and fire vulnerability (Nelson 2001; Flores et al. 2014, 2017; Resende et al. 2014) due to the strong El Niño in the years 2015/16 (Jimenez-Munoz et al., 2016), inadequate forest management of igapós due to low productivity (Worbes 1997; Fonseca et al., 2009; Schöngart 2010, Scabin et al., 2012; Rosa et al., 2017) and also impacts caused by hydroelectric dams (Assahira et al., 2017).

Despite wide amazonian variety of natural ecosystems present striking differences between species compositions, structure and also forest biomass rates, some regions, especialy in igapós forests, have been scarcely studied since existing a forest extension comprising several square kilometers along to Amazon basin. In Amazon forests, there were a lot of studies related to carbon stocks estimations, ranging from local plot-levels to extrapolations on a continental-wide scale (Houghton et al., 2001; Malhi et al., 2004; Saatchi et al., 2007).

There have been increased and continued efforts to estimate carbon stocks in floodplain forest ecosystems and related to anthropogenic activities that influence the alteration of the carbon cycle (Bonan, 2008; Laurance et al., 2011). Currently, studies report that flooded forests have been presented their carbon stocks in decline with expressive losses due to deforestation and habitat degradation.

Furthermore, normal droughts that are occurring every year with the end of the rainy season and the lowering of watercourses, but extreme natural phenomena such as ENSO (El Niño-Southern Oscillation) may expose igapós forests to fire (Williams et al., 2005; Marengo et al., 2011; Flores et al., 2012). In addition, carbon stocks in intact old growth forests may be affected by global environmental changes, especially due to droughs intensification.

Thus, on account of the changes in land use and climate change: (1) Flooding height could be the main indicator to the different carbon stock estimations in Jaú igapó forest? (2) By a low strength and low resilience from igapós in general, is there any difference in terms of increasing in the grow annual rates and also stand-age along to the hydroedaphical gradient? (3) Edaphical variables and inundation height can affect substancially the productivity in woody biomass among sampled gradients?

An accurate characterization of coarse aboveground biomass in igapós forests is utmost importance to estimate their contribution to global carbon stocks. Therefore, the present study has the purpose to relate the carbon stock and carbon sequestration in woody biomass from flooded forests of black water igapó with hydroedaphical factors in Jaú National Park, Central Amazon. As noted already, igapós forests have been undergoing burning natural events associated with droughts in years of El Niño events. It was hypothesized that if the natural disturbance regimes determine the carbon variation, so probably the stand-age and tree growing process in terms of forest productivity were affected.

Materials and methods

Study region

The study was carried out in the seasonally flooded igapó forest in Jaú National Park, situated at Novo Airão region in Amazonas state, Brazil. This park has an area of about 2.272.000 hectares and covers Jaú and Unini rivers basins and their tributaries of right bank from the Negro River (FVA, 1998).

These rivers are dark waters and originated in terrain little elevated. On a local scale, frequent variations in the topography create an increasing temporary of water level on the lower and poorly drained areas during the rainy seasons.

According to Köppen classification, the climate is Af (Alvares et al., 2013), with annual average temperature of 26 ºC. The annual average of Jaú River hydrological level is from 6 to 10 m, between rainy and dry season period. A recent study pointed out that the flood average duration varies from 6 to 288 days $year^{-1}$ related to a flood heigh between 0,1 to 11,1 meters (Aguiar, 2015).

The dominant vegetation type is composed by 75% of terra firme forests, 13% by igapó forests, 10% campinas and campinaranas forests and anothers formations of lesser coverage (Radambrasil, 1978; Veloso et al.,1991; FVA, 1998).

In PARNA Jaú, aluvials soils have been presenting poor and distrofic source material and highly unwaterlogging (FVA, 1998; Aguiar, 2015). In lower land, the soils area characterized by the influence of drainage conditions, shallow with characteristics associated to the regular waterlogging of soil. The soil profile on study area could vary in sandy and clayey conditions (Aguiar, 2015).

Sampling design

On the flood area, it was monitorated six plots with a dimensional size of 50 x 200 m/ plot (1 ha) and geographical coordinates 01°49'-01°49 S/ 61°27'-61°38 W.

The plots were allocated at different topographical levels in order to capture maximum variation of forests along the hydrological gradients and parallel at river direction, distributed randomly. All them were established in each condition of inundation topographical level, tottaling a sampled area of 6 hectares with two plots by gradient.

In cover area by inundation, the plots have followed a hydroedaphic gradient based on inundation level from the igapó forest such as the topographical categories: - High flooded igapó forest (H.F); - Moderate flooded igapó forest (M.F) and; - Low flooded igapó forest (L.F). These plots integrate the Long-Term Ecological Project (PELD) from research group of Ecology, Monitoring and Sustainable Use of Wetlands (MAUA).

Database

Through the forest inventory data, it was obtained the diameter and height values from the sampled trees that followed by diameter at breast height DBH≥10 cm criterion. For trees species that were not measured the height, it was realized a modeling test by the following equation:

$$(DBH \times 22.0014) / (11.6908 + DBH) \quad (1)$$

Wood density informations (g cm^{-3}) were checked from Batista study database (2015), Parolin and Worbes (2000), Targhetta et al. (2015) and besides the Global Density Database when were necessary.

Hydroedaphical analysis of flood gradients

For chemical and physical soil characterization four soils samples by each plot where were collected to 20 cm depth from the centre of each one, totalling forty-four 50 x 50 m (2500 m^2) subplots. The samples were ovendried and analysed at the Plants and Soils analyse Laboratory at the Brazilian Agricultural Research Company, following standardized protocols described in Embrapa (1997).

For this study, were analysed 17 chemical variables, distributed by macro and micronutrients: C, O.M (organic matter), Na, P, K^+, Ca^{2+}, Mg^{2+}, A^{l3+}, Fe, Zn^+, Mn^{2+} and Cu; besides chemical attributes as pH, SB (sum of bases), t (effective cation exchange capacity), V (base saturation index) and m (aluminum saturation index).

Wood samples collecting

The wood samples were collected in 2015 between the months october to november. The extracted samples represented a total of 300 trees where the quantity by topography level was: 103, 104 and 93 trees species for high (H.F), moderate (M.F) and low (L.F) flooded igapó forest respectively along to gradient.

These samples or cores presented diameter of 5.15 mm (Haglöf, Suécia) extracted from diameter at breast height (DBH) with dendrological drill bit. This coarse material provided informations such as age tree and radial increments annual mean rates through Wood anatomy analysis (Worbes, 2002). The analysis were realized in Dendroecology Laboratory, INPA/Max-Planck. The age estimate was through direct counting from rings.

Carbon estimations on coarse wood biomass

The forest inventory database was turned into biomass estimations from tree allometric models. Unfortunately, there are not specific models yet available that depict ecosystems in the Amazon are seasonally flooded forests. However, the existing and usual models, both them considerate that aboveground biomass estimates in tropical forests are most accurate when taking into account diameter (DBH), tree height (H) and specific wood density (*ρ) (*Chave et al., 2005). Thus, were chosen three allometric models according to these criterion from authors studies as Cannell, 1984, Chave et al., 2005 and Feldpausch et al., 2012, respectively:

$$AGB = \pi \times (DBH/200)^2 \times \mathrm{H} \times \rho \times 0.6 \quad (2)$$

$$AGB = 0.0509 \times H \times \rho \times DBH^2 \quad (3)$$

$$AGB = \exp(-2.9205 + 0.9894 \ln(\rho \times DBH^2 \times \mathrm{H})) \quad (4)$$

AGB is the abouveground coarse biomass (kg), *DBH* it the diameter at breast height (cm), *H* is the tree total height (m) and *ρ* is the wood density (g cm^{-3}). The biomass estimations were represented by the average between the three models. All these models use for importance order are based on three independents parameters: DBH, wood density, wood age and height with the main purpose improving the biomass estimations (Chave et al., 2004, 2005; Schöngart et al., 2010, 2011; Feldpausch et al., 2012).

The carbon stocks was calculated according to Brown et al., (1995), for determining the carbon stock rates during entire life tree. According to authors, the carbon content stands for 50% from dry biomass (Clark et al., 2001; Roy et al., 2001; Malhi et al., 2004).

Analysis and modeling of growing rings

The main justify to use the tree ring analysis, it takes into account to obtain reliable estimates for tree ages and mean diameter growth rates which have successfully been aplied to estimate wood biomass productivity in different forest types of Central Amazonia (Worbes, 1997; Oliveira, 2009; Schöngart et al., 2010).

The tree ages were appraised through the rings number counting related to the growing and annual radial increment by the rings width measurement. The growing annual rings strutucture were examined macroscopically following Coster (1927, 1928) and Worbes (1985, 1989) wood anatomical classification.

In tree species, the rings boundary is characterized by thickness of the cell wall becomes larger and the cell lumen becomes smaller of the initial wood for latewood (vessel size/distribution variation) from earlywood to latewood, parenchyma bands limiting growth ring boundaries, alternating fiber and parenchyma bands and vessel density variation as seen bellow (Figure 1).

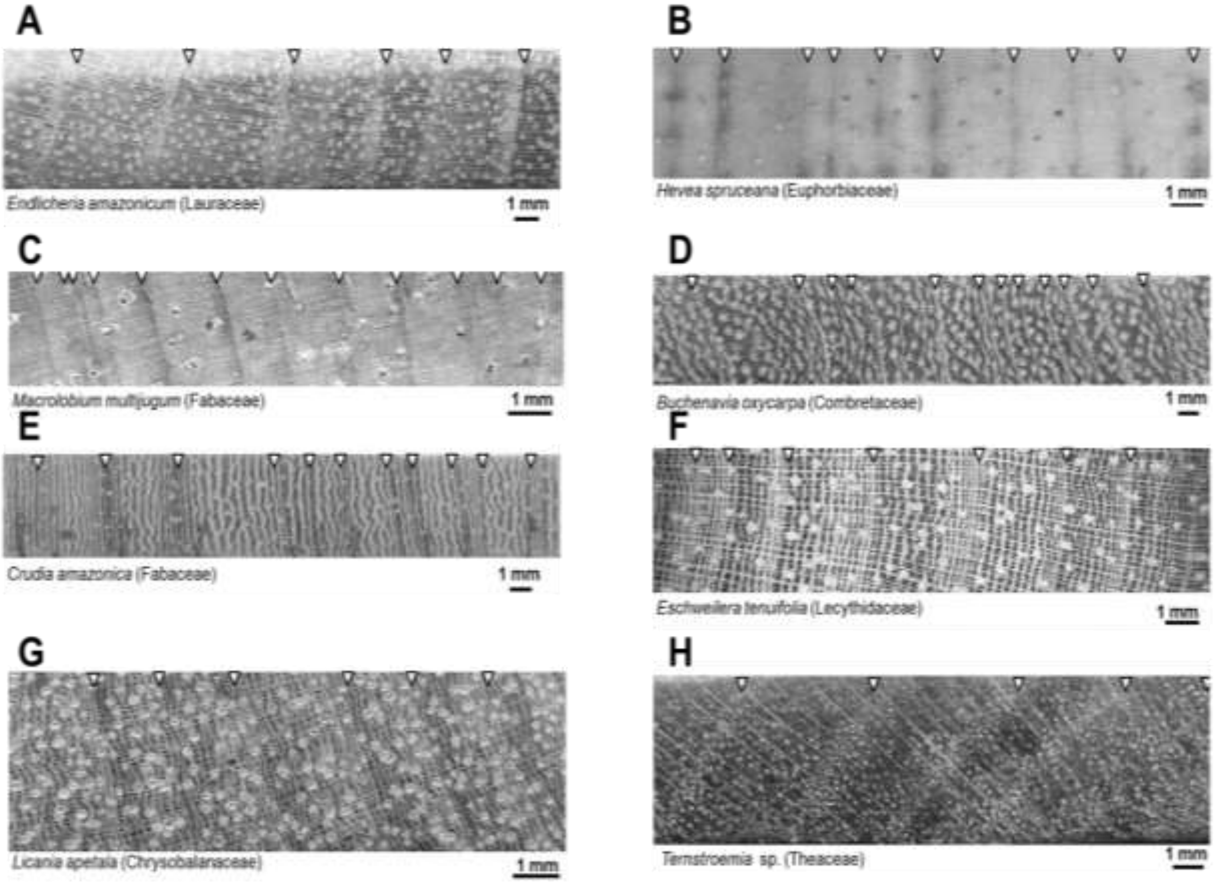

Figure 1- Macroscopial wood anatomy types of trees species from Igapós forests of Jaú: variations in wood density; (A,B) Thickness of the cell wall becomes larger and the cell lumen becomes smaller of the initial wood for latewood (vessel size/distribution variation) from earlywood to latewood (A- *Endlichera amazonicum*, B- *Hevea spruceaena*); (C,D) Parenchyma bands limiting growth ring boundaries (C- *Macrolobium multijugum* , D- *Buchenavia oxycarpa*); (E,F) Alternating fiber and parenchyma bands (E- *Crudia amazonica*, F- *Eschweilera tenuifolia*); (G, H) Vessel density variation (G- *Licania apetala*; H-*Ternstroemia* sp.) Arrows indicate boundary of the tree rings from 1 mm.

For these analysis, it was used a digital mensuration device with accuracy of 0.01 mm (LINTAB, Rinntech, Germany). The temporal sequences measures were realized by the TSAP software (Temporal Series Analysis, Rinntech, Germany).

The adjusted modeling was based on the age-diameter relation through a non-linear regression (sigmoidal) (Schöngart et al., 2007, 2010).

$$DBH = a/(1+b \times \text{age}^{c}) \qquad (4)$$

Through modeling analysis, it was possible to determine the current diameter increment (CDI, cm) for each age (t), followed by the equation below:

$$CDI = DBH(t) - DBH(t-1) \quad (5)$$

The annual growing rings counting wich estimates the individual tree were related to abouveground carbon stock rates through non-linear adjusting of sigmoidal function (Schöngart et al., 2011).

$$\text{C-stock} = a/(1+b \times age^{c}) \quad (6)$$

The estimates of sequestration (kg C $year^{-1}$) were obtained by the carbon stocks from the current year (**t**) and the last year (**t-1**).

$$\text{Sequestration} = \text{C-stocks}(t) - \text{C-stocks}(t-1) \quad (7)$$

Soil analysis

Analysis the edaphical factors influence on wood biomass along the inundation gradient, for this reason, it was realized three analysis through the PCA correlation method (Principal Component Analysis). The PCA analysis assists in the identification of similarity patterns existence into the soil sampled plots along the different topography levels.

The first PCA test considered soil samples values by plot. The second one, other two PCA analysis were used the average values from the soil chemical variables for each topography. The chemical variable analysis was classified in soil nutrients and soil chemical attributes.

Onward the first axis from each PCA result, it was applied three simple linear regression. The main purpose is to determine the environmental factors such as flooding height, soil nutrients and soil chemical attributes influence biomass productivity along to the hydroedaphical gradients.

Data analysis

For the statistical data, simple regression and PCA analysis, was used the R-Project for Statistical Computing free software (R Development Core Team, 2011), using the Vegan package (Oksanen et al., 2009).

To achieve the growth modeling rates, non-linear regressions analysis were realized through the X-Act 7.0 (Scilab) software.

Results

Hydroedaphical indicators and preview biomass estimates

According to PCA test (figure 2), both vectors (P1 e P2) have been explained for 72% from the data variability through a correlation matrix. The first axis (PC1) resulting from the PCA ordination explained 49% of the variation on soil characteristics. An edaphic variable that highly loaded onto PC1 were Fe index.

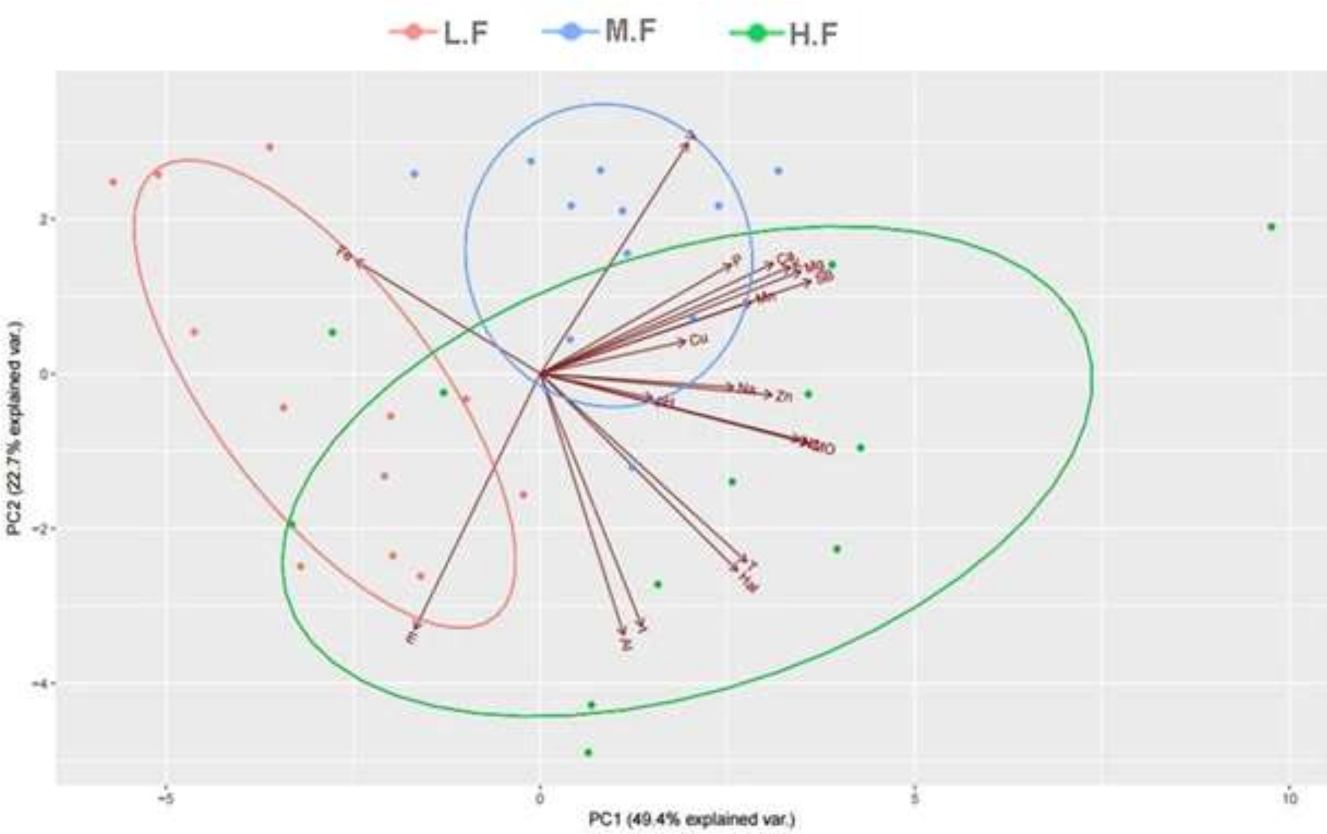

Figure 2- PCA results. Soil chemical variables effects according to the flooding gradient. The dispersion of the points in red, blue and green (-Low flooded igapó forest [L.F]; -Moderate flooded igapó forest [M.F] and -High flooded igapó forest [H.F] respectively) represent the samples from six plots.

Iron element has presented a proportion of up to four times higher in topography with flooding lower height (L.F). However, an expressive presence of carbon and organic matter are more in evidence in M.F and H.F only; on the other hand, this quantitative decreases until 50% in L.F.

Several edaphical components in rest, have beeing acting significaly in moderate and high flooded forest; in a particular case, phosphorus concentrations showed a closely effect related to both topographies (M.F/ H.F). Soils with more available P showed lower stand biomass rates, considerating the relation of five species of greater abundance and their respective tree individuals sampled along the flood gradients.

Estimates of biomass, carbon stock and tree age

Biomass estimates have resulted in approximately 170-200 Mg ha^{1} [H.F]; 220-390 Mg ha^{-1} [M.F] and 170-180 Mg ha^{-1} [L.F] igapó environmentals (table 1), where 50% from this biomass is content of C.

Table 1- Inundation height average, basal area and estimates of biomass and C-stocks in Igapó forests through diferents topographical levels in Jaú National Park. The topographical levels are: High flooded igapó forest [H.F]; Moderate flooded igapó forest [M.F] and; Low flooded igapó forest [L.F]).

Topographical levels	**Plot**	**Inundation height (m)**	**Basal area (m^2 ha^{-1})**	**Biomass (C-stocks) (Mg ha^{-1})**
H.F	P 1	7.7	34.1	196
	P 2	6.3	27.4	170
TOTAL			**61.5**	**366**
M.F	P 4	5.6	42.3	386
	P 5	4.9	29.6	226
TOTAL			**71.9**	**612**
L.F	P 9	1.6	22.4	172
	P 10	1.2	20.7	177
TOTAL			**43.1**	**349**

The different geographical positions showed similar biomass rates between high and low flooded forest. The plots located in the extreme topographies could be the regions more affected than intermediate topography.

The Fabaceae excelled in medium and high igapó environments, presenting individuals with ages varying from 29-147 years and 31-198 years, respectively. In high flooded forest (H.F), this tree family presented younger trees with ages ranging from 28-94 years, though. In addition, Fabaceae family presented higher biomass in relation to other families in all topographical gradient.

Table 2- Relation of five species of greater abundance and their respective tree individuals (N) sampled along the flood gradients. The biomass estimates were determined using the averages between the three models at the topography level. The age of the individuals was represented by the maximum and minimum amplitude of the number of growth rings.

Igapó	**Family**	**Specie**	**N**	**Biomass (kg ha^{-1})**	**Age (years)**
H.F	Sapotaceae	*Pouteria elegans*	10	41 – 501	23 – 63
	Lauraceae	*Nectandra amazonum*	9	33-772	38-96
	Chrysobalanaceae	*Licania apetala*	7	68-222	48-70
	Combretaceae	*Buchenavia ochroprumna*	6	169-878	43-71
	Fabaceae	*Hydrochorea marginata*	6	46-1.671	28-94
M.F	Ochnaceae	*Elvasia quinqueloba*	17	46-368	34-102
	Fabaceae	*Tachigali* sp.	15	53-1.266	29-147
	Ebenaceae	*Diospyros* cf. *vestita*	12	43-711	40-103
	Sapotaceae	*Micropholis humboldtiana*	10	33-653	53-109
	Pentaphylacaceae	*Ternstroemia candolleana*	10	69-528	41-86
L.F	Fabaceae	*Andira micranta*	8	67-1.115	31-78

Apocynaceae	*Aspidosperma spruceanum*	7	69-530	37-77
Goupiaceae	*Goupia glabra*	6	62-495	43-73
Fabaceae	*Aldina latifolia*	6	508-3.986	48-198
Sapotaceae	*Pouteria elegans*	5	212-1.129	64-120

According to the table 2 based on the five species of greatest abundance by topography, low flooded igapó forest of Jaú River showed larger estimates of aboveground biomass compared to another sampled topographic levels. The results ranged from 62 kg to almost 4 tons approximately. High and moderate flooded forest had their biomass rates obtained a maximum level in a little less than 2 tons both each on of them.

Evaluating the five species of greatest abundance by topography, the determined ages of the trees along the gradient (table 2), tree individuals of abundant species of the low flooded forest (L.F) with flooding height ranging from 1.2 m to 1.5 m, correspond to older individuals with a maximum age of up to 200 years. However, high flooded topography covers trees less than 100 years old, which are vulnerable in extreme flooding conditions of up to 7.70 m.

The relationship among age and diameter of trees analyzed in the different topographies, that indicated significant correlations (fig. 3A), explained 67-74% of the diameter variability. Also, it was observed once among age and carbon stocks projected in biomass, indicated significant correlations (fig. 3A), explaining 66-73% of the biomass variability.

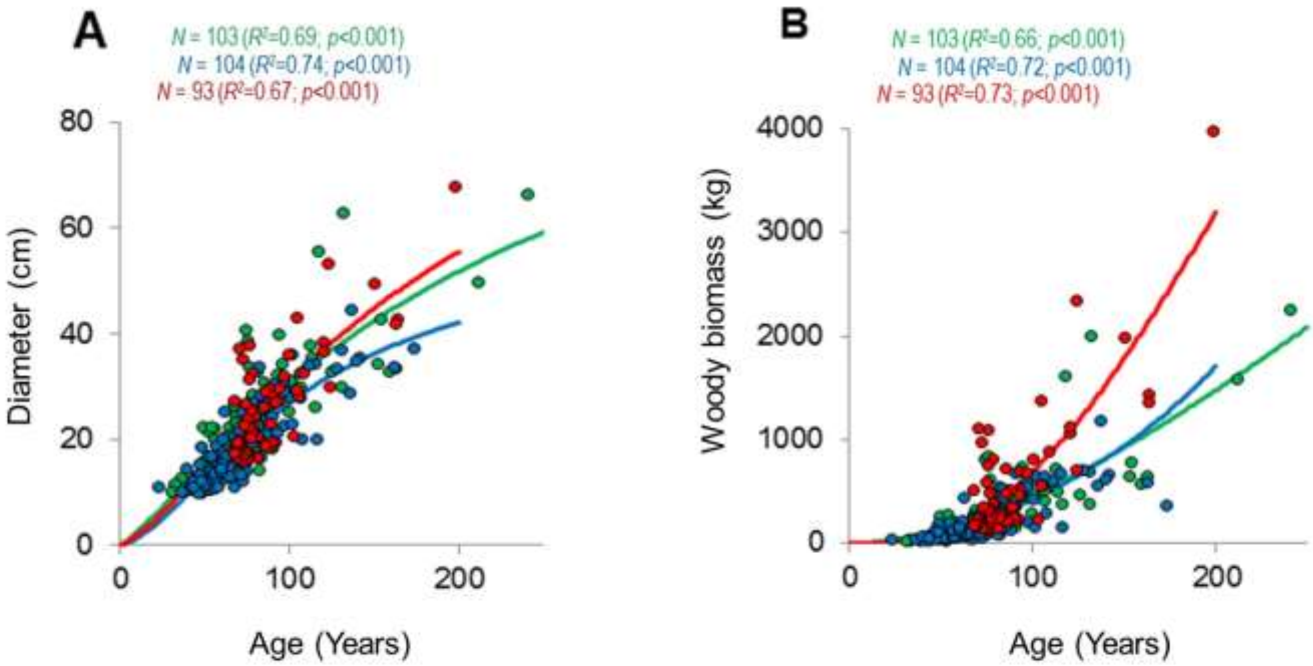

Figure 3- (A) Relation between age and diameter of tree species in igapó forests of PARNA Jaú in different topographies; (B) Relation between age and estimated woody biomass of tree species in igapó forests of PARNA Jaú in different topographies. The green lines are correlated to the high flooded igapó; Blue lines are correlated to the moderate flooded igapó; Red lines are correlated to the low flooded igapó forest respectively.

Growth modeling and biomass productivity

Based on applied growth model, relations between age with diameter and also age with biomass were carried out from mathematical modeling prognosis with the age group of the tree individuals in 200 years along the gradient. The age-diameter relation reached the higher diameter and increments rates over 200 years in lowly flooded igapó forest compared with another topographies.

The current diameter increment (CDI) accumulated in the three topographies, the values of 2.4±0.7 mm (high flooded forest), 2.1±0.8 mm (moderate flooded forest) e 2.8±0.6 mm (low flooded forest). The diameter values were of 34.0±17.7 cm (high flooded forest), 24.2±13.3 cm (moderate flooded forest) and 29.5±17.1 cm (low flooded forest).

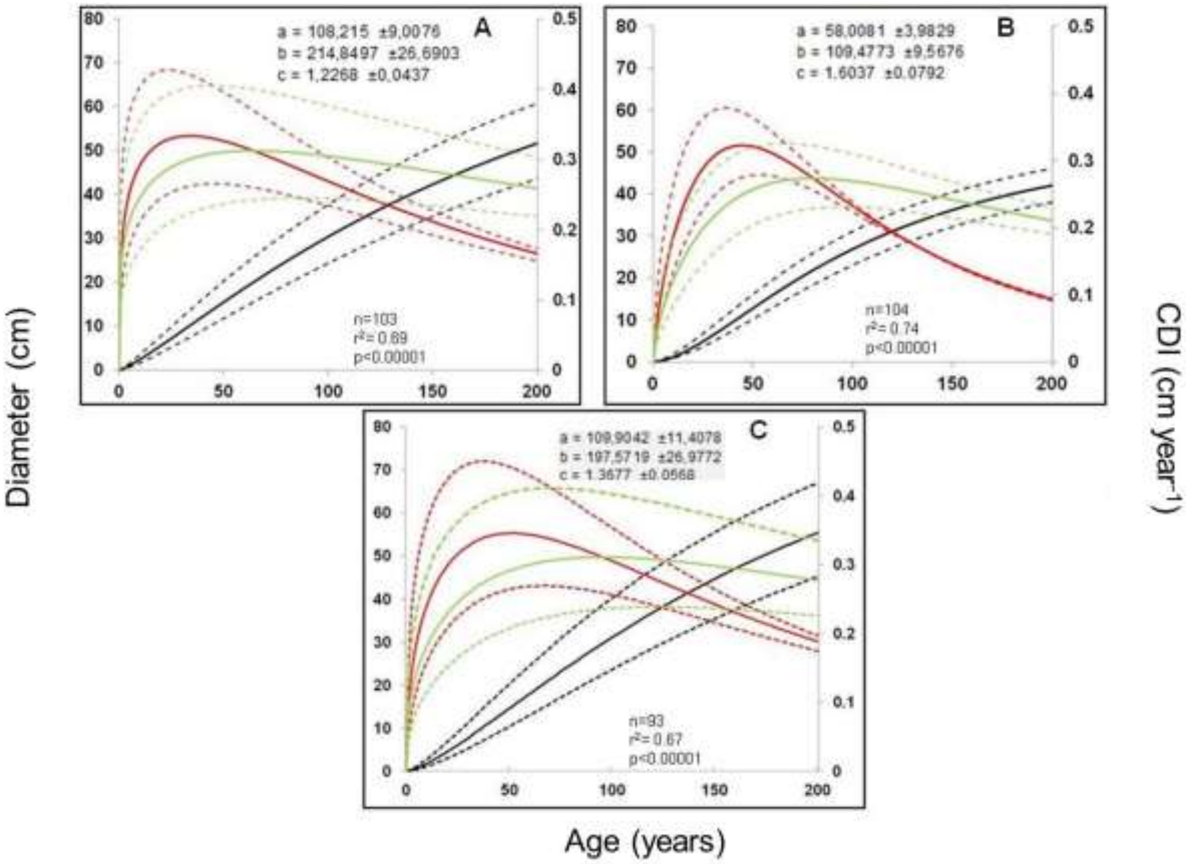

Figure 4- Age-Diameter relation for sampled species along to hydroedaphic gradient: (A) high flooded forest, (B) moderate flooded forest e (C) low flooded forest. The black line is the growth in diameter (D), the green line indicates the average annual increase and the red line indicates the current diameter increment (CDI). The parameters indicated are for the age-diameter relation of Eq. (04). Standard deviation is indicated by dotted lines.

Based on the significant correlations between age tree and woody biomass aboveground, were estimated annual rates of production in woody biomass (figure 5). The models indicate that low flooded igapó forest, although representing the gradient with a range of older tree individuals, this topographical level accumulates more woody biomass over their lifetime than trees in the topographies that undergo a longest duration flooding.

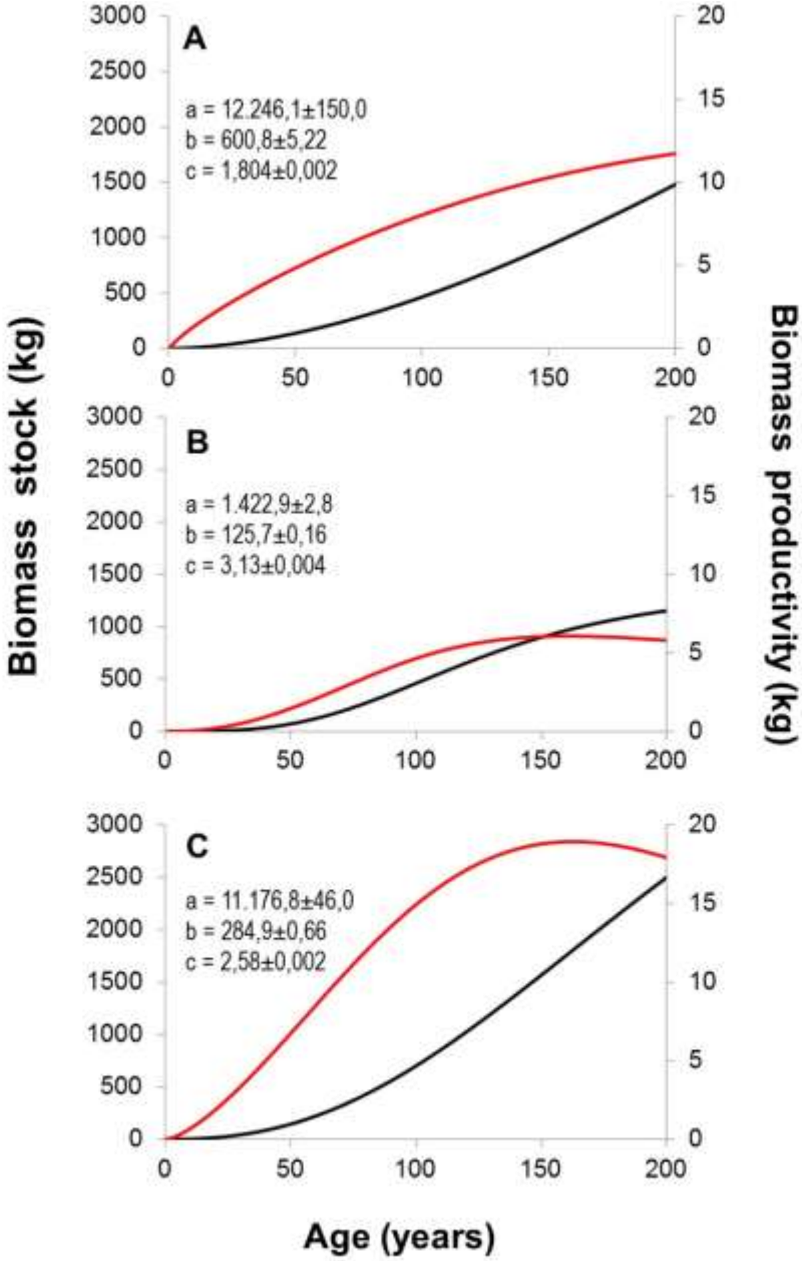

Figure 5- Relation between age and wood biomass forJaú igapó forest along to gradient (A) High flooded forest, (B) Moderate flooded forest and (C) Low flooded forest. The black line indicates the accumulation of biomass stock and the red line indicates the annual production in woody biomass. The obtained parameters are for the age-biomass relation. Eq. 4.

Productivity rates have shown along to inundation gradient, an average index approximadely around 5.1±1.6 Mg ha^{-1} $year^{-1}$ in Jaú igapó forests.

The productivity rates in coarse biomass were higher in upper gradient, that is, in the low flooded forest, ranging from 5.9 to 7.8 Mg ha^{-1} $year^{-1}$ when compared to the trees undergo to variable inundation levels. The forests growing in lower topographies, presented a lower productivity of 3.6 a 4.4 Mg ha^{-1} $year^{-1}$ (table 3).

Table 3- Productivity estimates in aboveground biomass from Jaú forest stand along to the hydroedaphical gradient.

	Plot	**Inundation height (cm)**	**Productivity (Mg ha^{-1} ano^{-1})**
High flooded igapó	1	772	4.4
	2	631	3.6
Moderate flooded igapó	4	557	5.2
	5	494	3.7
Low flooded igapó	9	155	5.9
	10	123	7.8

It is observed a negative trend among wood productivity and the inundation different levels, that is, when flooding height reduces, there is an extending rates of productivity in woody biomass thus allowing an increase of carbon sequestration rates (50% of coarse biomass) (fig. 6). The relation between productivity rates and the flooding height effect represented around 74%, evidencing a direct effect on the productivity of woody biomass due to the flood gradient.

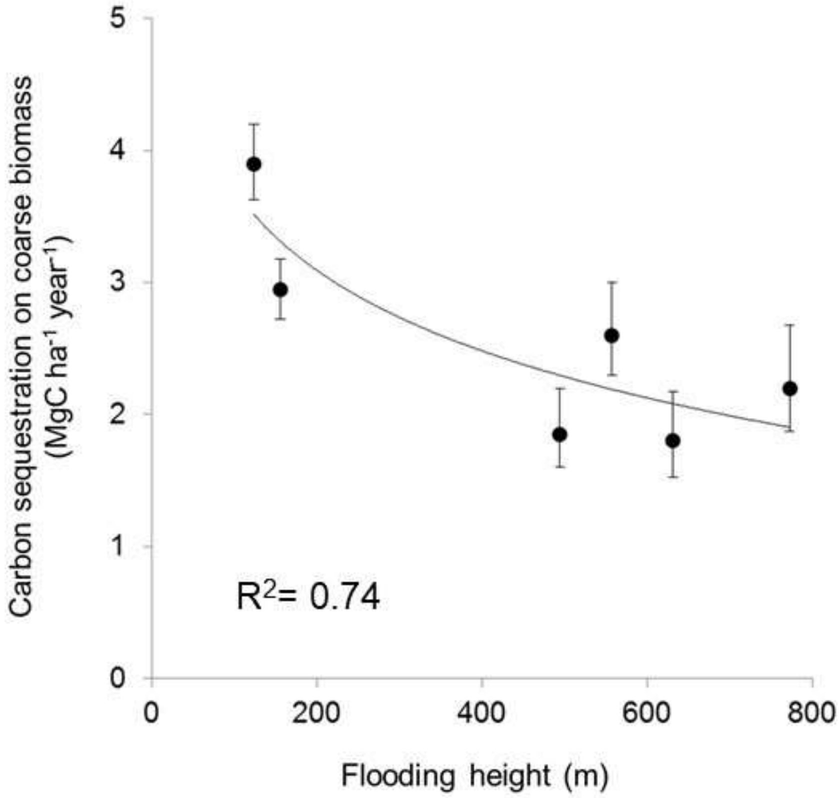

Figure 6- Relation between flooding height and carbon sequestration along the hyedaphical gradient adjusted by a negative nonlinear relation.

According to table 4, it is observed that the productivity rates in woody biomass, not presented a significative difference related to the soil macro and micronutrients effect (R^2= 0.03). Also, soil chemical attributes (R^2 = 0.07) not presented a significative correlation with the produtivity rates.

Table 4- Productivity estimations in woody biomass by hectare and their connection to hydroedaphical gradient.

	R^2 multiple	R^2 adjusted	*p*
Productivity with macro and micronutrients	0.23	0.03	0.34
Productivity withsoil chemical attributes	0.14	0.07	0.46
Productivity with flooding height	0.61	0.51	0.07

On the other hand, the height of the flood was shown an evident correlation with productivity (R^2=0.51; p=0.07).

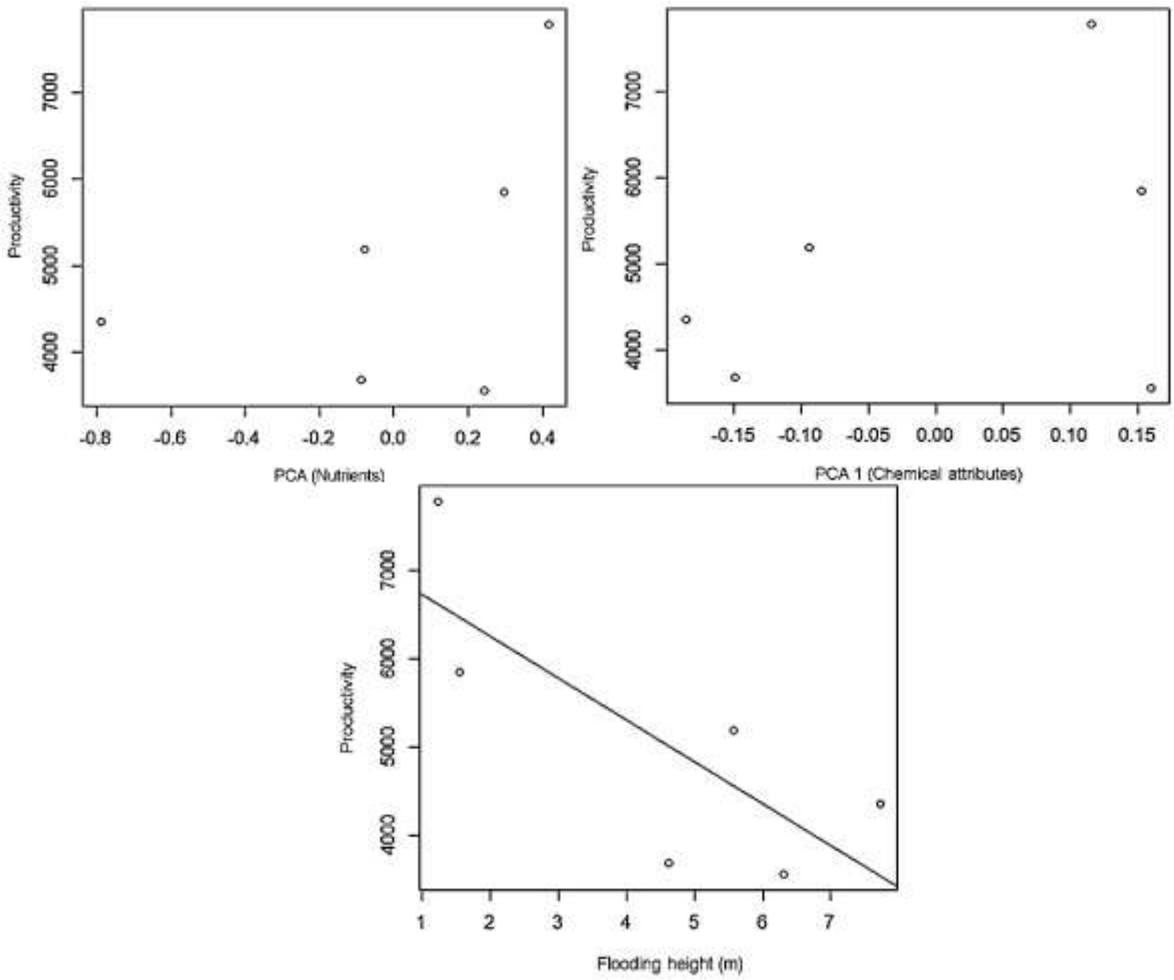

Figure 7- Simple Linear Regression of productivity with (A) Soil nutrients, (B) Soil chemical attributes (C) Flooding height.

The table 5 compares stock and sequestration of carbon in aboveground woody biomass between another amazonian ecosystems (igapós flooding forests, várzea and paleovárzeas forests and also terra firme forests).

Table 5- Comparison between average estimates of stored and sequestered carbon in woody biomass in floodplain forests of igapó, várzea, paleovárzea and continental forests in central Amazonia. In parenthesis, a range of minimum and maximum amplitude.

Search reference	**Ecossystem**	**Region**	**Carbon stocks in wood biomass (Mg C ha^{-1})**	**Carbon sequestration in woody biomass (Mg C ha^{-1} ano^{-1})**
This study	Igapó forest	PARNA Jaú, Jaú River	102 (80-130)	2.5 (1.8-3.9)
Andreae et al. (2015), Targhetta et al. (2015)	Igapó forest	RDS Uatumã, Uatumã River	74 (63-87)	-
Stadtler (2007)	Igapó forest	RDS Amanã, Amanã Lake	127 (114-152)	1.8 (1.2-2.4)
Batista (2015)	Igapó forest	Barcelos, Negro River	111 (48-170)	2.0 (1.2-3.0)
Schöngart et al. (2011)	Várzea forest	Mamirauá SDR, Solimões River	82.5 (8-120)	5.0 (2.7-8.4)
Cintra et al. (2013)	Paleovárzea forest	Interflúvio Purus-Madeira	120 (64-138)	2.8 (1.6-3.1)
Chambers et al. (2001)	Terra firme forest	BIONTE and PDBFF, Manaus	162 (116-196)	2.1 (1.6-3.1)

Evaluating the carbon stock and sequestration rates between different environments, there are differences on their estimates. Additioning, white and black waters flooding forests and paleovárzeas forests in general, store a lowest quantitative of carbon compared to terra firme forests.

Among studied igapó forests in the Central Amazonia, it was observed differences in rates between carbon stocks in woody biomass. Igapó forests from Uatumã River, had presented lowest estimates of carbon stocks rates when compared with another igapós sampled forests. On the other hand, highlighting the Negro River (Barcelos) and Amanã lake, both them had presented expressive carbon estimates. However, it exists a closely relation among carbon rates from Barcelos and Jaú River.

In comparison with várzeas and especialy paleovárzeas forests, the carbon stocks in aboveground biomass tend to be similar in the igapós of rivers of black water, but terra firme forests of the Central Amazon present larger stocks of carbon in the woody biomass (table 5).

The carbon sequestration rates in black water igapó forests from Jaú River, presented similar estimates with terra firme ecosystems, despite being reducted when compared with várzea and paleovárzeas forests estimates.

Discussion

Hydroedaphical indicators and preview biomass estimates

The present study showed the Jaú igapó ecosystem presented an evident relation among environmental variables with tree growing. This trend triggered in varied responses along the hydroedaphical gradient.

A study by Furch (1997) in the Tarumã-Mirim igapó river has indicated that there is a trend that igapó soils in geographic scale are relatively homogeneous. This condition does not matter the topographical level. However, regional scale, Montero et al. (2014) showed that the soil variations along a 600 km stretch the Negro River, among other factors, are responsible for the considerable variation of the floristic composition along different sections of the river.

For this reason, in floodplain florest, soil physical and especially chemical parameters suport important informations wich argues the reason for differenciated tree growing along to inundation levels where its results varying in a macro or micro land. In other words, the results showed that concentrations of soil macro and micronutrients could represent an overriding into wood biomass when consideredthe hydroedaphical gradient.

The expressive presence of carbon and organic matter are more in evidence in M.F and H.F only; on the other hand, this quantitative decreases until 50% in L.F. The Fe has presented a proportion of up to four times higher in the topographies with flooding lower height (L.F).

Hobbie et al., (2007), verified Fe^{+} is a strong driver of A-horizon C dynamics, or even, species traits (their influence on Al + Fe) play an important role along, with soil mineralogy, in influencing A-horizon C dynamics. Their analysis had confirmed that total soil C pools in the surface horizons are greater in plots with high extractable Fe^{+}/Al, therefore resulting in higher rates of woody biomass. In concordance, tree species that colonize the highest flood levels also occur in soils with elevated contents of clay whereas less flood-tolerant tree species occured upon intermediate to sandy substrates as *Pouteria elegans* tree family (Table 2).

In general, igapó soil were characterized by nutrient-poor edaphical conditions and possessed variable textures along to the gradient, there is predomination of silt and clay. These differents profiles are clearly when compared with another ecosystems such as terra-firme and campinarana soils.

The duration of the terrestrial and aquatic phase varies depending on the topography, which leads to a change in the floristic composition of the floodplain along the topographic gradient, depending on the degree of adaptation of the tree species to the floods (Wittmann et al., 2012). Studies have already proven in Central Amazonia, that soil characteristics and topography conditions influence the biomass stocks in the terra firme forests (Luizão, 1989; Tivy, 1995; Laurance et al., 1999; Nogueira, 2006; Quesada et al., 2012).

There is a high variation and changing into soil micro and macronutrients rates between flooding gradient (figure 2). In black-water floodplains from Uatumã Sustainable Development Reserve, Targhetta et al. (2015) achieved a similar result, when it seemed igapó environment has more soil variation when compared with campinarana soil. From this same study, edaphic variables were identified in analysis overall with high relation: C, N, Al, Mn and Fe. Even though the present study has not been the same result related to the other chemical elements, concentrations of Fe were commun in both studies. This prospect represent an important information concerning the hydroedaphical effects on tree species occurence and thereafter in biomass rates.

The uncommon interacting effect in this region, of soil nutrients with climate could be associated at the severe drought events over the last 40 years occured in the Amazon basin (Marengo, 2011) on longer timescales that will be explained much better later. Several hypotheses have been postulated on the variables of spatial nature, edaphic or not, associated with the gradual variation of biomass and the age of the trees that occur in oligotrophic soils, but most studies are inconclusive as to the importance and speed of the data involved.

The soils samples spread-wide in the graphic are indicating a high overall variability from flooding gradients to different directions and probably may assume an overiding role on aboveground biomass rates. This result is not necessarily the huge and main reason for the found estimates in this study, but also it should be considerated. This high variability was corroborated by Castilho et al. (2006) related searches in which they showed that one-third of the spatial variation of tree biomass was associated with soil texture, elevation and slope. Published data from literature, point to the edaphical heterogeneity seems to play a key role in maintaining high diversity in tropical forests (Tuomisto et al., 1995; Tuomisto e Ruokolainen, 1997). Despite of it, it is necessary to improve the scientifical investigations to a deeper understanding about the contribution of edaphical elements in tree species manner (Clark et al., 1999; Duque et al., 2002; Svenning, 1999; Tuomisto et al., 2002). These informations are relevants to get better the variation rates of aboveground biomass, productivity besides forest age.

For this study, iron element has presented a proportion of up to four times higher in topography with flooding lower height. Or even, obviously there is probably a closer relation with the tree size.

Brun et al. (2010) evaluated levels and amounts of soil nutrients, in particular Fe and Mn concentrations aboveground forest biomass in a comparative way in two secondary successional stages. Through the results, it was possible to argue these chemical variables could affect directly the wood biomass rates between different successional stages. Late successional forests (LSF) have presented high content of Fe and consequently higher levels in biomass. The amount of nutrients stored was always higher in the LSF, possibly due to the higher biomass accumulated and also due to probably the significant higher levels of Fe.

Several edaphical components, have beeing acting significaly in moderate and high flooded forest; in a particular case, P (phosphorus) concentrations showed a closely effect related to both topographies. Soils with more available *P* showed lower stand biomass rates, considerating the relation of five species of greater abundance and their respective tree individuals sampled along the flood gradients. This result was similar with Schietti et al. (2016). They observed this high concentration of *P* with lower biomass rates probably has a trend of decreasing density of stems. Quesada et al. (2012) achieved results indicating that *P* concentrations are better predictor of wood production rates and mostly influence in the forest growth variations. However, as seemed in this study, moderate and high flooded igapó indicated highest relation with *P* but these topographies are not more productive such as found this study in terms of woody biomass.

Estimates of biomass, carbon stock and tree age

Stephenson et al., (2014), found that of increasing growth not only has broad generality across species or forest biomes, it appears to hold regardless of competitive environment.

Thus, evaluating the entire database, not considering species order level, it is clear a closer relation of biomass estimates between the high and low flooded forest (366 and 349 Mg ha^{-1}). Intermediate gradients had presented greater results (612 Mg ha^{-1}).

The different geographical positions showed similar biomass rates between high and low flooded forest. That is, the top and bottom topographical ends on vulnerable conditions probably have declining their growth rates due to the gradual intensity of climatic phenomena and the anthropogenic impact in Amazonian igapós forest ecosystems.

Due to the extreme topographies local could be the regions more vulnerable, probably were highly affected than intermediate topography. This trend certainly maintains from another scientifcal searches that conduct the hypotesis igapós regions could undergo some severes environmental disturbances, in particular due to severe drought of El Niño events in Amazon basin (Resende et al., 2014; Flores et al., 2012; Nelson, 1997).

Due to favorable conditions to an ignition source when relative humidity of the understory dropped below 65 percent (Uhl et al. 1988), igapó forests representing a forest environments with a high susceptibility that favored the emergence of strong fires in large areas of forests near the headwaters of the Negro River (Williams et al., 2005; Sombroek, 2001).

This climatic scenario has led to the spread of fire that has led to mass mortality of large areas of forest. With the mortality of these individuals, there was natural regeneration that allowed the occurrence of younger trees in this region. This result corroborates with the results presented in this study as noted alrealdy, the igapó forest sampled area from Jaú River, showed to be formed by relatively young trees individuals compared to other floodplains ecosystems.

Due to their high sensitivity to fire, igapós forests not presented a greater resilience and consequently; their recovery is slower; this trend resulting in lower estimates. This suggests that besides flooded forest is less resistant to fire, could be the main reason, based on studies (Resende et al., 2014; Flores et al., 2012), to prove reduced biomass rates along to gradient.

However, adapted arboreal species to flooding conditions contribute to keep these biomass estimations. Igapó forests of the Negro River are characterized by a distinct species composition. Fabaceae, Euphorbiaceae, Sapotaceae, and Lecythidaceae are important families in igapós and várzeas ecosystems, but with significantly greater importance in the igapó (Junk et al., 2010). There are also variations in tree family importance along the latitudinal gradient, in a particular way on Fabaceae.

Tree species richness and composition were strongly influenced by location of the forest along the flood-level gradient, the successional stage and the geographic location from a hydroedaphic gradient (Wittmann et al., 2006; Targuetta et al., 2015). In this study, when consider the biomass rates of five species of most abundant, the role of some tree families played an important function in carbon stocks estimates and consequently in trees age within topographies.

Fabaceae, tree Family, excelled in medium and high igapó environments, presenting individuals with ages varying from 29-147 years and 31-198 years, respectively. On the other hand, in high flooded forest (H.F), this tree family presented younger trees with ages ranging from 28-94 years. In addition, Fabaceae presented higher biomass in relation to other families in all topographical ranges.

When it is evaluated only the species with high abundance index by topography, low flooded igapó forest showed larger estimates of aboveground biomass compared to another sampled topographic levels. Tree individuals in low flooded forest topography (L.F) have older trees with a maximum age of up to 200 years. However, the high flooded topography covers trees less than 100 years old, which are subject to extreme flooding conditions. These trees can be considered the youngest of all three sampled topographic class in the present study. In the igapós of the moderate topography, the most abundant species presented maximum ages of up to 150 years.

A strong argument that reinforce these results could be in reference not necessary to soil conditions only but also how are these soils conditions get before through hydrology effects. Soil nutrient status may play an important role in explaining the almost two-fold difference in stem turnover rates (Philips et al., 2004; Stephenson and van Mantgen, 2015), especially where are the topographies with a lower flooding height.

Forest dynamics in terms of biomass turn over and stand age were positively related to the soil water index (Targhetta et al., 2015). The inuntation influence in soil saturation seems to be an important parameter of direct relation on these variables.

In general, highly flooded sites are occupied by forests of lower stature and smaller trees (Targhetta et al., 2015). Aboveground biomass (AGB) decreases with growing rates related to height and duration of the annual inundations, this fact is confirmed in this study. This trend was described and proved through studies in Amazonian igapó forests along the Negro river (Schöngart et al., 2010) and Amazonian várzeas forests (Nebel et al., 2001; Schöngart et al., 2010).

The reductions of estimations across the gradients more flooded (H.F; M.F), from this study, provided low AGB where might be related to comparatively short growing periods availabe during the terrestrial phases. Trees that collonized this kind of area, are undergo to the regular flooding conditions drive by flooding pulse regime. These individuals present important physiological characteristics such as short life cycles and probably a trade-off strategy between fast growth rates and regeneration rates results in a long-term storage of AGB (Mitshi and Gosselink 2000; Hultine et al., 2013).

The significant correlations (fig. 3A) between age and diameter and also the age and carbon stocks indicated a closer relation among in the tree growing in Jaú River. Curiously, the tree ages in moderate flooded forest explained 74% of the total diameter variability. This result was upper when compared to another inundation levels, especially in low flooded forest. Targhetta et al. (2015) showed that, indeed tree diameter was not significantly related to the inundation and also neither soil characteristics.

Moreover, for this study, the statistic relation was highest in less inundation area, that is, in low flooded topography that presented an increase in relation of age with biomass variability. Tree species where are located in this topography (L.F), stock a higher biomass quantitative than another inundation levels. There is a closely relation defined in this trend: flooding and tree height it may however affects the increasing rates in biomass. Through another studies, tree height presented was significantly related to inundation and soil characterisitics (inundation: R^2=0.33, p<0.001; PC1: R^2=0.37, p<0.001), indicating higher forests upon less flooded substrates with higher contents of sand and lower fertility (Targhetta et al., 2015).

Thus, the achieved results indicated that tree individuals occurring in high igapós forests accumulate more biomass throughout the life compared to the trees that grow in the topographies subject to the longest floods.

Growth modeling and biomass productivity

As the minimum age of a forest can be determined by the age of the oldest recorded tree, the stand forest age achieved a maximum of 200 years, showing that Jaú Igapó forest are depicted by relatively young trees. Contrary, in another igapó environmental in Amazon, Stadler (2007) obtained minimum age estimates varying between 261 and 337 years, being considered mature forests along to different topographies. Indeed, for the present study, the age-diameter relation indicated in low flooded igapó forest, reached diameter and rates in higher increments over 200 years compared to the other topographies.

A reasearch evaluated the growth patterns of the *Macrolobium acaciifolium* (Benth) species in amazonian floodplains forests for igapós environmentals, the maximum age of the trees reached an age group of more than 500 years; however, for the várzeas environmentals, the age did not exceed 200 years. These values resulted in a mean radial increment significantly lower for the igapó forest with 1.52±0.38 mm $year^{-1}$ and várzea 2.66±0.67 mm ano (Schöngart et al., 2005).

The tree age and woody biomass aboveground relation presented significant correlations, especialy in topography where inundation level and duration is shorter. Therefore, the low flooded igapó forest indicate high potencial as a source of carbon, accumulating more woody biomass over their lifetime than trees in the topographies that undergo a longest flooding (M.F/ H.F). That is, forests in areas with longer dry season had lower density of stems and higher individual mass, whereas, according to Schietti et al., (2016), forests with higher frequency of storms had higher density of stems and lower means individual mass.

The most large and old tree individuals found from low flooded forest do not play a role only as a senescent carbon storing, assume an important function to fix actively large amounts of carbon compared to smaller and young trees from high flooded forest, though.

The high productivity of tropical forests is highly associated with environmental factors. Studies have shown that rainforests may exhibit some form of moisture limitation in the dry phase conditioning on the differential balance in biomass productivity (Malhi, 2012). Therefore, older forests tend to have low carbon efficiency when compared to secondary and younger forests (Litton, Raich & Ryan, 2007).

According to Stephenson et al., (2014), an older and big tree can add the same amount of carbon to the forest within a year as is contained in an entire mid-sized tree. That is, despite the reduction of the growing efficiency, the productivity could not be declined and the mass growth rates might increase continuously with tree size. In summary, older trees could sequestrate more carbon by leaves wide size due to enhance of photosynthetic metabolic activities. Thus, the high biomass productivity focuses primarily on the areas where flooding periods are shorter, evidencing a clear predisposition of the arboreal individuals to stay in those environments whose flood conditions are shorter.

Relations between productivity rates and the flooding height effect only, indicated a direct effect on the productivity of woody biomass due to the flood gradient. As long as flooding height reduces, there is an extending rates of productivity in woody biomass thus allowing an increase of carbon sequestration rates (50% of coarse biomass) (fig. 6). Higher rates of productivity in low flooded igapó forest confirming studies of Malhi (2012). It is likely that young trees will have the capacity to allocate higher concentrations of carbon as long as compete spatially for light and nutrients.

Furthermore, reduced concentrations of woody biomass in the Jaú region, when compared to other Amazonian ecosystems, may also be justified by the intensification of the hydrological cycle. Nevertheless it is not clear how an intensification of the hydrological cycle affects forest productivity and the Amazon carbon balance. According to Gloor et al., (2015), with a simultaneous strong trend toward an increase in the annual amplitude of river discharge, that is, it may however not be entirely coincidental that the onset of the intensification starts at approximately the same time as an increase of the global land carbon sink

There are suggests despite inconclusives, that argue this ecologycal phenomenon. Due to igapós environmental are known like vulnerable and fragile áreas to disturbances for any reasons in particular, natural disturbances. Blackwater floodplain forests presented low resistance and low resilience and slowly recovers due to droughts years occasionated by El Niño events and the intensifcation of the Amazon hydrological cycle both them are enhancing in the last decades (Gloor et al., 2013).

In floodplains, it is assumed that El Niño period due to cause low precipitation in the catchment area of the great rivers and their tributaries, extend the terrestrial phase and the diametric growth period of trees (Schöngart & Junk, 2007). This environmental effect becomes in favorable conditions for vegetation growth. Characteristics of the investigation period may be important or not for the biomass variation, the risk of fires and favorable chances for regeneration (Sombroek, 2001).

In this study, trees undergo shorter flood periods (L.F), are considered carbon sequestrators in El Niño years in an effective way than another trees located at moderate and high flooded forest. This condition is favorable for growth increasing (Schöngart et al., 2004, 2010). Also, physically restricted soils seem to amplify the effects of external disturbances by limiting the size of the tree and consequently hindering its growth (Schietti et al., 2016).

These gradual differences in productivity rates between the inundation levels along to a hydroedaphical gradient are explained also by the climate direct effect in environment. It is evident that both inundation conditions were affected by climate, however, high and moderate flooded forest were more affected. Trees where are in a topography with a shorter flooding period are able to realize photosynthesis process due to the shorter dormancy time, that is, in this area, there is a prolongation of the terrestrial phase favorable to growth. According to Sombroek (2001), the increase of CO_2 concentration in the atmosphere stimulates tree growth, resulting in a net absorption, which favors in the increase of the sequestration rates by the forest ecosystem in the last years.

As long as the flooding height reduces, the productivity rates in biomass increases, showing a direct effect on woody biomass productivity due to the flood gradient. This negative trend was evidenced in mature forests of the RDS Amanã. Woody biomass and the carbon stock increase with the decrease of the flooding time, and there is also a tendency to increase carbon sequestration (Stadler, 2007).

High correlation between flooding height and productivity in biomass, that is, the influence of flooding level in productivity estimates could be also probably associated to the ecological diversity due to variation of species composition along to the gradient (Targhetta et al., 2015).

The influence of flooding proves to be an important indicator in stand associated at diversity, composition and structure forest as noted already through productivity biomass rates. There is also strong evidence that variations in productivity are related to soil fertility besides soil water saturation index for both dry land and wetland forests. The authors Malhi et al., (2004) and Cintra et al., (2013), explain these variations result in differentiated age and carbon stocks for each and within environment. Variation in biomass stock can also be due to differences in growth conditions, site quality, age, and structure and management practices (Goswami, et al., 2013).

Through data from literature, from last decades, there is an increased and continued efforts in the past to estimate carbon stocks in floodplain forest ecosystems and related anthropogenic activities that influence the alteration of the carbon cycle (Bonan, 2008; Laurance et al., 2011). Studies also report that tropical forest carbon stocks are currently declining with losses due to deforestation and habitat degradation. Therefore, interaction effects among deforestation, fire and severe droughts potentially lead to carbon stock losses.

These differences may be related to differences in soil conditions, duration of flooding or natural or anthropogenic disturbances resulting in successional stages of different ages. In Uatumã Sustainable Development Reserve presented high mortality of trees in the igapó plains, mainly in low topographies to downstream of the

Balbina hydroelectric that was implemented in the 1980s (Assahira, et al., 2017) which probably resulted in a decrease in carbon stocks in this region.

The climatic variability was seemed in different responses between floodplain and terra firme forests. El Niño year, floodplain forests present a greater capacity to grow favoring higher rates of carbon sequestration. On the other hand, trees with occurence in terra firme forests grow less and consequently sequetrate carbon in less proportion when compared to igapós and várzeas forests.

Thus, older trees invest more in maintaining their existing large biomass, and perhaps higher ecological priority in maintaining the chemical defense of biomass, not investing in the acquisition of biomass new rates.

According to this context in the future scenarios, it intends to complement with future works that make it possible to better characterize these environments that suffer flooding influece so that it is possible to obtain more precise estimates that can be extrapolated to the whole basin.

Conclusion

In summary, the study showed the Jaú igapó ecosystem presented an evident relation among environmental variables and tree growing.

Low flooded gradient level presented an expressive results. Although the highest occurence of older tree individuals, this topographical level accumulates more woody biomass over their lifetime than trees in the topographies that undergo a longest duration flooding and where are yougest trees individuals.

The flooding height was shown to have a close correlation with productivity and also presented a strong relation between age and diameter. Areas where flooding periods are shorter have indicated that they are more productive in woody biomass.

In low flooded igapó forest presented high ecological potential reaching higher increments over 200 years. Furthermore, the relation between age x biomass rates determined that the carbon stock and the annual sequestration for this topography was approximately double the estimates reached compared to the remainder of the hydroedaphical gradient.

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CONCLUSÃO

O estudo mostrou que o ecossistema de igapó do Jaú apresentou uma evidente relação entre variáveis ambientais com o crescimento. A altura da inundação mostrou-se ter correlação significativa, fortemente relacionada com a produtividade. Áreas onde os períodos de alagamento são menores apontaram ser mais produtivas. A relação da idade e biomassa no decorrer do gradiente de inundação também foi significativamente correlacionada.

Cotas de inundação menores são altamente produtivas e que apresentaram forte relação entre idade/diâmetro. O baixo igapó apresentou árvores mais jovens e no alto igapó foram identificados indivíduos mais velhos. Esse ambiente menos inundado apresenta elevado potencial ecológico atingindo incrementos superiores ao longo dos 200 anos. Além disso, a relação idade x biomassa determinou que o estoque de carbono e o sequestro anual para essa topografia foi aproximadamente o dobro das estimativas alcançadas comparadas às demais.

CONSIDERAÇÕES FINAIS

As florestas de igapó do Jaú mostraram ter sua dinâmica de crescimento lenta e que ainda está em processo de recuperação quanto aos efeitos dos distúrbios climáticos, não apresentando, portanto, potencial para a exploração dos seus recursos naturais. O Parque Nacional do Jaú, pertencente ao Sistema Nacional de Unidades de Conservação, detentor de belezas cênicas e uma riqueza endêmica em fauna e flora, merece continuamente de medidas de conservação para manutenção e garantia dos seus recursos às gerações futuras.

O estudo sugere que outras investigações devam ser realizadas como forma de compreender os impactos que esses ambientes sofreram, além de subsidiar a conservação do patrimônio natural. Assim, é possível contribuir para a manutenção da biodiversidade e dos recursos hídricos, além de fornecer mecanismos que proporcionem melhoria das condições de vida das populações tradicionais locais.

A proposta de realização de novas pesquisas seguindo essa linha de investigação ao longo da bacia Amazônica, possibilitará futuramente alcançar uma rede macro de dados representativos e mais precisos sendo possível extrapolar a outros ambientes sujeitos à inundação. Assim, será possível estabelecer critérios técnicos voltados a implementação de políticas de gestão sustentável e favorecendo a ampliação de novas áreas a serem protegidas.