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BIOMASSA AÉREA VIVA DE PALMEIRAS NAS ZONAS RIPÁRIAS DE UMA FLORESTA DE TERRA-FIRME NA AMAZÔNIA CENTRAL

LOURDES YESENIA FALEN HORNA

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Dissertação apresentada ao Instituto Nacional de Pesquisas da Amazônia como parte dos requisitos para obtenção do título de mestre em Biologia (Ecologia).

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Após a exposição, o discente foi arguido oralmente pelos membros da Comissão Examinadora, tendo recebido o conceito final:

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Nada mais havendo, foi lavrada a presente ata, que, após lida e aprovada, foi assinada pelos membros da Comissão Examinadora.

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Sinopse:

Estudamos a contribuição da biomassa viva de palmeiras arborescentes com três tipos de equações alométricas em zonas ripárias; comparamos estas estimativas com a biomassa em zonas não ripárias e investigamos a influência do ambiente na variação espacial em 40 parcelas ripárias da Reserva Florestal Adolpho Ducke, Amazonas, Brasil.

Palavras-chave: Arecaceae, biomassa, ecologia de comunidades, heterogeneidade ambiental, florestas de lençol freático raso, Amazônia.

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Resumo

As estimativas de biomassa acima do solo na região amazônica permanecem incertas, em parte devido a extrapolações baseadas principalmente em amostras coletadas em terrenos bem drenados de florestas de terra firme. A maioria das estimativas de biomassa foi focada em árvores dicotiledôneas ou incluiu outros grupos de plantas dentro da categoria de árvores. As palmeiras dominam áreas que representam 20% da Amazônia brasileira. No entanto, sua contribuição para as estimativas de biomassa e a variação dentro das zonas ripárias têm sido pouco documentadas. Neste estudo, estimamos a biomassa de palmeiras maiores que 1–cm de diâmetro à altura do peito (1,3 m) em parcelas ripárias (n = 40); investigamos o potencial viés causado pelo uso de equações para árvores dicotiledôneas ou ao nível de família em vez de equações ao nível de espécie para estimativa de biomassa; comparamos a biomassa de palmeiras entre parcelas ripárias e não ripárias (n = 72); e avaliamos os efeitos das características do solo, topografia e igarapés sobre a biomassa de palmeiras em zonas ripárias. A biomassa média de palmeiras em zonas ripárias com base em equações ao nível de espécie (27,50 ± 12,94, intervalo: 3,32 – 63,27) Mg/ha foi três vezes maior do que a biomassa estimada com uma equação ao nível de família (9,0 ± 4,29, intervalo: 1,51– 21,25) Mg/ha, e foi maior que a biomassa média estimada com uma equação pantropical (20,46 ± 9,29, intervalo: 3,67 – 47,99) Mg/ha. A biomassa média de palmeiras nas zonas ripárias foi quatro vezes maior do que nas zonas não ripárias. Nas zonas ripárias, a biomassa de palmeiras foi alta em áreas mais planas com solos mal drenados, mas menor no entorno de igarapés com maior vazão. A inclusão de palmeiras pode contribuir para reduzir as incertezas nas estimativas de biomassa nas florestas amazônicas. O reconhecimento da importância das zonas ripárias pode melhorar as políticas de conservação.

Abstract

Above-ground biomass estimates in the Amazon region remain uncertain, in part, due extrapolations based mainly on samples collected in well-drained terrains of terra-firme forests. Most biomass estimates were focused on dicotyledonous trees or included other plant groups as a category of trees. Palms dominate areas that represent 20% of the Brazilian Amazon. However, their contribution to biomass estimates and the variation within riparian zones have been poorly documented. We estimated the biomass of palms larger than 1–cm diameter at breast height (1.3 m) in riparian plots (n = 40); investigated the potential bias caused by the use of dicotyledonous- or family- rather than species-level equations for biomass estimation; compared palm biomass between riparian and non-riparian plots (n = 72); and evaluated the effects of soil, topography, and stream characteristics in riparian plots on palm biomass. Mean palm biomass in riparian zones based on species-level equations (27.50 ± 12.94, range: 3.32 – 63.27) Mg/ha was three times greater than biomass estimated with a family-level equation (9.0 ± 4.29, range: 1.51– 21.25) Mg/ha, and was greater than mean biomass estimated with a pantropical equation (20.46 ± 9.29, range: 3.67 – 47.99) Mg/ha. Mean palm biomass in riparian zones was four times greater than in non-riparian zones. In riparian zones, palm biomass was high in flatter areas with poorly-drained soils, but lower around streams with higher discharge. Inclusion of palms can contribute to reducing the uncertainties in biomass estimates in Amazonian forests. Recognition of the importance of riparian zones may improve conservation policies.

SUMÁRIO

1. INTRODUÇÃO

As palmeiras (Arecaceae) são componentes emblemáticos e conspícuos da floresta tropical. Nas florestas amazônicas, seis das dez espécies de árvores mais comuns nos inventários florestais são palmeiras (ter Steege *et al.* 2013). Uma miríade de animais se alimenta de frutos de palmeiras e comunidades indígenas e rurais dependem das palmeiras para segurança alimentar e construção (Eiserhardt *et al.* 2011). A importância das palmeiras como fornecedoras de uma variedade de produtos (i. e., frutas, fibras, óleo e madeira) que garantem o bem-estar dos habitantes da Amazônia tem sido amplamente reconhecida (Zambrana *et al.* 2007, Cámara-Leret *et al.* 2014). No entanto, o papel das palmeiras nos serviços ecossistêmicos relacionados à regulação do clima por meio de estoques de carbono tem sido pouco estudado.

O papel negligenciado das palmeiras no ciclo do carbono pode ser atribuído ao fato de que a maioria dos programas de monitoramento florestal priorizaram um tipo de floresta na Amazônia chamado “terra-firme” (Luize *et al.* 2018). As florestas de terra-firme não são afetadas por inundações sazonais de grandes rios, como a várzea e o igapó (Bredin *et al.* 2020), mas as áreas alagadas aparecem em posições topográficas baixas com frequência, ao longo de pequenos igarapés (Costa *et al.* 2022). As equipes que estabeleceram as parcelas de amostragem muitas vezes evitaram áreas próximas a igarapés (e.g., Laurance *et al.* 1999), onde as palmeiras arborescentes são comumente abundantes (para algumas exceções, ver Castilho *et al.* 2006, Draper *et al.* 2014, Zelarayán *et al.* 2015, Toledo *et al.* 2017).

As palmeiras foram frequentemente excluídas ou consideradas como árvores dicotiledôneas em estimativas de biomassa acima do solo (e.g., Laurance *et al.* 1999, Baker *et al.* 2004) devido à falta de equações alométricas para palmeiras ao nível de família ou de espécie na época desses estudos. Árvores e palmeiras dicotiledôneas apresentam diferenças estruturais e funcionais. Por exemplo, a densidade da madeira em palmeiras tende a ser geralmente menor do que em árvores (Chave *et al.* 2009, Zanne *et al.* 2009), as árvores podem aumentar o tamanho dos ramos e da copa (Chave *et al.* 2005); mas o tamanho da copa é fixo em palmeiras, as quais raramente mostram ramos aéreos (Tomlinson 2006). Além disso, as palmeiras têm ausência de crescimento secundário, resultando em uma relação diâmetro-altura fraca na maioria das espécies de palmeiras (Goodman *et al.* 2013). Por essas razões, as equações alométricas de árvores não são apropriadas para a estimativa da biomassa de palmeiras.

As zonas ripárias são regularmente influenciadas pela inundação e estendem-se desde as margens dos igarapés até às margens donde ocorrem as comunidades de terras altas (Décamps *et al.* 2009). Nas florestas de terra-firme da Amazônia Central, a maioria das zonas ripárias localizam-se no extremo mais baixo do gradiente topográfico (Ribeiro *et al.* 1999). Essas áreas têm composição florística distintiva (Drucker *et al.* 2008, Schietti *et al.* 2014, Pansini *et al.* 2016, Guedes *et al.* 2022) e fornecem múltiplos serviços ecossistêmicos (Dybala *et al.* 2019). A vegetação em zonas ripárias contribui para o sequestro de carbono (Zelarayán *et al.* 2015), não apenas como biomassa acima do solo, mas também em solos com potencial de armazenamento de carbono a longo prazo (Sutfin *et al.* 2016). A variação na composição das plantas nos ecossistemas ripários está relacionada a mudanças no regime hidrológico, condições de umidade do solo e características da superfície do terreno (Sutfin *et al.* 2016).

O ambiente estressante em zonas ripárias, devido a eventos de inundação, influencia o crescimento das plantas e a dinâmica de recrutamento e mortalidade, permitindo o domínio de plantas adaptadas a solos mal estruturados (e.g., palmeiras; Emilio *et al.* 2014), que são comuns em condições alagadas, e consequentemente, modulam os estoques de biomassa. A anatomia vascular das palmeiras e a sua estrutura radicular diferem das árvores (Tomlinson 2006), e podem torná-las mais resistentes à embolia do que as árvores (Aparecido *et al.* 2015). Essas adaptações poderiam explicar a maior abundância de palmeiras arborescentes nas zonas ripárias.

As estimativas de biomassa de palmeiras variam grandemente na escala da paisagem (~1-10% da AGB por hectare) nas florestas de terra firme da Amazônia, e essa variação está relacionada às propriedades do solo, com maior biomassa de palmeiras em solos arenosos e mal drenados, onde o lençol freático está mais próximo da superfície (Castilho *et al.* 2006, Emilio *et al.* 2014, Toledo *et al.* 2017, Muscarella *et al.* 2020). As florestas de terra-firme sobre lençóis freáticos rasos (< 5 m) cobrem ~ 50% da área da bacia amazônica e estão principalmente confinadas às margens dos igarapés nas porções leste, norte e sul da Amazônia (Costa *et al.* 2022). Assim, a inclusão de palmeiras pode influenciar as estimativas de biomassa, especialmente quando as palmeiras dominam certos tipos de floresta (Goodman *et al.* 2013, Muscarella *et al.* 2020), como as zonas ripárias.

As estimativas de biomassa de palmeiras variam dependendo da disponibilidade e seleção de equações alométricas. As equações desenvolvidas para árvores dicotiledôneas apresentam baixo desempenho para estimar biomassa de palmeiras e podem induzir a superestimação, se comparadas com estimativas usando equações ao nível de família (e.g., Muscarella *et al.* 2020). As estimativas de biomassa com equações ao nível de família são potencialmente mais precisas do que aquelas obtidas com equações para dicotiledôneas, especialmente quando incluem altura; porém, podem subestimar a biomassa quando comparadas com estimativas de equações ao nível de espécie (Goodman *et al.* 2013). As relações alométricas diâmetro - altura variam entre as espécies de palmeiras (Avalos *et al.* 2019), portanto, agrupar diferentes espécies de palmeiras em uma equação ao nível de família afeta as estimativas de biomassa.

Neste estudo, nós visamos: (a) investigar a contribuição da biomassa de palmeiras na escala da paisagem (64 km2), somando 40 parcelas de 1 ha estabelecidas em zonas ripárias (parcelas ripárias) adjacentes aos igarapés de primeira a terceira ordem, a um conjunto de 72 parcelas de 1 ha (parcelas não ripárias) em uma floresta na Amazônia central; (b) avaliar o potencial viés causado pelo uso de equações desenvolvidas para árvores dicotiledôneas ou equações ao nível de família em vez de equações ao nível de espécie para estimar a biomassa de palmeiras; (c) comparar a biomassa de palmeiras entre parcelas ripárias e não ripárias; e (d) quantificar os efeitos das características ambientais (textura e nutrientes do solo, inclinação do terreno e vazão do igarapé) na variação espacial das estimativas de biomassa de palmeiras em zonas ripárias.

2. OBJETIVOS

- Conhecer a contribuição das palmeiras em zonas ripárias nas estimativas de biomassa acima do solo, em relação a zonas não ripárias, considerando o uso de equações alométricas ao nível de espécie, família e a equação pantropical.

- Investigar como os fatores ambientais relacionados ao solo, topografia e igarapés afetam a variação da biomassa de palmeiras em zonas ripárias.

3. CAPÍTULO 1

Falen, L.; Guedes, M.; Castilho, C. V.; Jorge, R. F.; Bezerra, F. M.; Magnusson, W. E.

Palm live above-ground biomass in the riparian zones of a forest in central Amazonia.

Manuscrito em revisão: Biotropica

Palm live above-ground biomass in the riparian zones of a forest in central Amazonia

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Abstract

Above-ground biomass estimates in the Amazon region remain uncertain, in part, due extrapolations based mainly on samples collected in well-drained terrains of terra-firme forests. Most biomass estimates were focused on dicotyledonous trees or included other plant groups as a category of trees. Palms dominate areas that represent 20% of the Brazilian Amazon. However, their contribution to biomass estimates and the variation within riparian zones have been poorly documented. We estimated the biomass of palms larger than 1–cm diameter at breast height (1.3 m) in riparian plots (n = 40); investigated the potential bias caused by the use of dicotyledonous- or family- rather than species-level equations for biomass estimation; compared palm biomass between riparian and non-riparian plots (n = 72); and evaluated the effects of soil, topography, and stream characteristics in riparian plots on palm biomass. Mean palm biomass in riparian zones based on species-level equations (27.50 ± 12.94, range: 3.32 – 63.27) Mg/ha was three times greater than biomass estimated with a family-level equation (9.0 ± 4.29, range: 1.51– 21.25) Mg/ha, and was greater than mean biomass estimated with a pantropical equation (20.46 ± 9.29, range: 3.67 – 47.99) Mg/ha. Mean palm biomass in riparian zones was four times greater than in non-riparian zones. In riparian zones, palm biomass was high in flatter areas with poorly-drained soils, but lower around streams with higher discharge. Inclusion of palms can contribute to reducing the uncertainties in biomass estimates in Amazonian forests. Recognition of the importance of riparian zones may improve conservation policies.

Keywords:

Allometric equations, Amazon rainforest, Arecaceae, Brazil, environmental heterogeneity, shallow water table forests.

3.1. Introduction

Palms (Arecaceae) are emblematic and conspicuous components of the tropical rainforest. In Amazonian forests, six of the ten most common tree species in forest inventories are palms (ter Steege *et al.* 2013). Myriad animals feed on palm fruits and indigenous and rural communities rely on palms for food security and household constructions (Eiserhardt *et al.* 2011). The importance of palms as providers of a variety of products (i.e., fruits, fibers, oil, and wood) that secure the wellbeing of Amazonian inhabitants has been widely recognized (Zambrana *et al.* 2007, Cámara-Leret *et al.* 2014). However, the role of palms in ecosystem services related to climate regulation through carbon stocks has been poorly studied.

The overlooked role of palms in the carbon cycle could be attributed to the fact that most forest-monitoring programs prioritized a widespread forest type in the Amazon called "terra-firme" (Luize *et al.* 2018). Terra-firme forests are not affected by seasonally inundations from large rivers, such as "várzea" and "igapo" forest types (Bredin *et al.* 2020), but waterlogged areas appear in low topographic positions frequently besides small streams (Costa *et al.* 2022). Teams establishing sampling plots have often avoided areas near streams (e.g., Laurance et al. 1999), where arborescent palms are commonly abundant (for some exceptions see Castilho et al. 2006, Draper et al. 2014, Zelarayán et al. 2015, Toledo et al. 2017).

Palms were frequently excluded or considered as dicotyledonous trees in above-ground-biomass (AGB) estimates (e.g., Laurance et al. 1999, Baker et al. 2004) due to the lack of palm-family or species-level allometric equations at the time of those studies. Dicotyledonous trees and palms have structural and functional differences. For instance, wood density in palms tend to be generally lower than in trees (Chave *et al.* 2009, Zanne *et al.* 2009), trees can increase branches and crown size (Chave *et al.* 2005); but crown size is fixed in palms that rarely show aerial branches (Tomlinson 2006). Furthermore, palms have absence of secondary growth, resulting in a weak diameter-height relationship in most palm species (Goodman *et al.* 2013). For those reasons, tree allometric equations are not appropriate for estimation of palm biomass.

Riparian zones are regularly influenced by inundation and extend from stream edges to the edges of upland communities (Décamps *et al.* 2009). In Central Amazonian terra-firme forests, most riparian zones are the lowest extreme of the topographic gradient (Ribeiro *et al.* 1999). These areas have distinctive plant-species composition (Drucker *et al.* 2008, Schietti *et al.* 2014, Pansini *et al.* 2016, Guedes *et al.* 2022) and provide multiple ecosystem services (Dybala *et al.* 2019). Vegetation in riparian zones contributes to carbon sequestration (Zelarayán *et al.* 2015), not only as AGB, but also in soils with potential for long-term carbon storage (Sutfin *et al.* 2016). Variation in plant composition within riparian ecosystems is related to changes in hydrologic regime, soil-moisture conditions and terrain surface features (Sutfin *et al.* 2016).

The stressful environment in riparian zones due to flooding events influences plant growth and mortality-recruitment dynamics, allowing the dominance of plants adapted to poorly-structured soils (e.g., palms; Emilio et al. 2014), that are common under waterlogged conditions, and consequently modulate AGB stocks. Palm vascular anatomy and root structure differ from trees (Tomlinson 2006), and could make them more resistant to embolism than trees (Aparecido *et al.* 2015). These adaptations could explain the greater abundance of arborescent palms in riparian zones.

Palm AGB varies greatly at the landscape scale (~1-10% of the AGB per hectare) in Amazon terra-firme forests, and this variation is related to soil properties, with higher palm AGB on poorly-drained sandy soils, where the water table is closer to the surface (Castilho *et al.* 2006, Emilio *et al.* 2014, Toledo *et al.* 2017, Muscarella *et al.* 2020). Terra-firme forests over shallow water tables (< 5 m) cover ~ 50% of the Amazon basin area and are mostly confined to the margins of streams in the eastern, northern, and southern portions of the Amazon (Costa *et al.* 2022). Hence, the inclusion of palms could influence AGB estimates, especially when palms dominate certain types of forest (Goodman *et al.* 2013, Muscarella *et al.* 2020), such as riparian zones.

Palm AGB estimates vary depending on the availability and selection of allometric equations. Equations developed for dicotyledonous trees perform poorly for palms and could induce AGB overestimation, if compared with family-level AGB estimates (e.g., Muscarella et al. 2020). The AGB estimates with family-level equations are potentially more accurate than those from dicot equations, especially when the equations include height, but can underestimate AGB when compared with species-level AGB estimates (Goodman *et al.* 2013). Diameter and height allometry vary among palm species (Avalos *et al.* 2019), so pooling different palm species in an equation affects AGB estimates.

In this study, we aim to (a) investigate the contribution of palms to forest AGB at the landscape scale (64 km^2), adding 40 1-hectare plots established in riparian zones (riparian plots) adjacent to first to third-order streams to a previous set of 72 1-ha plots (non-riparian plots) in a forest in central Amazonia; (b) evaluate the potential bias caused using dicotyledonous or family-level rather than species-level equations for palm AGB; (c) compare palm AGB between riparian and non-riparian plots; and (d) quantify the effects of environmental characteristics (soil texture and nutrients, terrain slope, and stream discharge) on the spatial variation in palm AGB estimates within riparian zones.

3.2. Methods

Study area and sampling design

The study was conducted in Reserva Florestal Adolpho Ducke (RFAD), on the outskirts of Manaus city, Amazonas State, Brazil (02°55'S, 59°58'W) (Figure 1). This reserve covers 10 km² of terra-firme tropical rain forest, with a closed canopy of 30–37 m (Guillaumet 1987, Ribeiro *et al.* 1999). Between 1966 and 2016 the mean annual rainfall at the RFAD was 2572 ± 351 mm. The driest month was August with a mean rainfall of 98.8 ± 49.1 mm and a mean temperature of 26 ± 1°C. The wettest month was April, with a mean rainfall of 331.4 ± 88.8 mm and a mean temperature of 25.2 ± 0.9°C (Esteban *et al.* 2021). The terrain in RFAD is hilly and drained by a dense stream network (Ribeiro *et al.* 1999). The dominant soil type is clayey yellow latosol on higher areas, transitioning to sandy hydromorphic podzols in the valley bottoms (Chauvel *et al.* 1987). The valley bottoms (hereafter, riparian zones) are areas with shallow water table and soils almost permanently waterlogged, especially during the rainy season (Schietti *et al.* 2014).

The RFAD covers two major drainage basins (western and eastern) separated by a central ridge (Jorge *et al.* 2016); however, the stream network can be divided into five sub-basins (Rodrigues *et al.* 2010). The RFAD has streams from first- to third order and it is not subject to flooding by large rivers (Schietti *et al.* 2014). The streams in the eastern basin flow to tributaries of the Amazon River, and those in the western basin flow to the Negro River (Castilho *et al.* 2006). Riparian zones are subject to flooding after heavy rain events, resulting in frequent waterlogging that lasts for hours after rain stops (Jorge *et al.* 2016). These conditions promote distinct plant-assemblage composition (Drucker *et al.* 2008, Schietti *et al.* 2014). The canopy in riparian zones reaches 25–30 m in RFAD with the presence of arborescent palms (e.g., *Oenocarpus bataua* and *Euterpe precatoria*); dicotyledonous trees (e.g., *Chrysophyllum sanguinolentum; Eperua duckeana and Pourouma ovata* - Toledo et al. 2017) and a dense understory composed of abundant herbs and stemless palms (Ribeiro *et al.* 1999).

We sampled 40 riparian plots distributed equally between the western and eastern basins within a 64–km^2 trail system across RFAD. Plots followed the RAPELD system, a spatially standardized sampling method for use in long-term ecological research, which allows comparisons among sampling sites (Magnusson *et al.* 2005). Riparian plots have a centerline that runs ≥ 1.5 m from stream margins in 10-m linear segments (see Figure 1). More detailed information can be found at https://ppbio.inpa.gov.br/en/Riparian_Plots.

Vegetation data

We sampled palms in riparian plots following the methods for sampling trees and palms in non-riparian plots (for details see Castilho et al. 2006). These plots follow the topographic contours to minimize within-plot variation in vegetation (Magnusson *et al.* 2005), and cover the classes (plateau, slope, and valley) most used to classify topography in the RFAD (Ribeiro *et al.* 1999). We used a hierarchical design in which diameter at breast height (dbh) was used to define sampling areas (Castilho *et al.* 2006) as follows: Stems with dbh ≥ 30 cm were sampled within ~1 hectare (ha) (250 x 40 m); stems with 10 cm ≤ dbh < 30 cm were sampled within ~0.5 ha (250 x 20 m); and stems with 1 cm ≤ dbh < 10 cm were sampled in a subplot of ~0.1 ha (250 x 4 m) (see Figure 1). RAPELD plots vary subtly in area, but for comparison with a previous study in non-riparian plots that used the approximate plot sizes (Castilho *et al.* 2006), we used the same methodology.

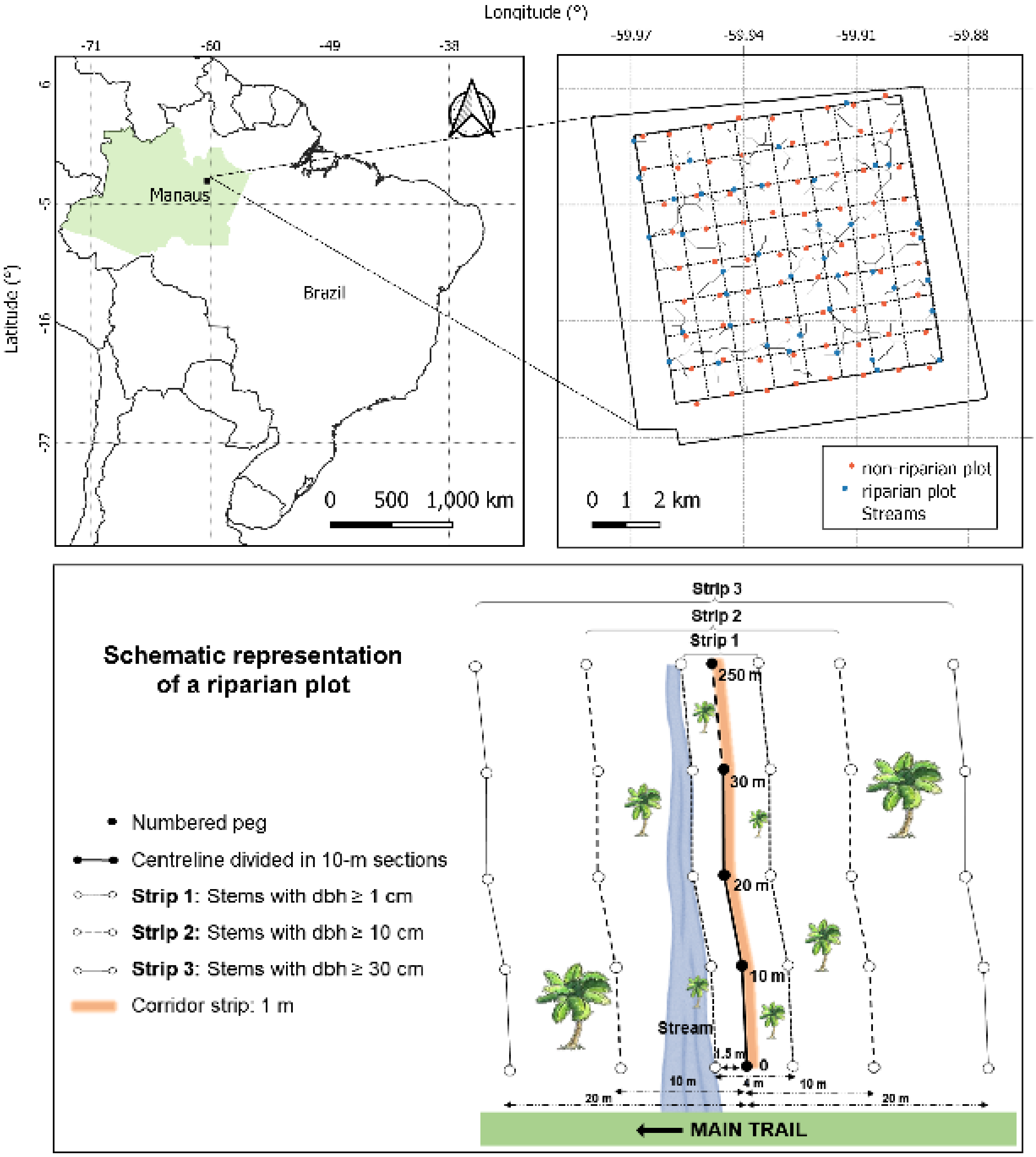

Figure 1. Map showing the study area located in Amazonas state in central Brazilian Amazonia and the grid system in Reserva Florestal Adolpho Ducke (RFAD) with 72 non-riparian plots (orange filled circles) and 40 riparian plots (blue filled circles), black lines represent streams. The bottom design is a schematic representation of a riparian plot and the hierarchical sampling of palms within each plot. Geographic coordinate system, datum WGS84.

Palm individuals were identified and measured in 40 riparian plots. The dbh was measured to the nearest 1 mm at 1.3 m above ground level. Stem height (H_{Stem}) was estimated visually in 40 plots by an observer. These visual estimates were calibrated against clinometer measurements in 4 plots. The observer moved to an equivalent distance to the stem height and registered this distance, measured the angle from the level of her eye to the ground, and between the level of her eye to the point where the first (lowest) leaf parted from the stem. Next, stem height was calculated using basic trigonometry. The relationship between visual estimated height (H_{VE}) and measured height (H) was $H = 0.92*H_{VE} + 1.83$ ($N = 183$, $r^2 = 0.79$), with H_{VE} ranges from 3.4 to 21.5 m (Figure S1). The identity of all palms was determined *in situ* with the assistance of a trained parataxonomist and checking the field guide “Flora da Reserva Ducke” (Ribeiro *et al.* 1999).

We used two allometric equations and a set of species-level equations to estimate AGB in riparian zones (Table S1). Since we aimed to investigate potential bias in using dicotyledonous equations to estimate palm AGB, we used the geographical-based Pantropical Equation (Chave *et al.* 2014). This equation is based on dbh; wood density (g/cm^3) and an environmental factor and is implemented in the BIOMASS package (Réjou-Méchain *et al.* 2017). Wood density was assigned to each species based on the finest taxonomy available in the Global Wood Density Database (Chave *et al.* 2009, Zanne *et al.* 2009). The environmental factor (*E)* is a measure of environmental stress estimated from the plot coordinates that account for variation in the height-diameter relationship when total height of individuals is not available.

We used the family-level equation for Amazonian palms developed by Goodman *et al.* (2013). This equation is based on dbh, H_{Stem} and dry-mass fraction (*dmf)*. Mean stem *dmf* for each genus is available in Goodman *et al.* (2013) and the overall mean (0.37) was used for other genera. As one of our goals was to estimate palm AGB more accurately, we used a set of species-level equations (Goodman *et al.* 2013). For species without a specific equation, we used the equation for species from the same genus or the family-level equation.

We compared palm AGB between riparian and non-riparian areas using our 40 riparian plots and an inventory dataset of 72 non-riparian plots at RFAD collected by Castilho *et al.* (2006). As palm height was not measured in that study, we applied the family-level equations of Goodman *et al.* 2013 that are based on dbh and *dmf* (Table S1).

Environmental data

Hydrological conditions in riparian zones were represented by the stream discharge (m^3/s). We used previously collected data on the width, depth, and flow velocity of streams adjacent to each riparian plot. The measurements were collected every 50 m at 6 points distributed along the stream(Jorge *et al.* 2016). The width (m) of the stream was measured using a tape measure stretched from one bank to the other, perpendicular to the stream course. Stream depth (m) was measured at nine regular intervals across the stream along a transect perpendicular to the stream bank. Water velocity (m/s) was estimated by launching a silicon ball in the current in the middle of the stream and recording the time for it to move 1 m (Jorge *et al.* 2016). Stream discharge was calculated as the product of the stream cross-sectional area (width x mean depth) multiplied by velocity. Stream-discharge values at the six points were averaged to obtain a single discharge value per plot.

Soil samples were collected in riparian plots at six points, each 50 m along the centerline to 10–cm depth. The six soil samples per plot were bulked into a single composite sample and cleaned of roots, air-dried, and sieved before laboratory analyses (Jorge *et al.* 2016). Samples were analyzed in the Thematic Laboratory of soils and plants at INPA following standard methods (EMBRAPA 2009).

We represent topography as slope that was measured perpendicularly to the main axis of the plot with a clinometer every 50 m, and used plot means in analyses. A summary of the environmental data is available in the Table S2.

Data analyses

We calculated percent differences for species-level equations compared to family-level and Pantropical equations and showed the mean percent difference in riparian plots. To compare AGB in riparian and non-riparian plots we used the non-parametric Wilcoxon rank sum test with the "coin" R package (Hothorn *et al.* 2008). Additionally, we reported the effect size to provide a quantitative measure of the magnitude of our results. We used the effect size of Pearson r correlation for the Wilcoxon rank sum test.

We used Principal Component Analyses (PCA) to describe soil gradients, including 12 chemical-physical soil attributes summarized in two axes. The PCA analyses revealed two main soil gradients in riparian zones. Axis 1 captured 41.9% of the total variation in the data and was correlated with Ca^{2+}, Mg^{2+}, Al^{3+}, K^{+}, P, Mn^{2+}, Zn^{2+}, and pH, which reflects the main gradients of soil fertility. Axis 2 accounted for 20.2% of the variation and was highly correlated with sand and silt contents (and to a lesser degree with Na^{+} and Fe^{2+}), reflecting the textural gradient in riparian soils. Since soil properties and topography are related in RFAD (Castilho *et al.* 2006), we tested for possible correlation. None of the soil variables were highly correlated with slope ($r < 0.355$ in all cases) (Table S3).

To investigate the influence of soil, hydrological and topographic gradients on palm AGB in riparian zones, we used a generalized linear mixed model (GLMM), assuming a

Gamma distribution for AGB and including sub-basin as a random effect in the model to control spatial autocorrelation between plots nested in the same sub-basin. Our model did not show multicollinearity problems (variance inflation factors (VIF)s < 1.51).

All analyses were undertaken in R version 3.6.3 (R Core Team 2020). The model was built using the “lme4” package (Bates *et al.* 2015). For calculation of VIFs, we used the “car” package (Fox & Weisberg 2019), to graphically display plots depicting partial residuals, we use the “visreg” package (Breheny & Burchett 2017), and to calculate the marginal and conditional R^2 (R^2_m; R^2_c) (Nakagawa & Schielzeth 2013) of the model we used the “performance” package (Lüdecke *et al.* 2020).

3.3. Results

Palm species and density in riparian plots

We recorded 2,379 stems (before strip extrapolation) distributed in 12 genera and 15 species in riparian plots, with *Oenocarpus bataua* and *Euterpe precatoria* being the most abundant species (Table 1).

The class containing palm with < 10 cm had the highest density (99.75 stems/ha) but represented, on average, less than 6.5% of the AGB per plot (estimated with every type of equation). Palm density in the class with dbh between 10 and 30 cm (98.40 stems/ha) represented the greatest portion of AGB per plot (93%). Stems with dbh > 30 cm occurred in low density (0.30 stems/ha) and represented less than 1.3% of AGB per plot (Table S4).

Table 1. Abundance and relative abundance of palm species registered in 40 riparian plots in Reserva Florestal Adolpho Ducke, Manaus, Amazonas, Brazil.

Species	**Abundance (stems)**	**Relative abundance (%)**
Oenocarpus bataua	1660	69.78
Euterpe precatoria	302	12.69
Socratea exorrhiza	144	6.05
Bactris acanthocarpoides	73	3.07
Astrocaryum gynacanthum	60	2.52
Bactris maraja	53	2.23
Iriartella setigera	28	1.18
Hyospathe elegans	20	0.84
Mauritia flexuosa	17	0.71
Geonoma máxima	8	0.34
Mauritiella aculeata	6	0.25
Oenocarpus minor	4	0.17
Syagrus inajai	2	0.08
Attalea maripa	1	0.04
Oenocarpus bacaba	1	0.04

Comparison between AGB-estimation equations

Across 40 riparian plots, palm AGB estimates vary depending on the selection of allometric equations. Based on species-level equations (AGB_{Sp}), palms contributed from 3.32 to 63.27 Mg/ha, with a mean of 27.5 ± 12.94 Mg/ha. The mean AGB estimated with family-level equation (AGB_{F1}) was 9.04 ± 4.29 Mg/ha, and the values range from 1.51 to 21.25 Mg/ha. Using the Pantropical equation (AGB_P), mean biomass was 20.46 ± 9.29 Mg/ha, and ranges from 3.67 to 47.99 Mg/ha. Palm AGB_{Sp} was on average 37% and 208% greater than AGB_{F1} and AGB_P, respectively (Figure 2).

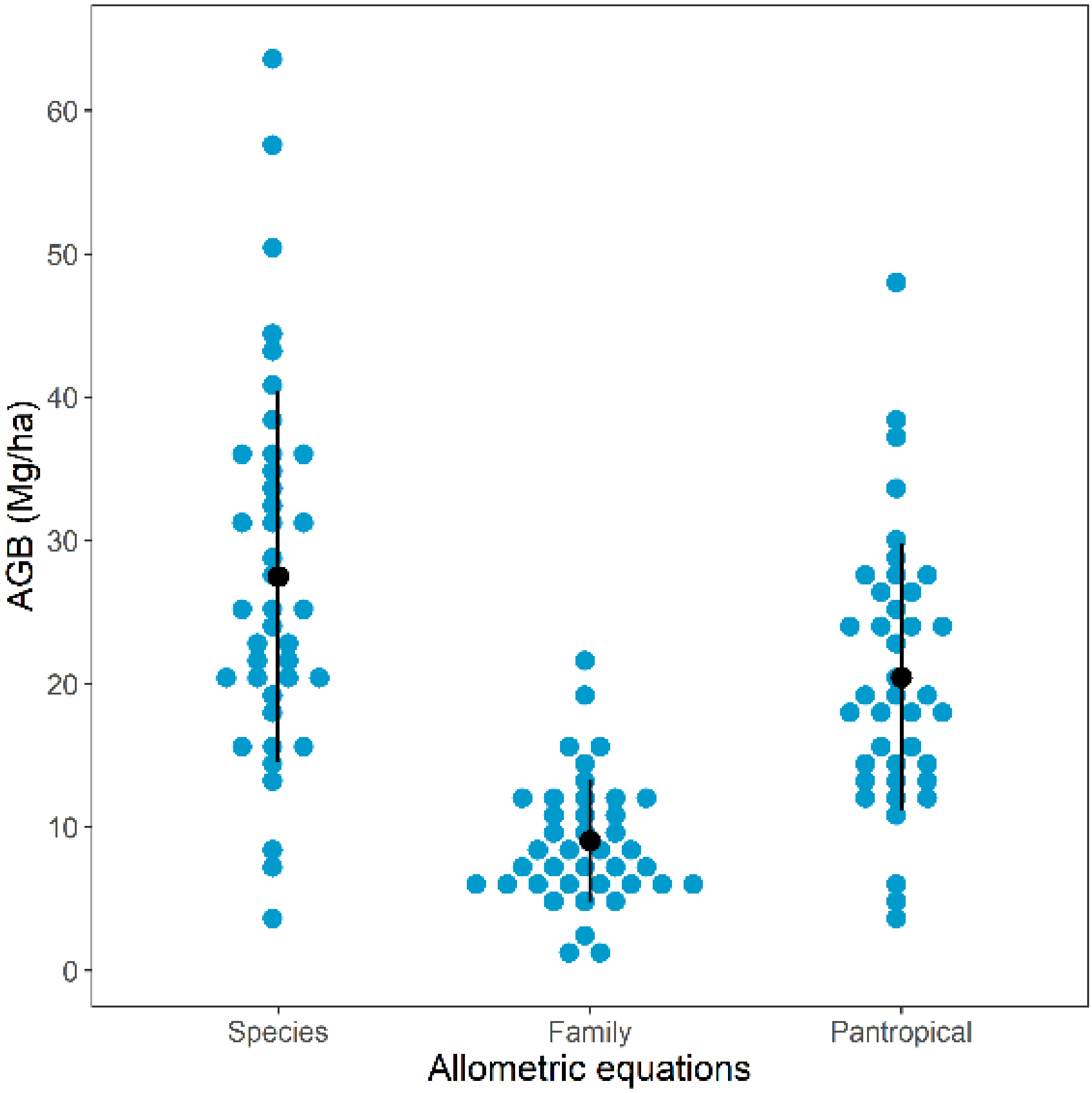

Figure 2. Dot histogram of palm AGB in 40 riparian plots estimated with Pantropical, Family-level and Species-level equations. Error bars and mean values are represented in black color for each AGB-estimation equation.

Palm AGB in non-riparian vs. riparian plots

Mean palm AGB_{F2} in non-riparian plots (2.39 ± 4.15, range: 0.06 – 26.38) Mg/ha was 78% lower than in riparian plots (10.97 ± 4.97, range: 2.13 – 26.41) Mg/ha (Figure 3). A Wilcoxon rank sum test confirmed that AGB_{F2} in non-riparian plots was significantly lower than in riparian plots ($Z = -7.58$, $P < 0.005$, effect size Pearson r correlation = 0.72). Median AGB_{F2} was 1.02 and 9.97 in non-riparian and riparian plots, respectively. Although non-riparian plots were not designed to uniformly sample riparian environments, some of them were located partially in valley bottoms ($n = 19$) and categorized as "bottomland plots" according to the topographical classification of Costa et al. (2009). Nevertheless, when we used the same test excluding those plots, we obtained similar results ($Z = -8.07$, $P < 0.005$, effect size Pearson r correlation = 0.84). Likewise, palm AGB_{F2} estimated in bottomland plots was significantly lower than in riparian plots ($Z = -3.37$, $P < 0.005$, effect size Pearson r correlation = 0.44).

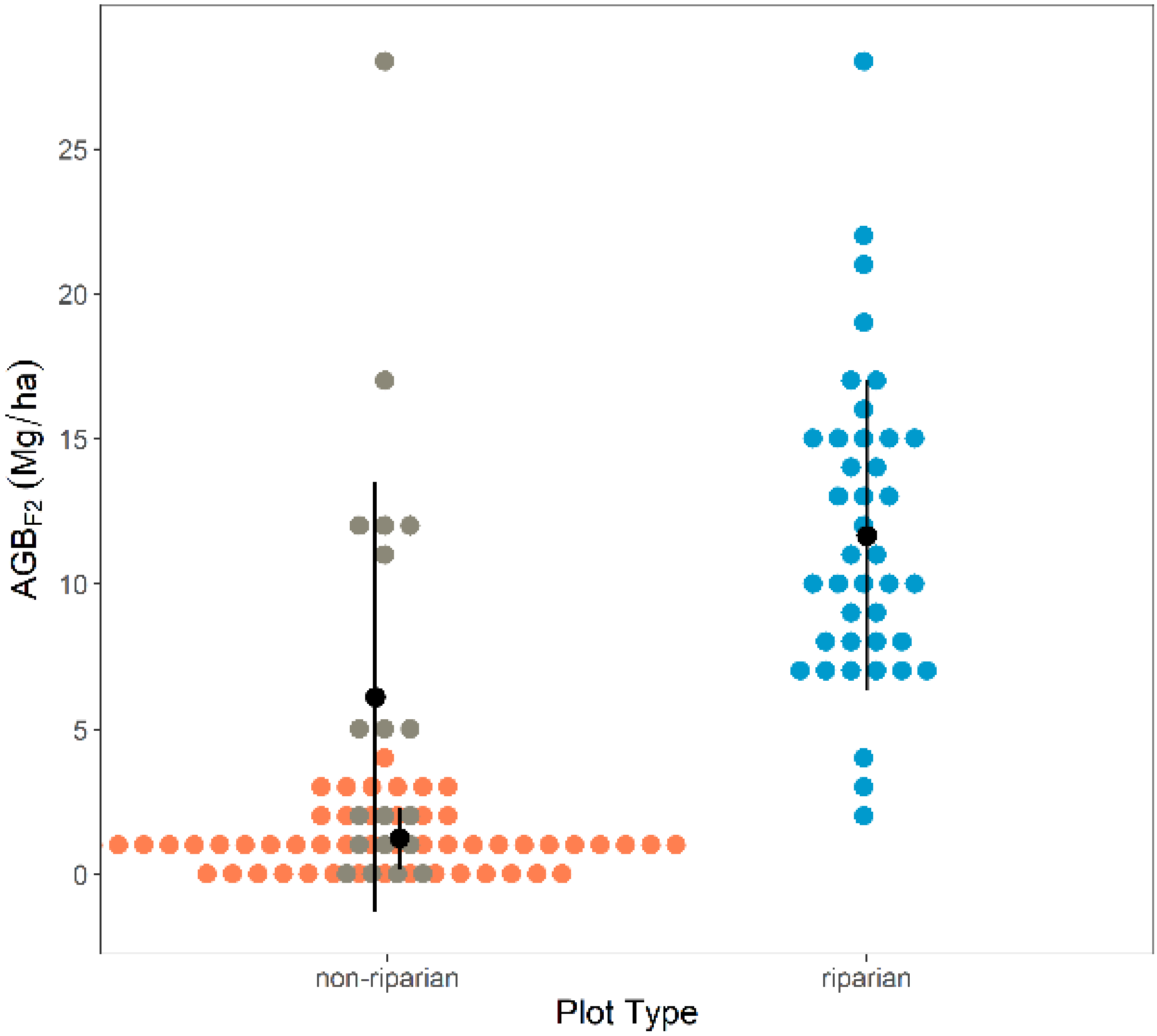

Figure 2. Dot histogram of palm AGB_{F2} in 72 non-riparian plots, that include 19 bottomland plots (gray points) and 40 riparian plots. Error bars and mean values are represented in black color for each type of plot.

Influence of environmental variables on riparian-palm AGB

The regression model including soil, hydrological and topographical gradients as predictor variables and sub-basin, as a random effect, explained about 31% of the palm AGB variation among plots in riparian zones. A model including only fixed effects explained 19% of the AGB variation (Figure 4; Table 2). Soil properties did not contribute significantly to the model. AGB had a negative relationship with slope, with higher palm AGB in flatter riparian zones. AGB was negatively affected by stream discharge, indicating that higher palm AGB is associated with banks of smaller streams. Applying the following transformation: **[exp(coefficient)-1] * 100**, we found that for each increase of one degree in slope, AGB decreases by 4%, and for each increase in stream discharge (m^3/s), AGB decreases by about 617%. As stream discharge varied from 0.004 to 0.425 m^3/s (Table S2), the differences between the lowest and highest discharges in our samples would have resulted in a difference of about 262% in AGB.

Table 2. Summary of multiple-mixed-regression analyses examining the effects of environmental variables on palm AGB_G in riparian plots. Marginal R^2 (variance explained by fixed effects; R^2_m), conditional R^2 (variance explained by the fixed effects + random effect; R^2_c).

Fixed effects	**Estimate**	***SE***	***P***
Intercept	3.60313	0.18894	< 0.001
Stream discharge	-1.97427	0.79016	0.0125
Slope	-0.0365	0.01852	0.0487
Axis 1 of PCA	-0.01972	0.03228	0.5412
Axis 2 of PCA	0.03773	0.07133	0.5968
Random effect	**Variance**	R^2_c	R^2_m
Residual	0.02868	0.31	0.19
sub-basin	0.1566		
$N_{sub\text{-}basin}$	5		
Observations	40		

Abbreviation: *SE*, standard error.

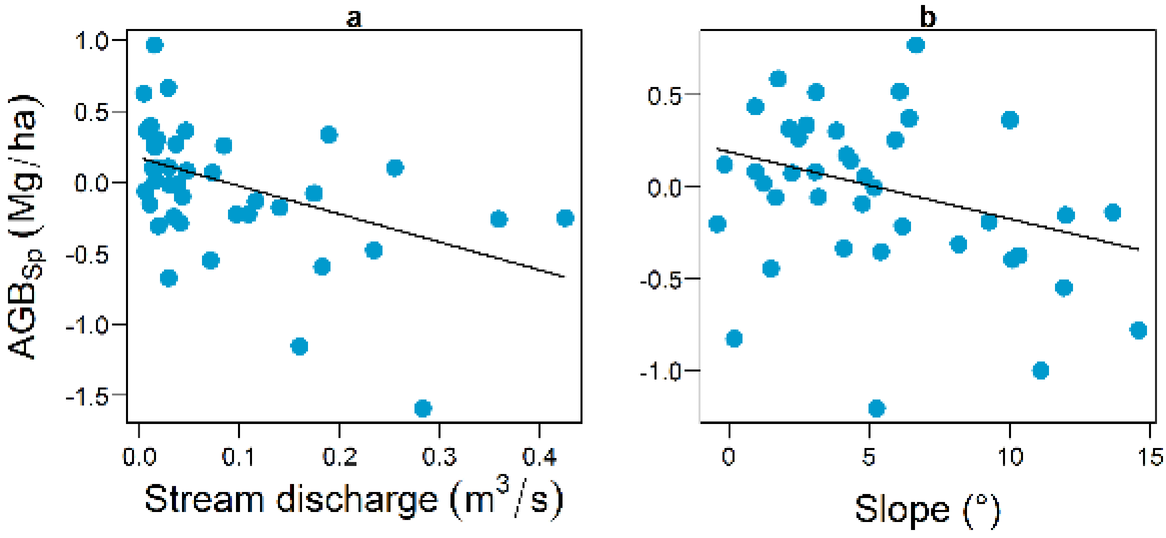

Figure 3. Partial regressions derived from the multiple regression model showing the relationships between palm AGB_{Sp} and (a) stream discharge (m^3/s), and (b) Slope (°).

3.4. Discussion

Effect of allometric-equation selection on palm AGB estimates

Goodman's palm equations and Chave's pantropical equations are valid in the range of 4-50 cm and 5-156 cm, respectively. As applied these equations for smaller palm sizes (dbh < 5 cm), this may result in potential errors caused by extrapolating allometric models beyond their valid dbh range (Chave *et al.* 2004). However, palms in dbh class < 5cm represented, on average, less than 0.81 Mg/ha (4.33%) when using the three groups of allometric equations.

In riparian plots, AGB_{Sp} estimates were 208% greater than AGB_{F1}. Species- and family-level equations developed by Goodman *et al.* (2013) were used on the same sample, that included 9 palm-tree species and 136 individuals, so the large differences are likely to be related to the relative abundance of each species in the plots. While species-level equations can slightly overestimate AGB, family-level equations tend to underestimate AGB for some species such as *O. bataua* (Goodman *et al.* 2013), that represented the major palm component in our study area. However, palm species vary in allometry in response to geographic position and forest strata (Avalos *et al.* 2019). We used palm- and species-level equations developed from Western Amazonian samples, so there may be some bias when these equations are applied on plots located in Central Amazon forests, despite the two locations having similar species composition (e.g., *O. bataua, E. precatoria, M. flexuosa, S. exhorriza*).

AGB_{Sp} estimates were 37% greater than AGB_{P} estimates. Allometric equations generated for trees estimate AGB based on dbh and perform relatively poorly at estimating palm AGB because diameter and height are not usually related in palms (Goodman *et al.* 2013, Muscarella *et al.* 2020). Palms grow taller with proportionally smaller diameters than dicotyledonous trees (Avalos *et al.* 2019), so AGB of tall palm individuals with small diameters could be underestimated by the Pantropical equation (Goodman *et al.* 2013). Chave's Pantropical equation was developed based on a dataset of 2,410 tree harvested individuals. The authors cautioned that it should only be used for broadleaf tree species and different equations should be use for palms and other taxa (Chave *et al.* 2005).

General allometric equations used for dicotyledonous trees (and some palm family-level equations) commonly use palm total height as one of the equation components. Although total height is a good estimator of palm AGB (Goodman *et al.* 2013), measurements of total height in the field can be subjective, because individuals of some species (e.g., *O. bataua*) have a large portion of total height in their elongated crowns. Stem-height measurements in datasets are important to improve the accuracy of palm AGB estimates. We estimated stem height visually and calibrated our estimates, but more precise methods (e.g., using laser hypsometers, LiDAR airborne systems) are needed for future assessments, especially in palm AGB-dynamics research.

Palm AGB contribution across riparian and non-riparian plots

Palm AGB_{F2} in riparian plots was on average 10.97 Mg/ha and was four times higher than AGB_{F2} in non-riparian plots. Mean palm AGB_{F2} in non-riparian plots was 2.39 Mg/ha and represented less than 1% of total AGB in these plots. However, palms are conspicuous components in some forest types, such as riparian zones. Although 19 non-riparian RAPELD plots did not follow a design for sampling riparian environments, they included portions of riparian zones. The AGB in those plots was on average 16.65 Mg/ha, lower than the mean value of palm AGB found in riparian plots. Conventional square plots would underestimate mean palm AGB in the riparian zone even more. Therefore, sampling riparian environments using standardized protocols can improve the understanding of how palm AGB is distributed at the landscape scale.

Areas where arborescent palms dominate do not occur only near streams. Large, low-lying valleys and terrain depressions could be relatively farther from stream margins, but closer to the water table and in consequence be subject to waterlogging and poor-drainage conditions (Schietti *et al.* 2014). To improve palm AGB estimates it is necessary to know where each taxon is abundant. Recent remote-sensing advances combining satellite and airborne imageries with field data may help reduce uncertainties in palm AGB estimates (e.g., Tagle Casapia et al. 2019; Wagner et al. 2020).

Variation in palm AGB within riparian zones

Topography and hydrological characteristics explained 19% of palm AGB variation among riparian plots in our study area. Palm AGB decreased on steep slopes, and this may be related to palm root systems. Most palm species do not develop extensive roots but have roots with high resistance to water pressures (Tomlinson 2006). Although this may confer a competitive advantage in poorly-drained and shallow-water-table soils (Emilio *et al.* 2014), shallow root systems are less suitable for establishment and stability in steep areas. Moreover, topography drives water availability, so it is expected that palms on steep slopes would have less access to water and nutrients (Schietti *et al.* 2014). In contrast, the distribution of *Iriartea deltoidea*, the most abundant palm species in a forest from Ecuador, was not related to topography (Valencia *et al.* 2004). Species with stilt roots, such as *I. deltoidea*, maintain stability under diverse slope conditions (Avalos *et al.* 2005). Likewise, the density of arborescent palms (>10 m tall) in a forest in Costa Rica peaks on steep slopes, probably because treefall gaps favor palm recruitment (Clark *et al.* 1995).

RFAD is not affected by the flooding regimes of large rivers, but local rainstorms change the stream discharge rapidly in riparian zones (Drucker *et al.* 2008). Although palms in Amazonian forests tend to occur in waterlogged environments, extreme flooding events affect processes, such as seed germination, establishment, survivorship, and recruitment of plants, which may explain the lower abundance of palms near larger streams (Svenning 2001, Eiserhardt *et al.* 2011). For example, *E. precatoria* seeds do not germinate under anoxic conditions (Gonçalves *et al.* 2010) and germinated seeds of *S. exorrhiza* had high mortality rates during the flooded period (Pacheco 2001). Although flooding has strong effects on the distribution of palms, it remains unclear if those effects are more related to the anoxic conditions or other indirect factors typical of flooded environments, such as low vegetation structure and high light availability (Eiserhardt *et al.* 2011).

Soil properties are associated with topography in Central Amazonia (Chauvel *et al.* 1987) and in a large dataset of plots, they explained 55% of AGB variation, with higher palm AGB on sandy soils (Castilho *et al.* 2006). We included soil properties in our analyses, but they were not associated with palm AGB variation among riparian plots. Soil physical characteristics in riparian plots varied little in comparison to the variation over the entire reserve, where sand-percentage ranges from 8-78%. This may explain why we detected no association with soil physical properties. Soil fertility has been associated with palm-assemblage composition at local scales within lowland rainforest in western Amazon (Vormisto *et al.* 2000). However, we did not detect an association between soil chemical properties and palm AGB. Soil nutrient content in central Amazonia varies subtly and there is only a weak relationship between tree (including palms) AGB and nutrients in RFAD (Castilho *et al.* 2006).

Much of the variation in palm AGB in riparian plots remains unexplained. Riparian areas are heterogeneous environments, with different gradients of water retention, light incidence, and flooding patterns (Pazin *et al.* 2006, Drucker *et al.* 2008). Those effects are assumed to influence palm composition and, therefore, palm AGB (Toledo *et al.* 2017). However, changes in the composition are more evident for understory than for arborescent palms (Costa *et al.* 2009). Variation in dominant species between riparian zones may be related to dispersal limitation (Costa *et al.* 2009) and complex interactions between palms and dispersers (Eiserhardt *et al.* 2011).

Historical human impacts may also play a role in the distribution of dominant palm species at landscape and smaller scales (Eiserhardt *et al.* 2011). *O. bataua* was the most abundant palm species in our sample. This species depends on natural or anthropogenic gaps for recruitment of adults (Guarín *et al.* 2014). There is evidence that pre-Colombian societies affected the distribution and abundance of useful plants, such as *O. bataua* (Levis *et al.* 2017). Thus, it is possible that human past disturbances have contributed to the high biomass of *O. bataua* and present biomass-variation between riparian plots. Moreover, changes in palm distribution at the landscape scale can result from recent harvesting by residents (e.g., Clark et al. 1995). The southern edge of the RFAD has had close contact with suburbs since the early 2000s and palms and their fruits are harvested in plots near the edge (C. Castilho, unpublished).

Conclusions and future directions

Our study shows that stratifying studies of palm biomass and including covariables, such as stream discharge, can reduce uncertainty in biomass estimates. However, more effort is needed to collect palm stem-height data in the field and develop allometric equations for more species (Goodman *et al.* 2013, Muscarella *et al.* 2020). Moreover, to reduce the AGB-estimation uncertainties in the Amazon region, we need to include estimates in riparian zones, where arborescent palms are abundant components and their contribution to biomass is greatest. AGB of stemless palms represent a small percentage (Nascimento & Laurance 2002), but stemless palms can be very abundant (Higashikawa *et al.* 2019) and it is not known whether their AGB varies among habitats as does the biomass of arborescent palms. Recent studies are recognizing the need to consider all forest strata to understand regional patterns of dominance in Amazonia (e.g., Draper et al. 2021). Thus, including stemless palms, which occupy the understory strata of the forest, may improve the understanding of the role of palms in the carbon cycle (Castilho *et al.* 2006).

Palms in areas with shallow water tables, such as riparian zones, are more resistant to drought and can compensate for biomass loss in forests affected by moisture deficits in the context of climate change (Sousa *et al.* 2020). However, riparian zones are subject to anthropogenic pressures which could change stream discharge patterns and biomass stocks. Current Brazilian conservation law protects only a 30-m-wide riparian buffer around small streams. We believe that recognizing the role of riparian zones and their components in the carbon balance could contribute to improvements in conservation policies.

3.5. Acknowledgments

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3.6. Conflict of interest

The corresponding author confirms on behalf of all authors that there have been no involvements that might raise the question of bias in the work reported or in the conclusions, implications, or opinions stated.

3.7. Author Contribution Statement

Lourdes Falen: Conceptualization, Methodology, Project administration, Investigation, Data curation, Formal analysis, Writing - original draft, Writing - review & editing, Visualization. **Mariane Guedes:** Investigation, Project Administration, Writing – review & editing. **Carolina V. de Castilho:** Investigation, Writing – review & editing. **Rafael F. Jorge:** Investigation, Writing – review & editing. **Francisco M. Bezerra**: Investigation, Writing – review & editing. **William E. Magnusson:** Conceptualization, Methodology, Formal Analysis, Resources, Writing – original draft, Writing – review & editing, Supervision, Funding Acquisition. All authors contributed critically to the drafts and gave final approval for publication.

3.8. Data Availability Statement

The authors intend to archive the data in the dataONE's repository.

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3.10. Supporting Information

Table S1. Allometric equations used to estimate aboveground biomass (AGB, kg dry mass) from stem height and total height (H_{Stem} and H_{Total}; m), diameter at breast height (dbh; cm), dry mass fraction (*dmf*; g/g); wood density (*WD;* g/cm^3) and Environmental Factor (*E*). Values of *dmf* are available in Goodman *et al.* 2013; *WD* values are in the Global Wood Density Database (Chave *et al.* 2009, Zanne *et al.* 2009) and *E* are calculated with the BIOMASS package (Réjou-Méchain *et al.* 2017).

Allometric equations for palm AGB estimation

Pantropical Equation (Chave *et al.* 2014)

$AGB_P = [\exp(-2.024 - 0.896 \times E + 0.920 \times \log(WD) + 2.795 \times \log(\mathrm{dbh}) - 0.0461 \times (\log(\mathrm{dbh}^2))] \times 1000$

Species/genus level (AGB_{Sp}) (Goodman *et al.* 2013)

Astrocaryum AGB = $21.302 \times H_{Stem}$

Attalea AGB = $\exp(3.2579 + 1.1249 \times \ln(H_{Stem} + 1))$

Euterpe AGB = $0.02227 \times \mathrm{dbh}^3$

Mauritia AGB = $\exp(2.4647 + 1.3777 \times \ln(H_{Stem}))$

Mauritiella AGB = $2.8662 \times H_{Stem}$

Oenocarpus AGB = $\exp(4.5496 + 0.1387 \times H_{Stem})$

Socratea AGB = $\exp(-3.7965 + 1.9929 \times \ln(\mathrm{dbh}^2 \times H_{Stem}))$

Family-level (Goodman *et al.* 2013)

$AGB_{F1} = 0.5551^4 \times (dmf \times \mathrm{dhb}^2 \times H_{Stem})^{0.25}$

$AGB_{F2} = \exp(-2.0752 + 2.6401 \times (\ln(\mathrm{dbh}) + 0.8426 \times \ln(dmf))$

Table S2. Summary statistics of soil attributes, stream discharge and slope in 40 riparian plots at Reserva Florestal Adolpho Ducke, Manaus, Amazonas, Brazil.

Variable	**Min**	**Max**	**Mean**	**SD**
Stream discharge (m^3/s)	0.004	0.425	0.088	0.102
Slope (°)	-0.42	14.58	5.269	3.922
Ca^{2+} (cmol/kg)	0.042	0.164	0.075	0.028
Mg^{2+} (cmol/kg)	0.051	0.24	0.103	0.041
Al^{3+} (cmol/kg)	0.44	1.67	0.729	0.309
Na^{+} (cmol/kg)	0.012	0.037	0.025	0.006
K^{+} (cmol/kg)	0.025	0.128	0.062	0.024
P (mg/kg)	3.603	18.503	7.42	3.152
Fe^{2+} (mg/kg)	41	368	119.525	72.594
Mn^{2+} (mg/kg)	0.3	2.1	0.963	0.488
Zn^{2+} (mg/kg)	0	2.3	0.765	0.381
Sand (%)	59.62	94.12	81.089	8.089
Silt (%)	2.5	19	9.938	4.479
pH (H_2O)	4	5.74	5.071	0.355

Table S3. Correlations between 12 soil attributes and two ordination axes produced by Principal Components Analyses (PCA). Correlations with absolute value > 0.3 are shown in bold.

Soil attributes	**PCA1**	**PCA2**	**Slope (°)**
Ca^{2+} (cmol/kg)	**0.832**	-0.258	-0.109
Mg^{2+} (cmol/kg)	**0.940**	0.013	-0.019
Al^{3+} (cmol/kg)	**0.817**	0.330	0.099
Na^{+} (cmol/kg)	-0.030	**0.468**	-0.088
K^{+} (cmol/kg)	**0.847**	0.176	-0.039
P (mg/kg)	**0.795**	0.249	0.094
Fe^{2+} (mg/kg)	0.262	**0.478**	0.054
Mn^{2+} (mg/kg)	**0.728**	-0.461	**-0.355**
Zn^{2+} (mg/kg)	**0.707**	-0.180	-0.109
Sand (%)	-0.058	**-0.817**	0.028
Silt (%)	-0.015	**0.880**	0.146
pH (H_2O)	**-0.580**	0.167	-0.040
Slope (°)*	-0.057	0.141	-
Variation explained (%)	41.9	20.2	

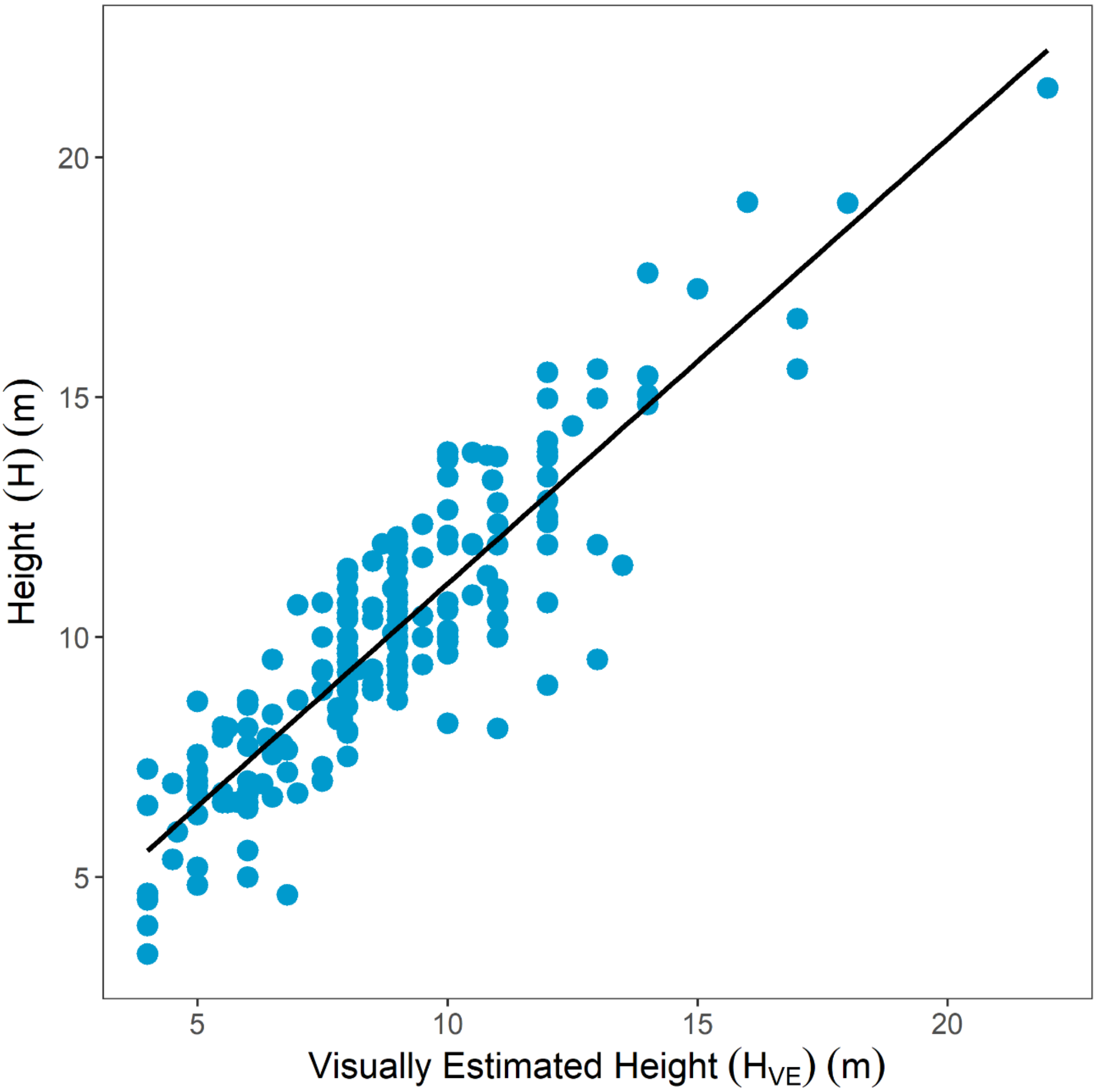
* Slope was not included in soil ordinations, but we tested the correlation between slope and each soil variable alone and with the PCA axes.

Table S4. Density and palm AGB of different diameter size classes in 40 riparian plots at Reserva Florestal Adolpho Ducke, Manaus, Amazonas, Brazil.

Classes of dbh (cm)	**Density (Ind/ha)**	**Pantropical equation**		**Family-level equation**		**Species-level equations**	
		AGB (Mg/ha)	% AGB	AGB (Mg/ha)	% AGB	AGB (Mg/ha)	% AGB
≥1, 5>	71.0 ± 69.1	0.2 ± 0.2	1.1 ± 1.4	0.1 ± 0.1	1.4 ± 1.8	0.8 ± 1.2	4.3 ± 6.7
≥5, 10>	28.8 ± 18.7	0.4 ± 0.3	2.2 ± 2.5	0.3 ± 0.3	4.5 ± 7.0	0.4 ± 0.7	2.1 ± 4.3
≥10, 20>	75.1 ± 36.7	12.1 ± 5.9	58.8 ± 11.2	5.4 ± 2.8	58.6 ± 11.6	18.1 ± 10.2	63.4 ± 12.4
≥20, 30>	23.3 ± 11.9	7.6 ± 4.0	37.2 ± 11.2	3.0 ± 1.5	34.2 ± 11.6	8.0 ± 3.9	29.9 ± 10.8
≥30	0.3 ± 0.8	0.2 ± 0.7	0.8 ± 2.0	0.2 ± 0.6	1.3 ± 3.5	0.1 ± 0.4	0.3 ± 0.8

Values are mean ± standard deviation (in parentheses).

Figure S1. Relationship between visual estimated height (H_{VE}) and measured height (H). $H = 0.92*H_{VE} + 1.83$ ($N = 183$, $r^2 = 0.79$).


Height (H) (m)
20
15
10
5
5
10
15
20
Visually Estimated Height (H_{VE}) (m)

4. CONCLUSÕES

Esta pesquisa mostra que a estratificação de estudos de biomassa de palmeiras e a inclusão de covariáveis, como vazão de igarapés, podem reduzir a incerteza nas estimativas de biomassa. No entanto, é necessário aumentar os esforços para coletar dados de altura do caule das palmeiras no campo e desenvolver equações alométricas para mais espécies (Goodman et al. 2013, Muscarella et al. 2020). Além disso, para reduzir as incertezas de estimativa da biomassa na região amazônica, precisamos incluir estimativas em zonas ripárias, onde as palmeiras arborescentes são componentes abundantes e sua contribuição para a biomassa é maior.

Palmeiras em áreas com lençóis freáticos rasos, como as zonas ripárias, são mais resistentes à seca e poderiam compensar a perda de biomassa em florestas afetadas por déficits de umidade no contexto das mudanças climáticas (Sousa et al. 2020). No entanto, as zonas ripárias estão sujeitas a pressões antrópicas que podem alterar os padrões de descarga dos rios e os estoques de biomassa. A atual lei brasileira de conservação protege apenas uma faixa de 30 m de largura ao redor de pequenos igarapés. Acreditamos que reconhecer o papel das zonas ripárias e seus componentes no balanço de carbono pode contribuir para melhorias nas políticas de conservação.