Soil fertility of fluvial islands increases with proximity to an Amazonian white-water river

Gilson de Souza Ferreira Neto (gilsonsouzaferreiraneto@gmail.com)
INPA: Instituto Nacional de Pesquisas da Amazonia https://orcid.org/0000-0003-0475-0952
FABRICIO BEGGIATO BACCARO
INPA: Instituto Nacional de Pesquisas da Amazonia
CARLOS ALBERTO NOBRE QUESADA
INPA: Instituto Nacional de Pesquisas da Amazonia
AXA SIMÕES FIGUEIREDO
INPA: Instituto Nacional de Pesquisas da Amazonia
REGISON OLIVEIRA
INPA: Instituto Nacional de Pesquisas da Amazonia
ERISON GOMES
INPA: Instituto Nacional de Pesquisas da Amazonia
WILSON ROBERTO SPIRONELLO
INPA: Instituto Nacional de Pesquisas da Amazonia
ADRIAN PAUL ASHTON BARNETT
INPA: Instituto Nacional de Pesquisas da Amazonia

Research Article

Keywords: Soil factors, mixed water, fluvial archipelago, fluvisols, Central Amazonia

Posted Date: April 23rd, 2021

DOI: https://doi.org/10.21203/rs.3.rs-340662/v1

Abstract

The nutrient content of soils is considered a productivity key factor. Sediment input from Amazonian rivers is one of the natural sources of soil fertility for fluvial islands and riverbank flooded forests. Despite the importance of soil factors for ecosystems, few edaphic studies along riverine sediment-gradients have been undertaken in tropical areas. The current study provides a step forward by describing soil nutrients in a mixed water (sediment-poor black water with input of sediment-rich whitewater) fluvial archipelago. To investigate how geographic distance from a whitewater river mouth affects island soil properties, soil chemical and physical attributes were determined at 61 sampling sites on 35 islands. The studied Central Amazon fluvial islands showed high variability in our fluvisols soil properties. In general, the fluvial island soils were acid and with low fertility. Islands from Jaú and other sites closer to the sediment source (the river Rio Branco) had higher soil fertility than islands of the Anavilhanas Archipelago, which are further away from the sediment source. Our results show that sediment inputs from Amazonian rivers can play an important role in soil properties, and this research increases our understanding on the origin and evolution of one of the largest freshwater archipelagos in the world. Given that soil fertility is often correlated with forest productivity, the main results reported here may also help improve management plans and conservation policies for fluvial island environments of Central Amazonia.

Introduction

Sediment input from large Amazonian rivers is one natural source of fertility for flooded forests growing on riverbanks (Junk et al. 2011). Such environments are subject to annual pulses of inundation (Montero and Latrubesse 2013). The volume of organic ions and sediments received vary with location, so that flooded forests periodically inundated by sediment-rich whitewater (várzeas) grow on fertile soils, while those inundated by sediment-poor black and clearwater rivers (igapós) have poorer soils (Prance 1979; Junk et al. 2011; Goulding et al. 2003). Although very useful, such categorical classification of water types simplifies a natural continuum. For example, the Rio Branco has an intermediate amount of organic ions, greater than that present in Guiana Shied-derived black water rivers, such as the Rio Negro, but less than those found in rivers of Andean origin such as Madeira and Solimões (Goulding et al. 2003). The Rio Branco is unusual because it is a sediment-rich whitewater river, while all neighboring rivers are sediment-poor (black-water) (Leenheer and Santos 1980). This spatial configuration may directly affect the Anavilhanas archipelago, a system of fluvial islands within the nutrient-poor Rio Negro domain that are hydro-chemically influenced by the more nutrient rich Rio Branco (Marinho et al. 2020).

Fluvial islands are productive ecosystems that play an important role in biogeochemical cycles and geomorphological processes (Kalliola et al. 1991; Osterkamp et al. 1998; Abril et al. 2013). In Amazonia, fluvial island systems, together with flooded forests, represent 30% of Amazon Basin forest types (Junk 2013). As a result of differences in sediment loading by their inundating rivers (Marinho et al. 2020), the input of sediments from Amazonian rivers acts in synchrony with annual phenological patterning of leaf and fruit production (Montero et al. 2014), which are responsible for seasonal lateral movements of vertebrates between flooded and non-flooded environments (Buendía et al. 2018).

The nutrient content of a soil is strongly linked to productivity (Quesada et al. 2012; Grau et al. 2017). A global meta-analysis found that higher productivity can be a good predictor of species diversity of several invertebrate, vertebrate and plant groups (Mittelbach et al. 2001). For instance, plants growing on more fertile soils that provide more favorable conditions for establishment and growth (Malhi et al. 2004), can invest more carbon in reproduction (i.e. flowers and fruits), than in secondary compounds or nutrient acquisition via root production and exudation (Vitousek 1984; Coley et al. 1985; Quesada et al. 2010; Quesada et al. 2011). Despite the importance of soil factors for several groups of plants and animals, few edaphic studies have been undertaken in flooded environments, particularly in Amazonia (Furch and Junk 1997; Piedade et al. 2005; Targhetta et al. 2015).

Amazonian archipelagos have been, and continue to be, threatened by anthropogenic disturbances (Macedo and Castello 2017; Flores et al. 2017). In the Anavilhanas archipelago, for example, hunting and logging is rapidly changing the landscape of islands (Souza Filho et al. 2006; Scabin et al. 2012). This is especially relevant since the increase of extreme climate events associated with the frequency and volume of precipitation is predicted to affect the flooding pulse in the Amazon and the contribution of sediments of Amazon rivers (Filizola et al. 2011; Marengo and Espinoza 2016). Knowledge of soil fertility and properties can be of great importance to supply information about soil management and the functioning of fluvial ecosystem to safeguard against ongoing anthropogenic disturbances.

The aim of the current study was to provide information on how sediment inputs from a sediment-rich whitewater river can affect soil fertility on downstream fluvial islands located in a sediment-poor black water system. The hypothesis is that soil nutrients will decrease accordingly with increasing distance downstream from the Rio Branco (which acts as a sediment source).

Methods

Study area

The study was carried out within two protected areas and surrounding sites on the Rio Negro, central Amazonian, Brazil — Anavilhanas National Park (farther from the Rio Branco) and Jaú National Park and other sites in the proximities of the Jaú National Park (Fig. 1). Both conservation units are located within the lower Rio Negro basin.

Natural fluvial islands can be either terrestrial or aquatic environments, depending on the season of the year (Junk et al. 2011). The annual flood pulse (the inundation of the floodplain and its subsequent dry phase) is seasonal and gradual (Junk et al. 1989). During peak water levels, fluvial islands and river margin forests are flooded, often to depths of up to 15 meters, for more than seven months per year (Irion et al. 1997). During the high water-level phase, most fluvial islands are completely inundated, so temporarily transforming terrestrial environments into aquatic ones (Montero and Latrubesse 2013). At both Anavilhanas and Jaú, the water is at the lowest level between October and November, and at the maximum level between June and July (Montero and Latrubesse 2013).

Sampling design

We firstly established a 2 by 2 km virtual sampling grid in the entire study area, and then placed sampling stations as close as logistically possible to the grid intercept points. For this, satellite images from Google Earth GeoEye were used, with decisive criteria based on river water color. Therefore, our sampling effort was concentrated on islands on the left side of Rio Negro. This design covered the majority of the fluvial islands within Jaú and Anavilhanas National Parks, resulting in 61 sampling sites: 27 sites occurred on islands in Jaú National Park and other sites in the proximity of Jaú National Park, while 34 sites were placed on islands further from the Rio Branco in the Anavilhanas National Park. At each site, a 0.1 ha plot (10 x 100 m) was established. The maximum above-water area of the islands sampled ranged from 50 to 11.000 hectares (mean ± SD = 2.406 ha ± 2.766; Median = 962; Max = 11.064), where almost 80% of the sites were placed on islands smaller than 2.000 hectares based on satellite images.

Soil sampling and analysis

Soil samples were collected at each sampling site, with a minimum distance of 10 m between samples. After leaf litter removal, soil was collected to a depth of 20 cm using a Dutch auger. All samples within a plot were then combined in order to obtain one pooled sample per site. Soil sampling was conducted during the dry season of 2017. For each pooled soil sample, inorganic nitrogen - ammonium (NH_4^+) and nitrate (NO_3^-) were then prevented from volatizating by storing field samples individually in a styrofoam box, and then transferring them to the ICMBio base freezer at Novo Airão. Chemical analyses were carried out at the Thematic Laboratory of Soils and Plants at the National Institute of Amazonian Research (INPA, Manaus), with soils frozen upon arrival in the laboratory to avoid volatization after travelling from the base freezer.

The following soil characteristics were obtained: 1) pH, determined using 10 grams of fine soil in 25 milliliters H_2O for 1 minute, with a mechanical stirrer; 2) concentrations of Na, K, Ca, Mg, Al, all determined with the Silver-Thiourea (Ag-TU, as described in Quesada et al. 2010); 3) Sum of bases was considered as the sum of concentrations of Na (sodium), K (potassium), Ca (calcium) and Mg (magnesium) (Pleysier and Juo 1980), while cation exchange capacity was calculated from the equation: Cation Exchange Capacity = (Sum of Bases + Aluminium) (Pleysier and Juo, 1980). For this, cationic extraction was made in a 0.01M Ag-TU solution, stirred together with the sample for 4 h, (Anderson and Ingram 1989); 4) To estimate total phosphorus and total cations, soil samples were digested using sulfuric acid and hydrogen peroxide, with 0.25 g of soil added to 5 ml of distilled water and left to settle overnight. The following day, 5 ml of H_2SO_4 was added and sample heated until a temperature of 360 ºC was reached, where after cool, 0.5 ml of hydrogen peroxide (H_2O_2) was added with this process was repeated 10 times. Total phosphorus reading was obtained by colorimetry in a Shimadzu Spectrophotometer, while total cations were read with atomic absorption via Flame Atomic Absorption Spectrometry (AAS) (Murphy and Riley 1962). Available organic (P_o) and Inorganic phosphorus (P_i) were extracted with $NaHCO_3$ (Sodium Bicarbonate) (Olsen 1954). 5) Preparation of extracts for inorganic nitrogen analysis used 20 grams of soil and 40 millimeters of potassium sulfate (K_2SO_4) at 0.5 molar in falcon tubes for 15 minutes with centrifugation at 200 rpm. Extracts were then decanted for 30 minutes and filtered and frozen for further analysis of N-inorganic contents. Ammonium and nitrate were determined by colorimetry, using a Shimadzu Spectrophotometer (UV mini 1240). Samples destined for N analysis were not oven-dried. For all other soil analyses, each soil sample was oven dried at 65 ºC, and particles smaller than 2 mm removed with a soil sieve of 0.05 (Anderson and Ingram 1989); and 6) Soil particle size was estimated by the pipette method, using 10 g of fine soil pre-treated with physical and chemical dispersants. Then, silt percentage was separated according to their grain size, which was calculated from the difference between the total weight of sand and clay (Gee and Bauder 1986). For more details about soil attributes, see Online Resource 1.

Data analysis

The center of the closest sampled island to the Rio Branco mouth (S 01.36634º, W 061.79113º) was used to measure the distance to all other sampling sites. We used a Principal Component Analysis (PCA) to accommodate correlated soil variables and reduce data dimensionality in order to test if the soils of Anavilhanas were different from soils of Jaú and the other sites. We also created additional models for other soil variables in order to investigate the relationship between geographic distance and soil chemical and physical variables. To test the hypothesis that soil fertility is affected by geographic distance from the Rio Branco, we used a regression model, with cartographic linear distance to the Rio Branco as the predictor, and PC1 as the response variable. We checked that residual plots met model assumptions visually. To standardize the data and build the PCA, we used the vegan package (Oksanen 2013). All statistical analyzes were performed in R version 3.3.1 (R Core Team 2019).

Results

At regional scale, a diverse range of soil properties was found. In terms of soil particle size, Anavilhanas soils showed less variation than sites closer to the Rio Branco, and could generally be classified as clay loam (average 40 ± 6.1; 36 ± 7.8 and 23 ± 13.1, for silt, clay and sand respectively). On the other hand, soils from islands closer to the Rio Branco were classified as silty clay loam (average 46 ± 8.9; 36 ± 9.1 and 18 ± 14, for silt, clay and sand respectively). In general, the percentage of silt was higher in sites closer to the Rio Branco, but there was no statistical difference between percentage of clay and sand along the soil gradient ($p < 0.05$). The aluminum concentration decreases in richer soils ranging from 0.1 to 0.7 mean [SD] = 0.4 [0.2]. The distribution of exchangeable base cations and aluminium across the basin can be associated with the range of variation in soil pH, ranging from 4.4 to 5.4 mean [SD] = 4.9 [0.23] ($p = 0.002$). The highest pH values (> 5.0) occurred in richer soils, whereas the lowest (< 4.5) occurred in a site further from the Rio Branco (Table 1).

Table 1
Relationships between the geographic distance from the Rio Branco and soil chemical and physical variables. Average values, standard deviation and range of soil factors for Anavilhanas sites, Jaú and surrounding areas sites and all sites combined.

	Anavilhanas				**Jaú**				**Ana & Jaú**		**All sites**		
Edaphic variables	Average	Standard deviation	Max	Min	Average	Standard deviation	Max	Min	Pr(>|t|)	R2	Average	Standard deviation	M
ph[H2O]	5.0	0.2	5.5	4.5	4.8	0.2	5.2	4.4	0.002279	0.1	4.9	0.2	5
Na[cmolc/kg]	0.07	0.02	0.3	0.1	0.1	0.03	0.2	0.09	0.00000000721	0.48	0.1	0.04	0
K[cmolc/kg]	0.02	0.001	0.05	0.01	0.03	0.01	0.1	0.01	0.0000003758	0.13	0.027	0.01	0
Ca[cmolc/kg]	0.3	0.3	1.1	0.04	0.1	0.1	0.6	0.04	0.05819	0.24	0.2	0.21	1
Mg[cmolc/kg]	0.5	0.2	1.0	0.1	0.3	0.1	0.6	0.14	0.00000874	0.28	0.4	0.2	1
Al[cmolc/kg]	0.4	0.2	0.7	0.1	0.3	0.2	0.7	0.14	0.105	0.04	0.4	0.2	0
Porg[mg/kg]	43.5	14.8	86.3	24.8	16.3	9.0	52.0	5.8	0.00000002808	0.53	28.3	18.0	8
Pinor[mg/kg]	30.3	12.8	62.2	12.7	13.4	10.1	48.4	4.7	0.0000000568	0.39	20.9	14.1	6
Nitr[ug/g]	3.4	2.7	11.2	0.5	1.4	0.8	3.6	0.1	0.0000702	0.23	2.3	2.1	1
Amo[ug/g]	60.1	24.3	144.6	36.7	28.1	9.0	50.4	14.9	0.000000555	0.34	42.3	23.6	1
Ninor[ug/g]	63.5	24.2	147.1	39.2	29.6	9.0	52.1	16.2	0.000000117	0.38	44.6	24.3	1
SB[cmolc/kg]	1.0	0.5	2.3	0.3	0.5	0.2	1.3	0.2	0.0000000101	0.31	0.7	0.5	2
CEC[cmolc/kg]	1.4	0.4	2.3	0.6	0.8	0.3	1.5	0.3	0.00922	0.42	1.1	0.5	2
Ptot[mg/kg]	350.4	97.4	549.8	142.5	222.3	68.7	502.8	125.2	0.003357	0.43	279.0	104.3	5
Clay[%]	35.6	9.1	57.0	14.0	36.4	7.9	50.0	19.0	0.767	0.001	36.1	8.5	5
Silt[%]	46.3	8.8	61.0	28.0	40.4	6.2	51.0	23.0	0.112	0.01	43.0	8.0	6
Sand[%]	18.2	15.0	59.0	1.0	23.3	13.0	58.0	5.0	0.00108	0.04	21.0	14.2	5

Individual maps for the two important indicators of soil properties (sum of bases and total phosphorus) showed a similar pattern (Fig. 2). For sum of bases (mean [SD] = 0.7[0.5], range = 0.2–2.3), more than a third of the sites ranged between 0.391–0.650 cmolc/kg and about a fifth of the sites had more than 1 cmolc/Kg. For total phosphorus (mean [SD] = 279 [104.3], range = 125.2–549.8), almost half of the sites had less than 250 mg/kg. However, a third of the sites had more than 300 mg/Kg. For organic phosphorus (mean [SD] = 28.3[18.0], range = 5.8–86.3), more than half of the sites had less than 30 mg/kg, while less than a quarter had more than 40 mg/kg, while for inorganic phosphorus (mean [SD] = 20.9[14.1], range = 4.7–62.2) more than half of the sites had less than 20 mg/kg, while a third had more than 25 mg/kg. A consistent trend was found across the soil gradient which reveals that sum of bases and total phosphorus can vary on average more than five or six times, respectively, with the lowest values generally found in sites further from the Rio Branco (Fig. 2). Finally, for nitrate (mean [SD] = 2.3[2.1], range = 0.1–11.2), only a sixth of the sites had more than 5 ug/g, while for ammonium (mean [SD] = 42.3[23.6], range = 14.9–144.6), a quarter of the sites had more than 50 ug/g and for inorganic nitrogen (mean [SD] = 44.6[24.3], range = 16.2–147.1), a sixth of the sites had more than 60 ug/g. The proportion between nitrate and ammonium decreases from 0.056ug/g in Anavilhanas sites to 0.049ug/g in Jaú sites and surrounding areas closer to the Branco River.

As expected, the distance to Rio Branco (lm) was a strong driver for island soil fertility (mean [SD] = 112 [60], range = 5–195, $p < 0.05$; $R^2 = 0.57$) (Fig. 3).The distance to the Rio Branco explains over 30% of the variation in the availability of SB, ECEC, Na, Po, Pi, PT, and inorganic N, on the fluvial islands.

The first principal component explained ≅ 55% and the second component explained ≅ 14% of the total variance in soil properties of the fluvial islands (Fig. 4). Jaú sites had more variability (mean [SD] = 4.81 [5.44] – range 0.34 to 19.1), while sites from Anavilhanas varied between 0.1 to 10.21(mean [SD] = 5.005 [2.46] in the first principal component. Mobile rock derived elements were the soil factors that correlated the strongest with the first principal component (PC1), with their influence on the PCA loadings declining in the order SB > ECEC > Mg > Ca > Na > P_T. Aluminum was the dominant cation in the studied sites with magnesium being the second and calcium the third. Non-mobile total phosphorus and available organic P also followed mobile cations (Online Resource 2), which together with the silt of the islands could suggest the recent entry of elements in the islands closer to Rio Branco and the high weathering of other islands in Anavilhanas. Therefore, mobile elements account for most of the variation in island soil properties.

Discussion

There was large variation in soil fertility and physical properties observed along the fluvial islands investigated. However, the distance from the mouth of the Rio Branco was an important predictor of the amount of nutrients and the soil structure of the fluvial islands. Due to differences in temperature, pH and quantity of suspended sediments, the Rio Branco sediment-rich white water is not rapidly mixed in Rio Negro sediment-poor black water, resulting in a “plume” effect of the discharge of the white water over the Rio Negro (Simon et al. 2019). As the Rio Negro is a wide and a relatively slow river, the suspended nutrients are gradually deposited on the fluvial islands (Latrubesse and Stevaux 2015). Thus, islands closer to the mouth of the Rio Branco, have soils that are richer in nutrients, while islands further away from the mouth of the Rio Branco, have in average poorer soils.

In general, with increasing distance to the Rio Branco, island soils became less silty and contained less nutrients. Overall, soil nutrients such as sum of bases was highly variable along our sampled islands (ranging from 0.18 to 2.34 cmolc/kg), but in general soil nutrients (mean = 0.73 cmolc/kg) were lower compared to terra-firme forest soils in the Central Amazon basin standards (Quesada et al. 2012), and more fertile compared to typical igapó soils from Uatumã Reserve (Targhetta et al. 2015).

The variation in soil fertility is usually related to suspended sediments, but can also be associated with island age and elevation (Radambrasil 1978). Natural islands of Anavilhanas are systems that vary greatly in age, as these features have been forming over hundreds or even thousands of years (≅ 150–22.000), and their soils are still evolving (Cunha and Sawakushi 2017). Nutrient levels and soil physical conditions are inter-related; because both are affected by pedogenetic development and geology, but soils with older pedogenetic development are often less fertile (Quesada et al. 2010). The richer soil sites, above the area corresponding to the Jaú National Park had the largest variation in soil attributes. These sites are located in a different geomorphological region than Anavilhanas. While the Jaú National Park area has huge, muddy islands, the Anavilhanas area contains more compact and wider islands (Latrubesse and Stevaux 2015).

The high acidity recorded is a common feature in flooded environments (Barrios and Herrera 1994; Barbosa et al. 2019). Soil nutrient concentrations can be also directly related to low pH (Schroth et al. 2003; Hillel 2003), which negatively contributes to the availability of effective cation exchange capacity (ECEC). Because these soil factors occupy the colloid exchange sites in the soil, there is a preferential exclusion of cations (Ca, K, Na and Mg) (Hillel 2003; Aprile and Lorandi 2012). The proportion between exchangeable bases and exchangeable aluminium in a soil depends on the quality of parent material and its mineral assemblage (Quesada et al. 2010). Here, the aluminium is the main nutrient that is varying, which is likely due to that aluminum is one of the nutrients that remain as a product of weathering (as a sesquioxides) and it can also supply notably to soil effective cation exchange capacity (I_E) when the weathering of aluminium interlayered minerals is taking place (Thomas 1974). As surface charge density decreases, soils experience base cation leaching, and subsequently aluminium liberations from 1:1 minerals begin to control, with the hydrolysis of aluminium following a release of $H+$ to soil solution, which can lower the pH (Uehara and Gillman 1981).

Because of the annual flood pulse which causes trees to be under water for several months, fluvial island soils also display a scarcity of other nutrients such as nitrogen. However, nodulations in stems and adventitious roots have been recorded in several Amazonian flooded forest species (Parolin et al. 2004), which suggests the presence of nitrogen-fixing adaptations to overcome the scarcity of this nutrient in such habitats. Nutrient export to the floodplain is counteracted by aquatic macrophytes, and subsequently the process of decomposition of these plants during the terrestrial phase releases nutrients into the soil (Furch and Junk 1997). Species capacities to obtain nutrients, and their differential tolerance to flooding and soil acidity, can influence competitive ability and so determine the patterns of successful plant establishment in fluvial islands ecosystems (Piedade et al. 2005; Parolin and Wittmann 2010).

Edaphic variation is strongly related to the local geological matrix, its age of sedimentation and distance to the source of suspended sediments that originate the islands, highlighting the influence of the Rio Branco on soil nutrient availability. Most nutrients used here can be recommended for researchers to make quick assessments of the relationship between soil fertility and species composition of animals and plants. The results of this study can be used as a baseline to assess relationships involving edaphic factors and sediment inputs from Amazonian rivers, and their relationship with plant and animal species composition and turnover along a soil gradient.

Declarations

Funding

This study was funded by The Rufford Foundation (grant number 20754- 1 to GSFN) and Idea Wild.

Competing interests

The authors declare that they have no conflict of interest.

Ethics approval

This study was approved by the Chico Mendes Institute for Biodiversity Conservation (ICMBio)

(permit numbers 55180-1 and 59367-1).

Consent to participate

Not applicable

Consent for publication

Not applicable

Availability of data and material (data transparency)

All data produced from this study are provided in this manuscript.

Code availability (software application or custom code)

Not applicable

Author contributions

GDSN conducted field sampling. GDSFN, ASF and EG performed laboratory analysis. CAQ supported the study. GDSFN performed data analysis and was a major contributor in writing the manuscript. All authors read and approved the final manuscript.

Acknowledgments

We had the material support from the Thematic Laboratory of Soils and Plants (INPA) and Amazonian Mammal Research Group (GPMA) and the logistic support from ICMBio. We are very grateful to all laboratory technicians for instructions on soil analyses. GDSFN thanks the National Council for Scientific and Technological Development [130817/2016-3] and The National Institute of Amazonian Research in the context of the National Inst. of Science and Technology (INCT), in Ecology.

References

Abril G, Martinez J, Artigas L, Moreira-Turcq P, Benedetti M, Vidal L, Meziane T, Kim J, Bernardes M, Savoye N, Deborde J, Souza E, Albéric P, Landim Souza M, Roland F (2013) Amazon River carbon dioxide outgassing fuelled by wetlands Nature 505:395-398. https://doi.org/10.1038/nature12797

Aprile F, Lorandi R (2012) Evaluation of Cation Exchange Capacity (CEC) in Tropical Soils Using Four Different Analytical Methods, Journal of Agricultural Science 278:4-6. https://doi.org/10.5539/jas.v4n6p278

Anderson JM, Ingram JSI (1989) Tropical Soil Biology and Fertility. Soil Science 157-265. https://doi.org/10.1097/00010694-199404000-00012

Barbosa MVM, Fernandes TA, Siqueira GB, Siqueira FLT, Morais PB (2019) Spatial Variability of the Physicochemical Properties of Soils from Seasonally Flooded Forest Fragments on a Tropical Plain. Applied and Environmental Soil Science. https://doi.org/10.1155/2019/1814937

Barrios E, Herrera R (1994) Nitrogen cycling in a Venezuelan tropical seasonally flooded forest: soil nitrogen mineralization and nitrification. Journal of Tropical Ecology 10:399-416. https://doi.org/10.1017/s0266467400008075

Buendía C, Kleidon A, Manzoni S, Reu B, Porporato A (2018) Evaluating the effect of nutrient redistribution by animals on the phosphorus cycle of lowland Amazonia. Biogeosciences 15:279-295. https://doi.org/10.5194/bg-15-279-2018

Coley P, Bryant J, Chapin F (1985) Resource Availability and Plant Antiherbivore Defense. Science 230:895-899. https://doi.org/10.1126/science.230.4728.895

Cunha DFD, Sawakuchi AO (2017) Evolução sedimentar do Arquipélago de Anavilhanas no baixo Rio Negro, Amazônia Central

Flores BM, Holmgren M, Xu C, Van Nes EH, Jakovac CC, Mesquita RC, Scheffer M (2017) Floodplains as an Achilles heel of Amazonian forest resilience. Proceedings of the National Academy of Sciences 114:4442-4446. https://doi.org/10.1073/pnas.1617988114

Filizola N, Guyot JL, Wittmann Martinez H, Oliveira JM (2011) The significance of suspended sediment transport determination on the Amazonian hydrological scenario. Sediment transport in aquatic environments 45-64, 2011. https://doi.org/10.5772/19948

Furch K, Junk WJ (1997) Physicochemical conditions in the floodplain. The Central Amazonian Floodplain, Floodplain: Ecology of a Pulsing System. Ecological Studies Vol. 126, Springer, Berlin 69-108, 1997

Gee GW, Bauder JW (1986) Particle size analysis. Methods of soil analysis: Part 1 Physical and mineralogical methods. 5:383-411. https://doi.org/10.2136/sssabookser5.1.2ed.c15

Goulding M, Barthem RB, Ferreira EJG (2003) The Smithsonian Atlas of the Amazon. Smithsonian Institution, Washington, pp 253

Grau O, Peñuelas J, Ferry B, Freycon V, Blanc L, Desprez M, Guitet S (2017) Nutrient-cycling mechanisms other than the direct absorption from soil may control forest structure and dynamics in poor Amazonian soils. Scientific reports 45017:23-7. https://doi.org/10.1038/srep45017

Hillel D (2003) Introduction to environmental soil physics. Elsevier. https://doi.org/10.1016/b978-0-12-348655-4.x5000-x

Irion G, Junk WJ, Mello JASN (1997) The large central Amazonian river floodplains near and geomorphological aspects. In: Junk WJ (ed) The Central Amazon Floodplain: Ecology of a Pulsing System. Springer-Verlag, Berlin pp. 23–46. https://doi.org/10.1007/978-3-662-03416-3_2

Junk WJ, Bayley PB, Sparks RE (1989) The floodpulse concept in river-floodplain systems. Can. Spec. Publ. Fish. Aqu. Sci. 106, 110–127.

Junk WJ, Piedade MTF, Schongart J, Cohn-Haft M, Adeney JM, Wittmann F (2011) A classification of major naturally-occurring Amazonian lowland wetlands. Wetlands 31, 623–640. https://doi.org/10.1007/s13157-011-0190-7

Junk WJ (2013) The central Amazon floodplain: ecology of a pulsing system. Springer Science & Business Media. 126

Kalliola R, Salo J, Puhakka M, Rajasilta M (1991) New Site Formation and Colonizing Vegetation in Primary Succession on the Western Amazon Floodplains. The Journal of Ecology 877-901. https://doi.org/10.2307/2261087

Latrubesse EM, Stevaux JC (2015) The Anavilhanas and Mariuá Archipelagos: Fluvial Wonders from the Rio Negro, Amazon Basin. In: Vieira BC, Salgado AAR, Santos LJC. Landscapes and Landforms of Brazil. Dordrecht: Springer Netherlands 157-169. https://doi.org/10.1007/978-94-017-8023-0_14

Leenheer JA, Santos UDM (1980) Considerações sobre os processos de sedimentação na água preta ácida do Rio Negro (Amazônia Central). Acta Amazonica 10:343-357. https://doi.org/10.1590/1809-43921980102343

Macedo M, Castello L (2017) State of the Amazon: Freshwater connectivity and ecosystem health

Malhi Y, Baker T, Phillips O, Almeida S, Alvarez E, Arroyo L, Chave J, Czimczik C, Fiore A, Higuchi N, Killeen T, Laurance S, Laurance W, Lewis S, Montoya L, Monteagudo A, Neill D, Vargas P, Patino S, Pitman N, Quesada C, Salomao R, Silva J, Lezama A, Martinez R, Terborgh J, Vinceti B, Lloyd J (2004) The above-ground coarse wood productivity of 104 Neotropical forest plots. Global Change Biology 10, 563-591. https://doi.org/10.1111/j.1529-8817.2003.00778.x

Marengo JA, Espinoza JC (2016) Extreme seasonal droughts and floods in Amazonia: causes, trends and impacts. International Journal of Climatology 36, 1033-1050. https://doi.org/10.1002/joc.4420

Marinho RR, Filizola Jr, Cremon NP (2020) Analysis of Suspended Sediment in the Anavilhanas Archipelago, Rio Negro, Amazon Basin. Water 1073:4-12. https://doi.org/10.3390/w12041073

Mittelbach GG, Steiner CF, Scheiner SM, Gross KL, Reynolds HL, Waide RB, Willig MR, Dodson SI, Gough L (2001) What is the observed relationship between species richness and productivity? Ecology 82: 2381-2396. https://doi.org/10.1890/02-3128

Montero JC, Latrubesse EM (2013) The igapó of the Rio Negro in central Amazonia: linking late-successional inundation forest with fluvial geomorphology. Journal of South American Earth Sciences 46:137-149. https://doi.org/10.1016/j.jsames.2013.05.009

Montero JC, Piedade MTF, Wittmann F (2014) Floristic variation across 600 km of inundation forests (igapó) along the Rio Negro, Central Amazonia. Hydrobiologia 729, 229-246. https://doi.org/10.1007/s10750-012-1381-9

Murphy J, Riley J (1962) A modified single solution method for the determination of phosphate in natural waters. Analytica Chimica Acta 27, 31-36. https://doi.org/10.1016/s0003-2670(00)88444-5

Oksanen J (2013) Multivariate Analysis of Ecological Communities in R: Vegan Tutorial, http://vegan.r-forge.r-project.org

Olsen RS (1954) Estimation of available phosphorus in soils by extraction with sodium bicarbonate. US Dept. Agric. Stat, pp. 939

Osterkamp W (1998) Processes of fluvial island formation, with examples from Plum Creek, Colorado and Snake river, Idaho. Wetlands 18:530-545. https://doi.org/10.1007/bf03161670

Parolin PD, Simone O, Haase K, Waldhoff D, Rottenberger S, Kuhn U, Junk WJ, (2004) Central Amazonian floodplain forests: tree adaptations in a pulsing system. The Botanical Review 70:357-380. https://doi.org/10.1663/0006-8101(2004)070[0357:caffta]2.0.co;2

Parolin P, Wittmann F (2010) Struggle in the flood: tree responses to flooding stress in four tropical floodplain systems. AoB Plants. https://doi.org/10.1093/aobpla/plq003

Piedade MTF, Junk WJ, Adis J, Parolin P (2005) Ecologia, zonação e colonização da vegetação arbórea das Ilhas Anavilhanas. Pesquisas, Botânica. 56, 117-143

Pleysier JL, Juo ASR (1980) A single-extraction method using silver-thiourea for measuring exchangeable cations and effective CEC in soils with variable charges. Soil Science 129:205–211. https://doi.org/10.1097/00010694-198004000-00002

Prance G (1979) Notes on the Vegetation of Amazonia III. The Terminology of Amazonian Forest Types Subject to Inundation. Brittonia. 31:26-38. https://doi.org/10.2307/2806669

Quesada C, Lloyd J, Schwarz M, Patiño S, Baker T, Czimczik C, Fyllas N, Martinelli L, Nardoto G, Schmerler J, Santos A, Hodnett M, Herrera R, Luizão F, Arneth A, Lloyd G, Dezzeo N, Hilke I, Kuhlmann I, Raessler M, Brand W, Geilmann H, Moraes Filho J, Carvalho F, Araujo Filho R, Chaves J, Cruz Junior O, Pimentel T, Paiva R (2010) Variations in chemical and physical properties of Amazon forest soils in relation to their genesis. Biogeosciences 7:1515-1541. https://doi.org/10.5194/soil-6-53-2020

Quesada CA, Lloyd J, Anderson LO, Fyllas NM, Schwarz M, Czimczik CI (2011) Soils of Amazonia with particular reference to the RAINFOR sites. Biogeosciences 8:1415-1440. https://doi.org/10.5194/bg-8-1415-2011

Quesada CA, Phillips OL, Schwarz M, Czimczik CI, Baker TR, Patiño S, Fyllas NM, Hodnett MG, Herrera Almeida R (2012) Basin-wide variations in Amazon forest structure and function are mediated by both soils and climate. Biogeosciences 9:2203-2246. https://doi.org/10.5194/soil-6-53-2020

Radambrasil (1978) Levantamento dos Recursos Naturais, Ministério das minas e energia, Departamento nacional da produção mineral. Folha SA-20 Manaus. DNPM/Projeto Radambrasil, Rio de Janeiro, Rio de Janeiro, Brazil

R Core Team (2019) R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org

Scabin AB, Costa FRC, Schöngart J (2012) The spatial distribution of illegal logging in the Anavilhanas archipelago (Central Amazonia) and logging impacts on species. Environmental conservation 39:111–121. https://doi.org/10.1017/s0376892911000610

Schroth G, Lehmann J, Barrios E (2003) Soil nutrient availability and acidity. Trees, crops and soil fertility: concepts and research methods. CABI, Wallingford pp. 93-130. https://doi.org/10.1079/9780851995939.0093

Simon C, Osterholz H, Koschinsky A, Dittmar T (2019) Riverine mixing at the molecular scale–An ultrahigh-resolution mass spectrometry study on dissolved organic matter and selected metals in the Amazon confluence zone (Manaus, Brazil). Organic Geochemistry 129:45-62. https://doi.org/10.1016/j.orggeochem.2019.01.013

Souza Filho PWM, Paradella WR, Souza Jr, Valeriano C, Miranda FP (2006) Sensoriamento Remoto e recursos naturais da Amazônia. Ciência e Cultura. 58, 37-41

Targhetta N, Kesselmeier J, Wittmann F (2015) Effects of the hydroedaphic gradient on tree species composition and aboveground wood biomass of oligotrophic forest ecosystems in the central Amazon basin. Folia Geobotanica 50:185-205. https://doi.org/10.1007/s12224-015-9225-9

Thomas MF (1974) Tropical Geomorphology. The McMillan Press, London. 331

Uehara, G. and Gilman, G (1981) The Mineralogy, Chemistry, and Physics of Tropical Soils with Variable Charge Clays, Westview Press, Boulder, Colorado. https://doi.org/10.1097/00010694-198504000-00019

Vitousek PM (1984) Litterfall, nutrient cycling, and nutrient limitation in tropical forests. Ecology 65, 285-298. https://doi.org/10.2307/1939481

Figures

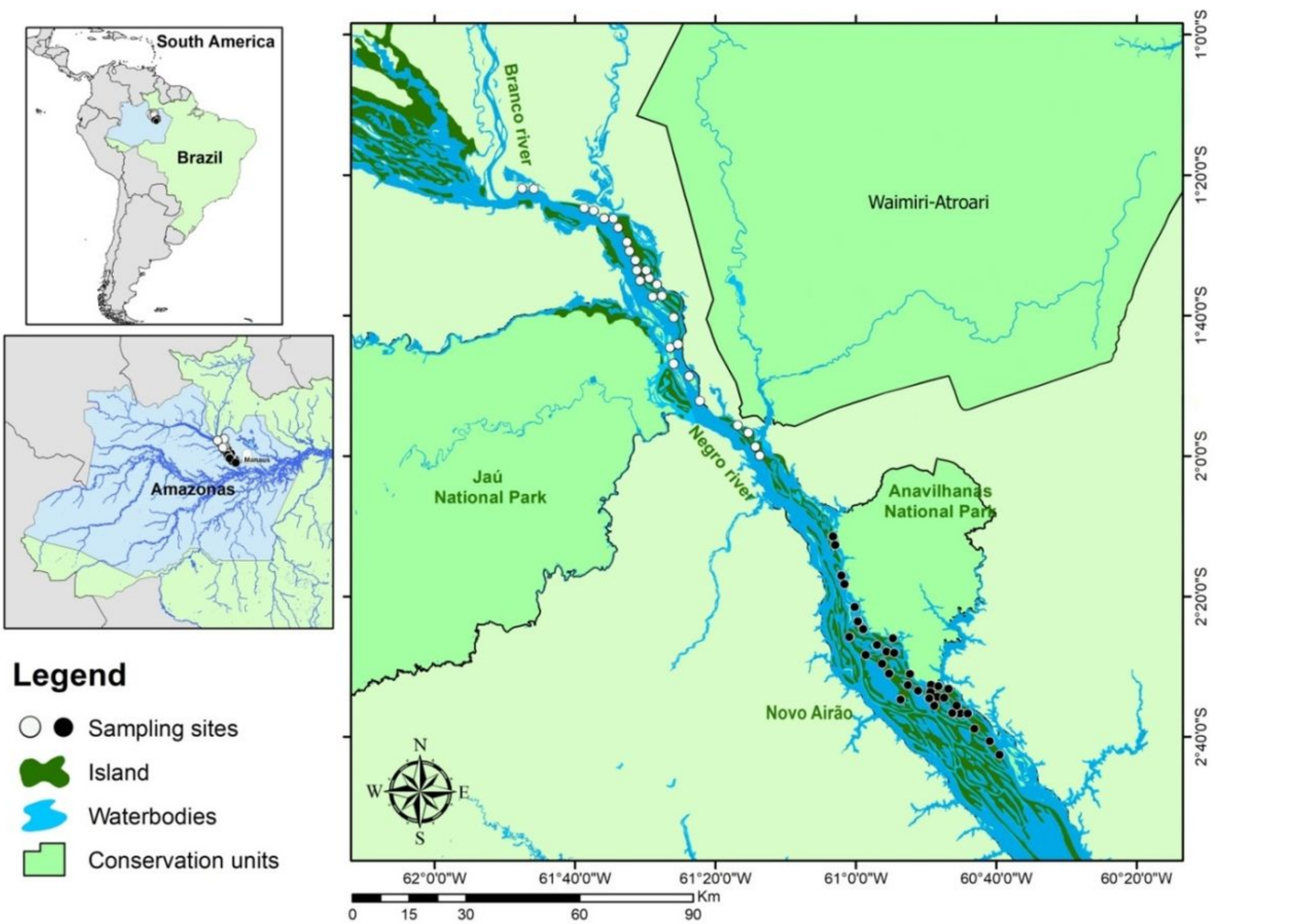

Figure 1

Map of fluvial island study sites. White dots indicate sites closer to the Rio Branco, black ones indicate more distant sites, where the soil chemical and physical attributes were collected.

A)

B)

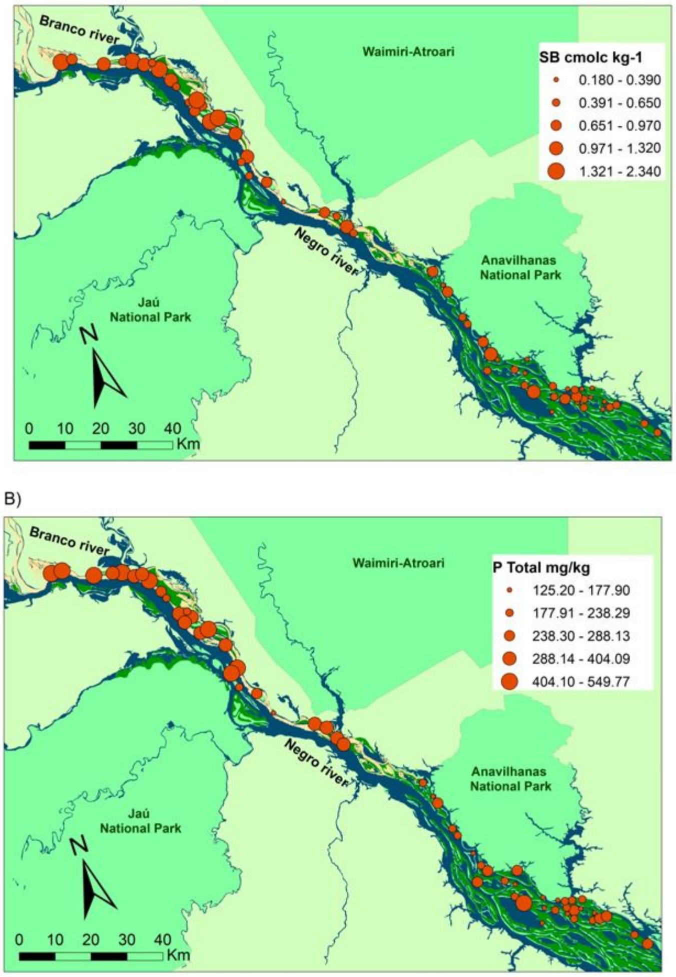

Figure 2

Distribution of soil properties across an Amazonian archipelago. A) Sum of bases; B) total phosphorus. Size of points represent soil concentration.

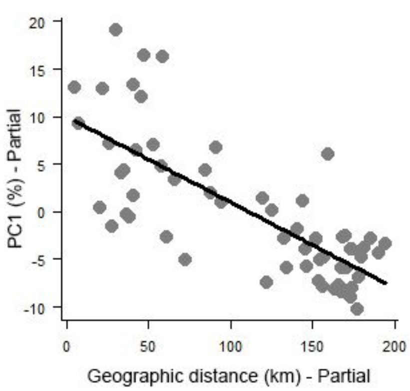

Figure 3

Relationship between the geographic distance from the Rio Branco and soil chemical and physical variables.

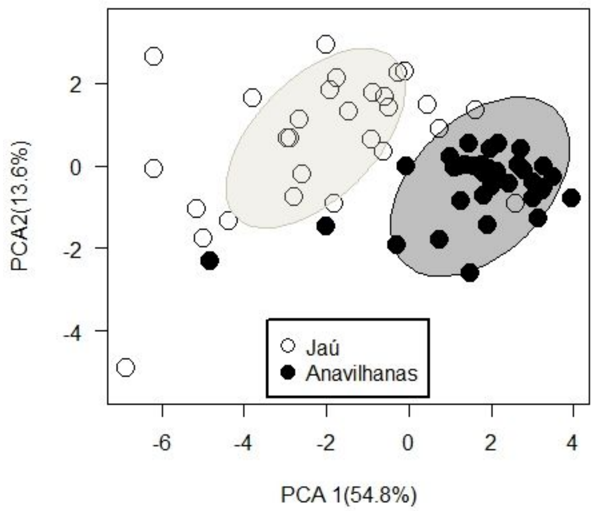

Figure 4

PCA of soil nutrients of Anavilhanas and Jaú fluvial islands. The Ellipses assume a multivariate normal distribution with the confidence interval of 95%, representing the Euclidean distance from the center group. Ellipses show clustering of the samples according to the river type.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- attachmenttomanuscript.docx