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VEGETABLE COVERAGE, ANTHROPOGENIC ACTION, AND PALEOCLIMATES IN THE CAATINGA

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Abstract

The Caatinga is dominated by a semiarid climate and a high plant biodiversity dealing with anthropogenic disturbance and climate change. Previous studies suggest that Caatinga became a completely soil-water pulse-dominated forest in response to reduced water availability at the end of the last ice age, around 10 cal kyr BP. This work aimed to identify vegetative and climatic evolution, and the human influence in the Cariri region, one of the driest parts of Brazil. We sampled soil in a temporal pond to identify pollen. The testimony is 170 cm in lenght and achieves 6,216 cal yr BP at the base. Pollen analysis indicates the presence of taxa representative of humid climates, between 6,216 and ca. 5000 cal yr BP, like Azolla, followed by implantation of Caatinga's modern configuration from ca. 4,900 cal yrs BP. After 2,700 cal yr BP, humid episodes occurred, possibly related to the El Niño - La Niña variation across the region, marked by increased algae and aquatic herbs concentrations. The occurrence of human activity species like Caryocar, Dioscorea, Spondias, and Licania suggest possibly landscape manipulation by pre – Columbian populations, and exotic Pinus and Prosopis reveal changes in the tree cover caused by European colonization in the Caatinga.

Keywords: Anthropocene; Dry Forest; Paleogeography; Semiarid Region; Sedimentology, Lakes, Lagoons & Swamps.

Resumo / Resumen

COBERTURA VEGETAL, AÇÃO ANTROPOGÊNICA E PALEOCLIMAS NA CAATINGA

A Caatinga é dominada por um clima semiárido e uma alta biodiversidade vegetal que lida com distúrbios antrópicos e mudanças climáticas. Estudos anteriores sugerem que a Caatinga se tornou uma floresta totalmente dominada pelo pulso de água do solo em resposta à redução da disponibilidade de água no final da última era glacial, por volta de 10 cal kyr AP. Este trabalho teve como objetivo identificar a evolução vegetativa, climática e a influência antrópica na região do Cariri, uma das regiões mais secas do Brasil. Amostramos o solo em uma lagoa temporal para identificar o pólen. O testemunho tem 170 cm de comprimento e atinge 6.216 anos cal BP na base. A análise polínica indica a presença de táxons representativos de climas úmidos, entre 6.216 e ca. 5000 anos cal AP, como Azolla, seguido pela implantação da configuração moderna da Caatinga de ca. 4.900 anos cal BP. Após 2.700 anos cal AP, ocorreram episódios úmidos, possivelmente relacionados à variação El Niño - La Niña na região, marcados pelo aumento da concentração de algas e ervas aquáticas. A ocorrência de espécies de atividade humana como Caryocar, Dioscorea, Spondias e Licania sugerem possivelmente manipulação da paisagem por populações pré-colombianas, e as exóticas Pinus e Prosopis revelam mudanças na cobertura arbórea causadas pela colonização européia na Caatinga.

Palavras-chave: Antropoceno; Floresta Seca; Paleogeografia; Região Semiárida; Sedimentologia, Lagos, Lagoas e Pântanos.

COBERTURA VEGETAL, ACCIÓN ANTROPOGÉNICA Y PALEOCLIMA EN LA CAATINGA

La Caatinga está dominada por un clima semiárido y una alta biodiversidad vegetal que se enfrenta a la perturbación antropogénica y al cambio climático. Estudios previos sugieren que Caatinga se convirtió en un bosque completamente dominado por pulsos de suelo y agua en respuesta a la disponibilidad reducida de agua al final de la última edad de hielo, alrededor de 10 cal kyr BP. Este trabajo tuvo como objetivo identificar la evolución vegetativa y climática, y la influencia humana en la región de Cariri, una de las partes más secas de Brasil. Tomamos muestras del suelo en un estanque temporal para identificar el polen. El testimonio mide 170 cm de largo y alcanza 6.216 cal año BP en la base. El análisis de polen indica la presencia de taxones representativos de climas húmedos, entre 6.216 y ca. 5000 cal año AP, como Azolla, seguido de implantación de la configuración moderna de Caatinga desde ca. 4.900 años cal BP. Después de 2700 años calóricos AP, ocurrieron episodios húmedos, posiblemente relacionados con la variación de El Niño - La Niña en la región, marcados por un aumento de las concentraciones de algas y hierbas acuáticas. La presencia de especies de actividad humana como Caryocar, Dioscorea, Spondias y Licania sugieren una posible manipulación del paisaje por parte de las poblaciones precolombinas, y las exóticas Pinus y Prosopis revelan cambios en la cobertura arbórea causados por la colonización europea en la Caatinga.

Palabras-clave: Antropoceno; Bosque seco; Paleogeografía; Región Semiárida; Sedimentología, Lagos, Lagunas y Pantanos.

INTRODUCTION

Understanding the evolution of vegetation over time is a key factor in predicting landscape dynamics in response to future climate changes (WERNECK et al., 2011). Ecosystems are constantly subject to change, both from natural and anthropogenic causes, and, therefore, this dynamic must be analyzed to develop conservation strategies to avert current climate changes (HANNAH et al., 2002; IPCC, 2019, 2022).

The Caatinga covers 11% of the Brazilian territory (844,453 km2) and is also home to 26 million people (IBGE, 2010). It is considered the largest seasonally dry forest ecosystem in the neotropics, composed of xeric shrubs, dry forests, and deciduous forests. All these vegetation types cover depressions, plateaus, and highlands, with diverse mosaics (SILVA; SOUZA, 2018). It has 3,347 plant species, 962 genera, and 153 recognized families, of which 526 species and 29 genera are endemic (FERNANDES, CARDOSO; QUEIROZ, , 2020). The presence of species initially described in Amazon and Atlantic rainforests in elevated plateaus of Caatinga, above 700 meters, suggests a potential biotic corridor which connected the two rainforests in the past (BEHLING et al., 2000; SOUZA, et al., 2022; WANG et al., 2004). The retraction of Northern Hemisphere ice sheets and northern sea-ice cover caused a northward shift in the Intertropical Convergence Zone position, which induced dry conditions after the end of the last ice age after 10 cal kyr BP (LEDRU; MOURGUIART; RICCOMINI, 2009; LEDRU et al., 1996; PRADO et al., 2013; WERNECK et al., 2011).

Humans migrated along South America about 15,500 yr BP (CRAMON-TAUBADEL et al., 2015). They produced evidence of occupation in several biomes, such as the Amazonia rainforest (FRANCO-MORAES et al., 2019), Atlantic rainforest (Araujo et al., 2017), Brazilian savanna (SOUZA et al., 2016), pampas region (DUBOIS; POLITIS, 2017) and dry forest (SOUZA et al., 2020). Pre-Columbian peoples may usage many species for food, medicinal, and fire uses, such as Astronium, Caryocar, Cordia, Dioscorea, Licania, Mimosa, Myracrodruon, Passiflora, Solanum, Spondias, Sida, and Tabebuia (ANDRADE et al., 2019; LUCENA et al., 2017; MENEZES et al., 2021).

Atmospheric circulation changes in this part of Brazil reflects Intertropical Convergence Zone migration, as well as atmospheric circulation changes in other tropical areas worldwide (WANG et al., 2004, 2006). Consequently, this part of Brazil is fundamental as a reference in paleoclimate studies in intertropical zone. However, the paleoenvironmental history of the Caatinga Quaternary is poorly known. This lack of information is mainly due to the lack of favorable environments for the preservation of palynomorphs, due to the hot and dry climate. Besides, predominance of erosive processes instead of depositional ones reduces the abundance of registers (MABESOONE; LOBO, 1980).

Among the studies carried out in the region, sediments found in the Catimbau Valley, in the state of Pernambuco, revealed the occurrence of tree taxa adapted to high humidity between 10,000 and 6,000 cal yr BP, followed by a gradual tendency towards dry conditions (MEDEIROS et al., 2018). In the Icatu River Valley, in continuous sediments with 11,000 cal yr BP, the predominance of taxa adapted to tropical rainforests in the Pleistocene/Holocene transition was observed, with a gradual decrease in humidity until the Middle Holocene, when a semiarid climate was established at ca. 4,500 cal yr BP (OLIVEIRA et al., 1999).

Marine sediments deposited in the Jaguaribe River Delta, 90 km off the coast of the state of Ceará noticed a decrease in Hedyosmum and Cyathea pollen around 8,500 cal yr BP (BEHLING et al., 2000). Studies conducted in elevated regions of the Caatinga in Ceará, Piauí, and Paraíba (MONTADE et al., 2014; PESSENDA et al., 2010) revealed the return of humid conditions from approximately 3,200 cal yr BP. Geochemical analyzes conducted in the Caatinga region support this climatic variations, with humidity at the beginning of the Holocene, followed by a dry phase starting at ca. 4,500 yr BP, with a period of torrential rains ca. 2,000 yr BP (CRUZ et al., 2009; MENDES, 2016; NACE et al., 2014; NOVELLO et al., 2012). These climate changes were linked to the sea surface temperature and atmospheric circulation that influenced the Intertropical Convergence Zone and the El Niño – La Niña phenomenon (CHENG et al., 2013).

Despite the data and the large area that Caatinga occupies in the country, this ecosystem has the lowest scientific information in Brazil (SANTOS et al., 2011; WERNECK et al., 2011). Therefore, significant gaps need to be filled in this area of knowledge. In this study, we analyzed soil samples to identify palynological records to describe the influence of the middle Holocene climate and

anthropogenic intervention on vegetation structure. We hypothesize that the lagoons represent essential records of recent paleoclimate evolution and human activities in Brazilain semiarid.

MATERIAL AND METHODS

STUDY AREA

Climate is equatorial tropical semiarid, with 6 to 11 dry months (KAYANO; ANDREOLI, 2009). Annual precipitation varies between 300 and 800 mm and mean monthly temperature are always above 22 °C. The region is subject to the influence of subtropical high- pressure areas linked to the semi-permanent South Atlantic anticyclone, which is in turn influenced by the Hadley (meridional) and Walker (zonal) circulations(GUERREIRO et al., 2013). This produces a rainfall regime that depends on geographical position once humidity carried out by oceanic mass is barred by the highlands (LUCENA et al., 2022).

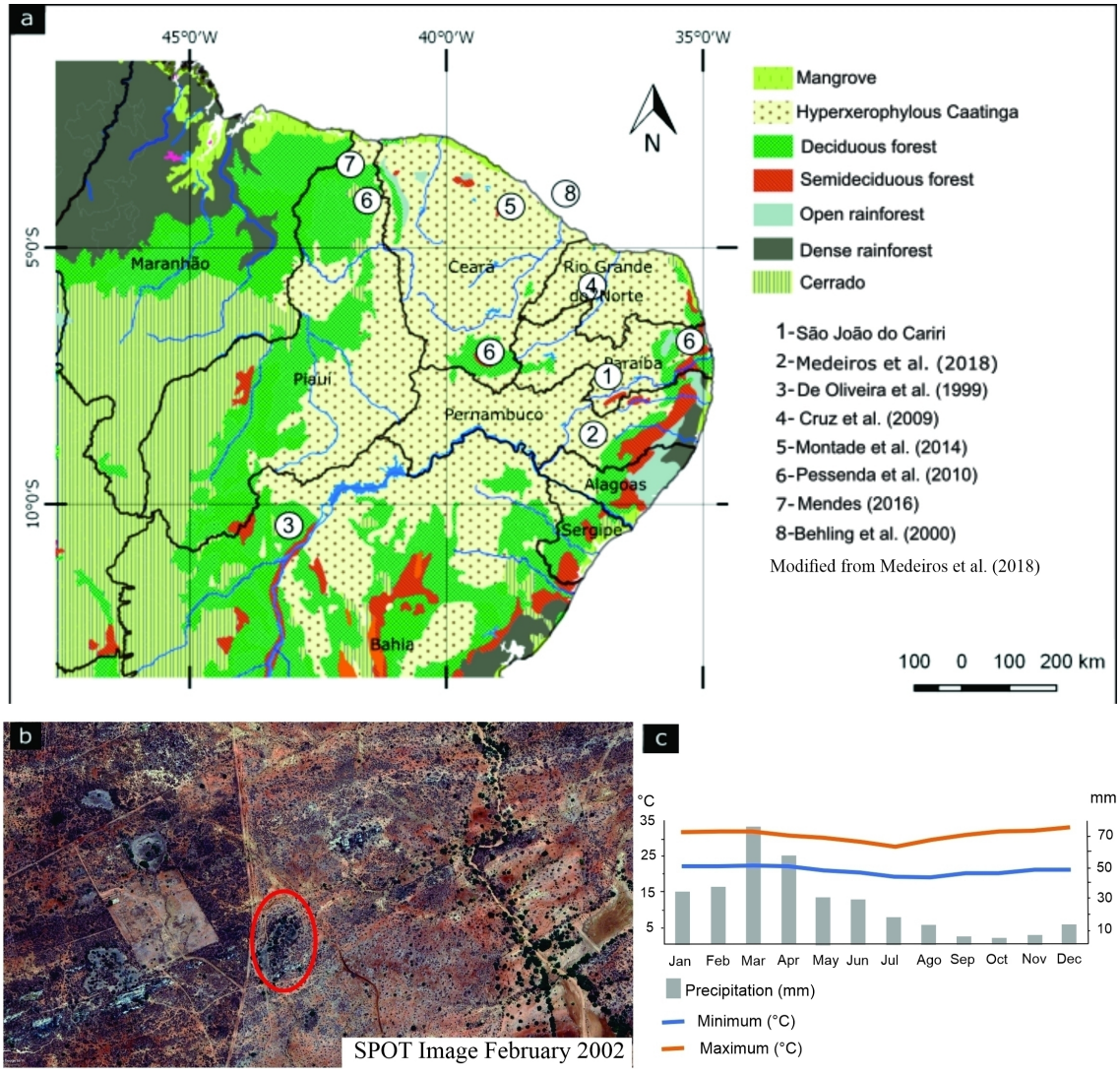

Figure 1 - Distribution of study area and previous studies according to vegetable cover (a), satellite image (b) and ombrothermic diagram (c) of the study area.

The altitude varies between 300, in pediment surfaces on Proterozoic gneiss and schists, and 1,100 m, highlands, cliffs and inselbergs associated with resistant rocks and horst–graben systems

(XAVIER et al., 2016). The vegetable cover has large endemic biodiversity (APG, 2016; COSTA; PERALTA, 2015; MAIA et al., 2015). Shrubs, 3-9 m height-trees that shed their leaves seasonally, cacti and arid-adapted grasses partially cover the soil (PRADO, 2000; SANTOS et al., 2012). Weathering and leaching are incipient, and the soil is intensively eroded during the four rainy months. Luvisols (40.9 % of the total area), Leptosols (35.6 %) and Regosols (3.9 %) dominates the study area (ARAÚJO FILHO et al., 2017). These soils are dominantly loamy, shallow (

The analyzes were carried out on sediments collected in a temporary lagoon located in the municipality of São João do Cariri, state of Paraíba, in the driest portion of Brazil at coordinates 7º 22' 24.72"S and 36º 31' 40.32"W (Figure 1). The average annual rainfall is 399 mm, and the average temperature is 23.2 °C. The dry seasonal mean rainfall is 10 mm.

Erythrina velutina and the exotic tree Prosopis juliflora cover the sediments accumulated in the studied lagoon. The vegetation surrounding this area is typical of the Caatinga and shaped by humans by centuries of wood removal, agriculture, and livestock (cattle, sheep, and mainly goats). Pioneer species dominated the surrounding area, such as Aspidosperma pyrifolium, Pilosocereus gounellei, Croton sonderianus, and Jatropha mollissima (PAES-SILVA et al., 2003; SILVA et al., 2019).

SAMPLING AND ANALYSIS

The sediment collection was carried out in a trench dug 1.5 x 1.5 m wide and 1.70 m deep in a periodically flooded lagoon until the outcrop of fresh rock. Sediments were described and sampled in situ, with intervals of 5 cm. Aliquots were extracted from samples at the Micropaleontology Laboratory of the University of São Paulo.

Samples of 1 cm^3 were submitted to the standard techniques of preparation for pollen analyses of Quaternary sediments (COLINVAUX et al., 1999), using HF to silicates removal, acetolysis reaction, and addition of one tablet of spores of Lycopodium clavatum (exotic marker) for calculating the pollen concentration (STOCKMARR, 1971). Pollen grains, spores, and other palynomorphs were identified, described, and counted with an optical microscope with a digital image capture system. The charred microparticles were counted in different sizes, above and below 100 µm. Crumpled, torn, or broken grains were identified as damaged pollen grains. The analyzes were performed under 600x and 1000x magnifications. The pollen types were identified according to the reference collection of the Laboratory of Micropaleontology and literature (COLINVAUX et al., 1999; LORENTE et al., 2017; OLIVEIRA, 1992; ROUBIK; MORENO, 1991; SALGADO-LABORIAU, 1973). The counts were performed up to a minimum of 300 pollen grains or 200 or 100 grains for samples with low palynomorph preservation.

After identification and morphological description, the taxa were quantified and treated statistically by the programs TILIA and TILIA GRAPH (GRIMM; TROOSTHEIDE, 1994). The zoning of the palynological profile was carried out using a similarity dendrogram by CONISS program (GRIMM, 1987). Diagrams were also performed using TILIA and TILIA GRAPH (GRIMM; TROOSTHEIDE, 1994). The percentage was calculated for pollen grains and other palynomorphs through separate sums.

Radiocarbon isotopes were determined in soil samples collected at 5-cm intervals. Samples were dried at 60 °C to constant weight, and root and plant remains were discarded by handpicking. The remaining plant debris were removed by flotation in 0.01 mol L-1 HCl, and then samples were dried and sieved. The particles which are finer than 0.210 mm were used for 13C enrichment (δ13C), total organic carbon (TOC), total nitrogen (TN), and C/N determination with a continuous flow isotope ratio mass spectrometer at the at Carbon 14 Laboratory of the Center for Nuclear Energy in Agriculture (São Paulo, Universidade de São Paulo). The δ13C results are expressed concerning the VPDB standard using the conventional δ (‰) notations. Analytical precision is ±0.15‰. The δ13C, TOC, TN, and C/N express environmental changes during sediment deposition. The photosynthesis process can be identified by δ13C (MONTADE et al., 2014; PESSENDA et al., 2010); values close to −32‰ indicate a photosynthetic process of type C3. Enriched δ13C values represent grassland vegetation and reflect the significant presence of C4 plants. Variations above 4‰ of δ13C in the same soil profile indicate changes in the plant community. High TOC and TN values are related to anaerobic conditions, which favor organic compound accumulation (MOREIRA et al., 2013). On the other hand, low TOC and TN values indicate oxidation and decomposition of organic matter. The C/N ratio expresses the polymerization of

organic compounds (GRÜNEBERG et al., 2014). Low C/N ratio values indicate the accumulation of predominantly light organic matter from weakly-decomposed vegetal residues (MARTINS et al., 2011) and suggest that accumulation of organic residues is a recent process (FALLOON; SMITH, 2000; TADINI et al., 2018).

Organic carbon was dated by 14C method in four samples (BETA 462506, BETA 513367, BETA 513368, and BETA 583927) at the Beta Analytic Laboratory using the accelerator mass spectrometry technique. The samples were chosen according to high isotopic C variation ($\delta 13C \geq 4‰$) and/or palynological data. Samples were physically pretreated to remotion of vegetal fragments, insects, etc. After that, non-hydrolysable carbon (NHC) was isolated with two h treatments with HCl 1.0 mol L^{-1} at 90 °C, until the supernatant was clear or up to 5 times. The age model was defined using the rBacon Package (BLAAUW; CHRISTEN, 2011), with a 95% probability, and calibrations were defined using SHCAL13 curve (HOGG et al., 2013). The rBacon Package age model is an approach to age-depth modeling that uses Bayesian statistics to reconstruct accumulation histories for deposits by combining radiocarbon and other dates with prior information. Radiocarbon age is reported as 14C cal yr BP (Before AD 1950).

RESULTS

The profile sampled had 170 cm of brown clayey sand sediments, with radiocarbon ages between 6,216 to 703 cal yr BP, from the Middle Holocene (Table 1). These results indicate very slow sedimentation rates, with the peak of 0.08 cm/yr between 1,615 and 1,215 cal yr BP while the minimum was 0.016 cm/yr between 6,216 and 2,789 cal yr BP and 1,215 cal yr BP and the present.

Depth (cm)	Age C	Calibrated age (cal yr BP)
20	820 ± 30	703
55	1,770 ± 30	1,615
115	2,660 ± 30	2,789
170	5,600 ± 30	6,216

Table 1 - Radiocarbon ages of soil profile according to depth.

Three pollen zones were divided into (Figure 2): BES A, between 170 and 115 cm depth and 6,216 to 2,789 cal yr BP; BES B, between 115 and 55 cm depth and 2,789 to 1,615 cal yr BP, and BES C, between 55 to 0 cm depth and 1,615 cal yr BP to present. Terrestrial herbs composed 65 to 82% of pollen sum in the first zone (170 – 115cm; 6,216 to 2,789 cal yr BP), with up to 2,700 grains/cm^3. Arboreal species represented less than 20% of pollen sum and 1,013 grains/cm^3, and aquatic herbs represented up to 23% of pollen sum and 1,135 grains/cm^3. Damaged grains vary between 40% to 60% of pollen sum considering all pollen grains and reach 2,500/cm3, while carbonized microscopic particles reached 20,500/cm^3. Casearia, Chomelia, Mimosa, Moraceae, Myracrodruon, and Piptadenia are the most frequent arboreal specimens, and the most representative was Mimosa with 6,5%. Araceae and Poaceae are the most frequent terrestrial herbs, with a peak of approximately 40%, and Dioscorea (a species of human interest) appears with 5%. The aquatic herb registered were Azolla (0,8% at 170 cm depth - 4,6% at 115 cm depth- 1% at 55 cm depth), Cyperaceae (15% -2% -12%), and Spathiphyllum (0%-1%). The main aquatic herbs are Zygnema (up to 1.150 zygospores/cm^3) and Brotryococcus (622 zygospores/cm^3).

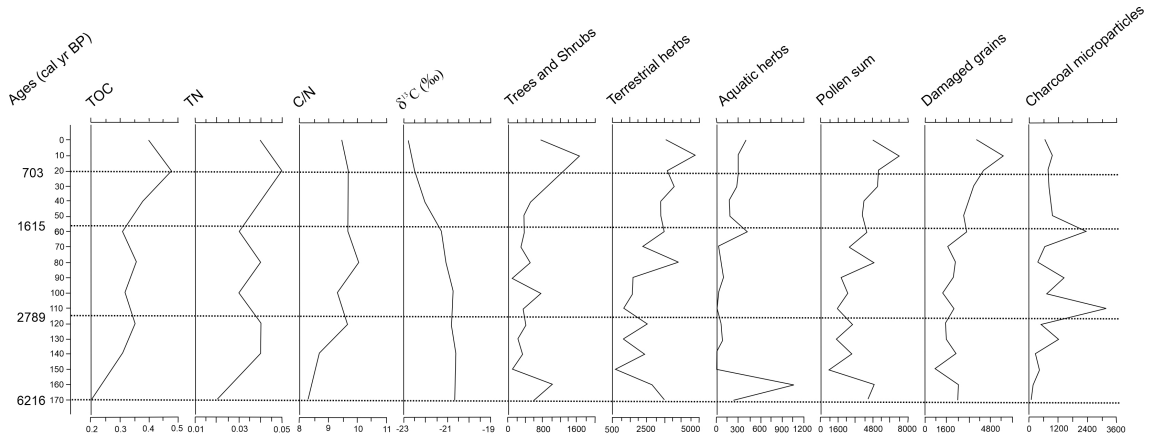

Figure 2 - Isotope diagram results, with concentration of pollen categories, pollen sum and charcoal microparticles.

In the second zone (115 – 55 cm; 2,789 to 1,615 cal yr BP), terrestrial herbs started with 75%, decreased to 57%, increased to 92%, and ended with 79%, with a peak of 4,000 grains/cm³. Arboreal species decreased from 30 to 5% at the end of the zone and registered up to 735 grains/cm³. Aquatic herbs varied between 2% and 12% and registered up to 487 grains/cm³. Between the palynomorphs, algae were predominant and decreased from 96 to 70%, with up to 2,221 zygospores/cm³. Damaged grains were 2,186/cm³ and up to 3,086/cm³, while carbonized microscopic particles registered the highest values at the beginning of the zone, with 41,785/cm³ followed by the decrease to 7,831/cm³ and the increase to 38,772/cm² at the end of the zone. Alchornea, Anacardiaceae, Astronium, Mimosoideae, Moraceae, Passifloraceae, Piptadenia, Rubiaceae, and Tabebuia are the most frequent arboreal specimens. Araceae, Asteraceae, and Poaceae are the most frequent terrestrial herbs, and Dioscorea appears again. Cyperaceae is the predominant aquatic herb, while Zygnema is the main algae, with a peak of 60%. In the third zone (55 - 0 cm; 1,615 to present), terrestrial herbs composed 69% to 85%, with up to 4,497 grains/cm³. Arboreal species varied between 9% to 24% and 15%, with up to 1,639 grains/cm³. Aquatic herbs represented less than 15%, while algae represented 85% between the palynomorphs, with up to 2,732 zygospores/cm³. Damaged grains varied between 2,905 to 5,778 to 3,816/cm³ while carbonized microscopic particles peaked at 35,293/cm and at the end of the zone decreased to 13,170/cm³. Alchornea, Astronium, Mimosa, Moraceae, Myracrodruon, Odontadenia, and Piptadenia are the most frequent arboreal specimens. Pinus and Prosopis, both exotic species, occur in this zone. Araceae (10%), Asteraceae (20% - 5%), and Poaceae (40% - 30% - 50%) are the most frequent terrestrial herbs. Cyperaceae (with an average of 10%) is the most frequent aquatic herb registered. Botryococcus (10% - 50% - 30%) and Zygnema (65% - 35% - 55%) are the main algae.

TOC was low along of the profile, below 0.5%, as well as the TN that was constantly less than 0.05% (Figure 2). δ13C values varied between -20 and -23‰ and suggest a photosynthetic process of type C3. C/N ratio, ranging from 10 to 8.7, indicates that the organic matter comes from aquatic herbs and/or algae.

DISCUSSION

The minimum sedimentation rate of 0,016 cm/yr between 6,216 and 2,789 correlates with the low-humidity of the Middle Holocene, observed for the Caatinga ecosystem from ca. 4,500 cal yr BP.

Terrestrial herbs dominated the records from the Middle Holocene, with a constant distribution throughout the profile. However, concentration rates reveal changes in vegetation physiognomy, sometimes with forest expansion, sometimes with retraction. These changes are also perceived in the variation in the representativeness of the shrub elements along with the profile and can be attributed to the climatic changes that occurred in Northeast Brazil during the Holocene (BARRETO, 2010; CRUZ et al., 2009; NACE et al., 2014; OLIVEIRA et al., 1999).

Palynological analyses indicate more humid conditions than the current one between 6,200 and 5,500 cal yr BP as well as registered in previous studies in karst regions (CRUZ et al., 2009; OLIVEIRA et al., 1999). Trees and shrubs such as Mimosa, Moraceae, Peltogyne, Sapium, and Sloanea have a wide distribution in South America ("Reflora - Virtual Herbarium", 2018). Besides, Arecaceae is typical of humid environments and Caryocar is commonly associated to the Brazilian Savanna (LORENZI, 1992). The occurrence of aquatic herbs, algae, depleted δ13C, and the lowest concentration of carbonized microparticles reinforce the indication of a more humid climate (TOLONEN, 1986). The presence of vegetation adapted to humidity in pollen data reinforces the hypothesis of the previous existence of a biotic corridor between the Amazon and the Atlantic Forest through the Caatinga during the last glaciation (BEHLING et al., 2000; LEDO; COLLI, 2017; OLIVEIRA et al., 1999).

Moisture loss is notable from 4,900 cal yr BP to the present, as observed by previous studies from Northeastern Brazil (CHENG et al., 2013; CRUZ et al., 2009; MENDES, 2016; NACE et al., 2014; OLIVEIRA et al., 1999). The dry forest expansion is marked by the presence of Licania (Oiticica), native to the region (BELTRÃO; OLIVEIRA, 2007), and Anacardiaceae, a family that has a native and endemic species (Apterokarpos) of this ecosystem ("Reflora - Virtual Herbarium", 2018). This moisture loss is indicated by a decline in the concentration data of all elements, associated with an increase in the amount of carbonized microparticles greater than 100 m, indicative of local fires (TOLONEN, 1986).

Moist conditions returned to the region after 2,100 cal yr BP, when terrestrial and aquatic herbs, pteridophytes, and algae increased. This wet period can be associated with the influence of the El Niño-La Niña variation (NOVELLO et al., 2012), which is responsible for prolonged droughts and above-average rainfall in the Brazilian semiarid region, respectively (CRUZ et al., 2009; NOVELLO et al., 2012). The oscillation between torrential rains followed by extreme droughts, with intervals of 2 to 4 years, is responsible for the presence of damaged grains, increasing their concentration, even with the highest incidence of broken grains. This high incidence of broken grains, seen throughout the profile, is directly related to the sub-aerial exposure of this material during dry events and its redeposition during wet events (CAMPBELL, 1991).

Abrupt climatic oscillations cease at approximately 1,615 cal yr BP. Palynological records evidence a vegetational stabilization, and an increase in the number of tree elements begins, reaching its highest peak, with 1,639 grains/ cm^3, approximately at 293 cal yr BP. The impoverishment of δ13C and the increase in the rate of TOC and TN in this period reinforce a dominance of herbaceous aquatic and algae elements. The total carbonized microparticles (including the two size ranges) also were more abundant, while the concentration of particles greater than 100 m decreased, indicating the occurrence of regional fires.

The pollen grains of Pinus and Prosopis, exotic elements of the Caatinga, identified in the pollen record dated from ca. 800 cal yr BP, indicate anthropization in the study area. However, the presence of these taxa in this period is attributed to bioturbation and/or cracks in the soil formed during periods of drought. These processes could rework the pollen grains in sediments of previous facies. Introduction of Pinus and Prosopis in Caatinga firstly occurred in 1942, for foraging purposes. Later, they were dispersed by commercial plantings and seeds in animal feces (AZEVEDO, 1961; GOMES, 1961). This discovery is fundamental to understanding changes generated by human activities in the Caatinga, modified since the beginning of the European colonization in 1663 (ALMEIDA, 1979; NANTES, 1979).

However, the landscape modification may be older than assumed since human interest elements, such as Caryocar, Dioscorea, Passiflora, Spondias, and Licania appear throughout the studied profile. Humans usually consume these species through the ingestion of fruits and tubers (ANDRADE et al., 2019; LUCENA et al., 2017; PENIDO et al., 2016). Pre-Columbian populations may have been responsible for the management of these plants for food throughout the study period, comparable to the Amazonian region (CARSON et al., 2015; WATLING et al., 2016). Dioscorea deserves mention as it occurs between 6,000 and 3,000 cal yr BP and 2,000 cal yr BP, when algae and aquatic herbs indicate higher humidity in the region, favoring human presence in this area. In the same period, taxa commonly used for medicinal purposes were identified, such as Myracrodruon (ANDRADE et al., 2019; PEREIRA et al., 2016) Sida (RODRIGUES; OLIVEIRA, 2020), and other species that today have economic importance for the use of its wood, such as Astronium, Cordia and Mimosa (ANDRADE et al., 2019; PEREIRA et al., 2016).

The municipality of São João do Cariri currently has five archaeological sites described and studied (AZEVEDO NETTO et al., 2007) and, therefore, the hypothesis that the communities that lived in these locations changed the past landscape, with the use of land, through plantings, harvesting, and burning, it cannot be discarded. Cultural forests have been reported since the Pleistocene/Holocene in the Amazonian region (BALÉE, 2013), and this occupation model may have been used in the other human settlements in Brazil.

CONCLUSIONS

The vegetation in the studied area reveals mosaics with Brazilian savanna, Amazon rainforest and Atlantic forest, suggesting that changes in climatic conditions in the past may have enabled the formation of biotic corridors. This allowed the expansion of wetter ecosystems and, therefore, the occurrence of this non-analogous vegetation.

The current Caatinga species are identified between 4,900 and 2,000 cal yr BP, indicating dry climate conditions. A short-wet phase returns between 2,000 and 1,615 cal yr BP, and the current semiaridity is re-established after this period. Vegetation alterations between elements typical of tropical forest and those of the current Caatinga, during the Holocene, are in sync with the climatic events recorded for the Brazilian Northeastern region.

The occurrence of species of human interest may suggest anthropogenic alteration of the landscape since the middle Holocene. In addition, the presence of the exotic trees, Pinus and Prosopis, in the pollen signal indicates that human impact on the landscape continued with European colonization.

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REFERENCES

ALMEIDA, E. História de Campina Grande. João Pessoa: Editora UEPB, 1979.

ANDRADE, A. M. F.; ALVES, C. A. B.; SANTOS, R. S.; SILVA, S. Inventário etnobotânico e uso das espécies madeireiras e não madeireitas na comunidade de Ouricuri, Pilões-PB, nordeste do Brasil. Equador, v. 8, n. 2, p. 399–421, 2019.

APG. An update of the Angiosperm Phylogeny Group classification for the orders and families of flowering plants. Botanical Journal of the Linnean Society, v. 181, n. 1, p. 1–20, 2016.

ARAUJO, A. G. M.; PAISANI, J. C.; SCHRAGE, T. J.; FEATHERS, J. K.; HARTMANN, G. A.; RICCI, O. The “Lagoa do Camargo 1” Paleoindian site: some implications for tropical geomorphology, pedology, and paleoenvironments in southeastern Brazil. Geoarchaeology, v. 32, n. 6, p. 662–677, 1 nov. 2017.

ARAÚJO FILHO, J. C.; RIBEIRO, M. R.; BURGOS, N.; MARQUES, F. A. Solos da Caatinga. In: CURI, N.; KER, J. C.; NOVAIS, R. F.; VIDAL-TORRADO, P.; SCHAEFE, C. E. G. R. (Eds.). . Pedologia - Solos dos Biomas Brasileiros. Viçosa-MG: Sociedade Brasileira de Ciência do Solo, 2017. p. 227–260.

AZEVEDO, G. Algaroba. Rio de Janeiro: Ministério do Meio Ambiente, 1961.

AZEVEDO NETTO, C. X.; DUARTE, P.; OLIVEIRA, A. M. P. Uma visão arqueológica da relação

entre cultura e ambiente. In: ESPONDIOLA, H. F.; ARRUDA, G. (Eds.). . História, natureza e território. Governador Valadares: UNIVALE, 2007. p. 1–8.

BALÉE, W. Cultural Forests of the Amazon: A Historical Ecology of People and Their Landscape. Tuscaloosa, Alabama: University of Alabama, 2013.

BARBOSA, G. M. N.; MARQUES, E. A. G.; KER, J. C.; ASSIS, I. R. DE; CUNHA, T. J. F.; SOUZA, L. DA S. Geotechnical properties of some kaolinite-rich brazilian vertisols. Revista Brasileira de Ciencia do Solo, v. 45, p. 1–23, 2021.

BARRETO, E. A. S. Reconstituição da pluviosidade da Chapada Diamantina (BA) durante o Quaternário Tardio através de registros isotópicos (O e C) em estalagmites. [s.l.] Universidade de São Paulo, 2010.

BEHLING, H.; W. ARZ, H.; PÄTZOLD, J.; WEFER, G. Late Quaternary vegetational and climate dynamics in northeastern Brazil, inferences from marine core GeoB 3104-1. Quaternary Science Reviews, v. 19, n. 10, p. 981–994, 2000.

BELTRÃO, N.; OLIVEIRA, M. Oleaginosas Potenciais do Nordeste para a Produção de Biodiesel: Documentos 177. Campina Grande - PB: [s.n.].

BLAAUW, M.; CHRISTEN, J. A. Flexible paleoclimate age-depth models using an autoregressive gamma process. Bayesian Analysis, v. 6, n. 3, p. 457–474, set. 2011.

CAMPBELL, I. D. Experimental mechanical destruction of pollen grains. Palynology, v. 15, p. 29–33, 1991.

CARSON, J. F.; WATLING, J.; MAYLE, F. E.; WHITNEY, B. S.; IRIARTE, J.; PRÜMERS, H.; SOTO, J. D. Pre-Columbian land use in the ring-ditch region of the Bolivian Amazon. Holocene, v. 25, n. 8, p. 1285–1300, 2015.

CHENG, H.; SINHA, A.; CRUZ, F. W.; WANG, X.; EDWARDS, R. L.; D'HORTA, F. M.; RIBAS, C. C.; VUILLE, M.; STOTT, L. D.; AULER, A. S. Climate change patterns in Amazonia and biodiversity. Nature communications, v. 4, p. 1411, jan. 2013.

COLINVAUX, P. A.; OLIVEIRA, P. E. DE; PATIÑO, J. H. Amazon Pollen Manual and Atla. Amstedrdan: Hardwood Academic, 1999.

COSTA, D. P.; PERALTA, D. F. Bryophytes diversity in Brazil. Rodriguesia, v. 66, n. 4, p. 1063–1071, 2015.

CRUZ, F. W.; VUILLE, M.; BURNS, S. J.; WANG, X.; CHENG, H.; WERNER, M.; LAWRENCE EDWARDS, R.; KARMANN, I.; AULER, A. S.; NGUYEN, H. Orbitally driven east–west antiphasing of South American precipitation. Nature Geoscience, v. 2, n. 3, p. 210–214, fev. 2009.

FALLOON, P. D.; SMITH, P. Modelling refractory soil organic matter. Biology and Fertility of Soils, v. 30, n. 5–6, p. 388–398, 2000.

FAVIER DUBOIS, C. M.; POLITIS, G. G. Environmental dynamics and formation processes at the pampean archaeological locality Zanjón Seco, Argentina. Geoarchaeology, v. 32, n. 6, p. 622–632, 1 nov. 2017.

FERNANDES, M. F.; CARDOSO, D.; QUEIROZ, L. P. DE. An updated plant checklist of the Brazilian Caatinga seasonally dry forests and woodlands reveals high species richness and endemism. Journal of Arid Environments, v. 174, n. October 2019, p. 104079, 2020.

FERREIRA, C. R. P. C.; ANTONINO, A. C. D.; SAMPAIO, E. V. DE S. B.; CORREIA, K. G.; LIMA, J. R. DE S.; SOARES, W. DE A.; MENEZES, R. S. C. Soil CO2 efflux measurements by alkali absorption and infrared gas analyzer in the Brazilian semiarid region. Revista Brasileira de Ciencia do Solo, v. 42, p. 1–10, 2018.

FRANCO-MORAES, J.; BANIWA, A. F. M. B.; COSTA, F. R. C.; LIMA, H. P.; CLEMENT, C. R.;

SHEPARD, G. H. Historical landscape domestication in ancestral forests with nutrient-poor soils in northwestern Amazonia. Forest Ecology and Management, v. 446, n. April, p. 317–330, 2019.

GIONGO, V.; CUNHA, T. J. F.; MENDES, A. S.; GAVA, C. A. T. Carbono no sistem solo-planta no semiárido brasileiro. Revista Brasileira de Geografia Física, v. 06, p. 1233–1253, 2011.

GOMES, P. A algarobeira. Rio de Janeiro: Ministério do Meio Ambiente, 1961.

GRIMM, E. C. CONISS: Textbook of Polen Analyses. New York: Wiley, 1987.

GRIMM, E. C.; TROOSTHEIDE, C. D. Tilia 2.000, program for plotting palynological diagrams. Sprigfield: Illinois State Museum, 1994.

GRÜNEBERG, E.; ZICHE, D.; WELLBROCK, N. Organic carbon stocks and sequestration rates of forest soils in Germany. Global Change Biology, v. 20, n. 8, p. 2644–2662, 2014.

GUERREIRO, M. J. S.; MAIA DE ANDRADE, E.; ABREU, I.; LAJINHA, T. Long-term variation of precipitation indices in Ceará State, Northeast Brazil. International Journal of Climatology, v. 33, n. 14, p. 2929–2939, nov. 2013.

HANNAH, L.; MIDGLEY, G. F.; LOVEJOY, T.; BOND, W. J.; BUSH, M.; LOVETT, J. C.; SCOTT, D.; WOODWARD, F. I. Conservation of Biodiversity in a Changing Climate. Conservation Biology, v. 16, n. 1, p. 264–268, fev. 2002.

HOGG, A. G. et al. SHCal13 Southern Hemisphere Calibration, 0–50,000 Years cal BP. Radiocarbon, v. 55, n. 04, p. 1889–1903, fev. 2013.

IBGE. Censo 2010.

IPCC. Climate change and land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security and greenhouse gas fluxes in terrestrial ecosystems. [s.l: s.n.].

___. Climate Change 2022: Impacts, Adaptation, and Vulnerability. [s.l: s.n.].

KAYANO, M. T.; ANDREOLI, R. V. Clima da Região Nordeste do Brasil. In: CAVALCANTI, I. F.; FERREIRA, N. J.; SILVA, M. G. A. J.; DIAS, M. A. F. S. (Eds.). . Tempo e clima no Brasil. São Paulo: Oficina de textos, 2009. p. 213–234.

LEDO, R. M. D.; COLLI, G. R. The historical connections between the Amazon and the Atlantic Forest revisited. Journal of Biogeography, v. 44, n. 11, p. 2551–2563, 2017.

LEDRU, M. P.; MOURGUIART, P.; RICCOMINI, C. Related changes in biodiversity, insolation and climate in the Atlantic rainforest since the last interglacial. Palaeogeography, Palaeoclimatology, Palaeoecology, v. 271, n. 1–2, p. 140–152, 2009.

LEDRU, M.; RAGA, P. I. S.; SOUBIS, F.; FOURNIER, M.; MARTIN, L.; SUGUIO, K.; TURCQ, B. The last 50,000 years in the Neotropics (Southern Brazil): evolution of vegetation and climate. Palaeogeography, Palaeoclimatology, Palaeoecology, v. 123, p. 239–257, 1996.

LORENTE, F. L.; BUSO JR, A.; OLIVEIRA, P. E. DE; PESSENDA, L. C. R. Atlas palinológico. Piracicaba: Laboratório 14C, 2017.

LORENZI, H. Árvores Brasileiras. Manual de identificação e cultivo de plantas arbóreas nativas do Brasil. Nova Odessa, SP: Instituto Plantarum, 1992.

LUCENA, R. F. P. DE; PEDROSA, K. M.; CARVALHO, T. K. N.; GUERRA, N. M.; RIBEIRO, J. E. DA S.; FERREIRA, E. DA C. Conhecimento local e uso de espécies vegetais nativas da região da Serra de Santa Catarina, Paraíba, Nordeste do Brasil. Flovet, v. 1, n. 9, p. 158–179, 2017.

LUCENA, R. L.; SILVA, F. E. B.; APRÍGIO, T. R. M.; CABRAL JÚNIOR, J. B. The Influence of Altitude on the Climate of Semiarid Areas: Contributions to Conservation. The International Journal of Climate Change: Impacts and Responses, v. 14, n. 2, p. 81–93, 2022.

MABESOONE, J. M.; LOBO, H. R. C. Paleosols as stratigraphic indicators for the cenozoic history of northeastern Brazil. Catena, v. 7, n. 1, p. 67–78, 1980.

MAIA, L. C. et al. Diversity of Brazilian Fungi Knowledge about the Brazilian fungal diversity was , until 2010 , recorded in few taxonomy and ecology. Rodriguésia, v. 66, n. 4, p. 1033–1045, 2015.

MARTINS, T.; SAAB, S. C.; MILORI, D. M. B. P.; BRINATTI, A. M.; ROSA, J. A.; CASSARO, F. A. M.; PIRES, L. F. Soil organic matter humification under different tillage managements evaluated by Laser Induced Fluorescence (LIF) and C/N ratio. Soil and Tillage Research, v. 111, n. 2, p. 231–235, jan. 2011.

MEDEIROS, V. B. DE; OLIVEIRA, P. E. DE; SANTOS, R. A.; BARRETO, A. M. F.; OLIVEIRA, M. A. T. DE; PINAYA, J. L. D. New holocene pollen records from the Brazilian Caatinga. Anais da Academia Brasileira de Ciencias, v. 90, n. 2, p. 2011–2023, 2018.

MENDES, V. R. Registro sedimentar quaternário na Bacia do Rio Parnaíba, Piauí: um estudo multi-indicadores voltado à investigação de mudanças climáticas. [s.l.] Universidade de São Paulo, 2016.

MENEZES, R.; SAMPAIO, E.; GIONGO, V.; PÉREZ-MARIN, A. Biogeochemical cycling in terrestrial ecosystems of the Caatinga Biome. Brazilian Journal of Biology, v. 72, n. 3 suppl, p. 643–653, 2012.

MENEZES, S. A.; PORTELA, B. Y. M.; LIMA, L. B.; VANDESMET, L. C. S. Ethnobotanical survey of Brazilian Northeast medicinal species with anti- inflammatory potential. Brazilian Journal of Development, v. 5, n. 10, p. 73015-730218238–182494, 2021.

MONTADE, V.; LEDRU, M. P.; BURTE, J.; MARTINS, E. S. P. R.; VEROLA, C. F.; COSTA, I. R. DA; MAGALHÃES E SILVA, F. H. Stability of a neotropical microrefugium during climatic instability. Journal of Biogeography, v. 41, n. 6, p. 1215–1226, 2014.

MOREIRA, L. S.; MOREIRA-TURCQ, P.; CORDEIRO, R. C.; TURCQ, B.; CAQUINEAU, S.; VIANA, J. C. C.; BRANDINI, N. Holocene paleoenvironmental reconstruction in the Eastern Amazonian Basin: Comprido Lake. Journal of South American Earth Sciences, v. 44, p. 55–62, 2013.

NACE, T. E.; BAKER, P. A.; DWYER, G. S.; SILVA, C. G.; RIGSBY, C. A.; BURNS, S. J.; GIOSAN, L.; OTTO-BLIESNER, B.; LIU, Z.; ZHU, J. The role of North Brazil Current transport in the paleoclimate of the Brazilian Nordeste margin and paleoceanography of the western tropical Atlantic during the late Quaternary. Palaeogeography, Palaeoclimatology, Palaeoecology, v. 415, p. 3–13, 1 dez. 2014.

NANTES, M. Relação de uma missão no Rio São Francisco. São Paulo: Nacional, 1979.

NOVELLO, V. F.; CRUZ, F. W.; KARMANN, I.; BURNS, S. J.; STRÍKIS, N. M.; VUILLE, M.; CHENG, H.; LAWRENCE EDWARDS, R.; SANTOS, R. V.; FRIGO, E.; BARRETO, E. A. S. Multidecadal climate variability in Brazil's Nordeste during the last 3000 years based on speleothem isotope records. Geophysical Research Letters, v. 39, n. 23, p. n/a-n/a, dez. 2012.

OLIVEIRA, P. E. DE. A palynological recordo f Late Quaternary vegetation and climatic change in Southearsten Brazil. [s.l.] Ohio University, 1992.

OLIVEIRA, P. E. DE; BARRETO, A. M. F.; SUGUIO, K. Late Pleistocene/Holocene climatic and vegetational history of the Brazilian caatinga: The fossil dunes of the middle Sao Francisco River. Palaeogeography, Palaeoclimatology, Palaeoecology, v. 152, n. 3–4, p. 319–337, 1999.

PAES-SILVA, A. P.; CHAVES, I. B.; SAMPAIO, E. V. S. B. Cobertura vegetal da bacia hidrográfica do açude namorado no Cariri Oriental paraibano. Agropecuária técnica, v. 24, p. 47–59, 2003.

PENIDO, A. B.; MORAIS, S. M. DE; RIBEIRO, A. B.; SILVA, A. Z. Ethnobotanical study of medicinal plants in Imperatriz, State of Maranhão, Northeastern Brazil. Acta Amazonica, v. 46, n. 4, p. 345–354, 2016.

PEREIRA, L. G.; VIEIRA, F. J.; ALENCAR, F. P. A.; CARVALHO, A.; BARROS, R. F. M. Floristic diversity in backyards of the Brazilian Northeast: an Ethnobotanical study in rural communities in Monsenhor Gil/PI. Espacios, v. 37, n. 20, p. 11, 2016.

PESSENDA, L. C. R.; GOUVEIA, S. E. M.; RIBEIRO, A. DE S.; OLIVEIRA, P. E. DE; ARAVENA, R. Late Pleistocene and Holocene vegetation changes in northeastern Brazil determined from carbon isotopes and charcoal records in soils. Palaeogeography, Palaeoclimatology, Palaeoecology, v. 297, n. 3–4, p. 597–608, 2010.

PRADO, D. E. Seasonally dry forests of tropical South America : From forgotten ecosystems to a new phytogeographic unit. Edinburgh Journal of botany, v. 57, n. 3, p. 437–461, 2000.

PRADO, L. F.; WAINER, I.; CHIESSI, C. M.; LEDRU, M. P.; TURCQ, B. A mid-Holocene climate reconstruction for eastern South America. Climate of the Past, v. 9, n. 5, p. 2117–2133, 2013.

Reflora - Virtual Herbarium.

RODRIGUES, F. C.; OLIVEIRA, A. F. M. DE. The genus Sida L. (Malvaceae): An update of its ethnomedicinal use, pharmacology and phytochemistry. South African Journal of Botany, v. 132, p. 432–462, 2020.

ROUBIK, D.; MORENO, P. Pollen and spores of Barro Colorado Island (Panama). St Louis: Missouri Botanical Garden, 1991.

RÜCKAMP, D.; AMELUNG, W.; THEISZ, N.; BANDEIRA, A. G.; MARTIUS, C. Phosphorus forms in Brazilian termite nests and soils: Relevance of feeding guild and ecosystems. Geoderma, v. 155, n. 3–4, p. 269–279, 15 mar. 2010.

SALGADO-LABORIAU, M. L. Contribuição a palinologia dos Cerrados. Rio de Janeiro: Academia Brasileira de Ciências, 1973.

SANTOS, J. C.; LEAL, I. R.; ALMEIDA-, J. S.; FERNANDES, G. W.; TABARELLI, M. Caatinga : the scientific negligence experienced by a dry tropical forest. v. 4, n. 3, p. 276–286, 2011.

SANTOS, R. M.; OLIVEIRA-FILHO, A. T.; EISENLOHR, P. V; QUEIROZ, L. P. Identity and relationships of the Arboreal Caatinga among other floristic units of seasonally dry tropical forests (SDTFs) of north-eastern and Central Brazil. v. 2, n. Fernandes 2003, 2012.

SILVA, A. C.; SOUZA, A. F. Aridity drives plant biogeographical sub regions in the Caatinga, the largest tropical dry forest and woodland block in South America. PLoS ONE, v. 13, n. 4, 1 abr. 2018.

SILVA, G. J. F.; MACÊDO, M. L. A.; SILVA, R. M. Caracterização espaço-temporal das tipologias vegetais em ambiente de caatinga degradada: quantificação por meio de variáveis biofísicas. Ateliê Geográfico, v. 13, n. 2, p. 92–110, 2019.

SOUZA, J. J. L. L. DE; SOUZA, B. I. DE; XAVIER, R. A.; PACHECO, A. A.; PESSENDA, L. C. R.; SANTOS BRITO, E. DOS. Archaeoanthrosol formation in the Brazilian semiarid. Catena, v. 193, n. April, p. 104603, 2020.

SOUZA, J. J. L. L. DE; SOUZA, B. I.; XAVIER, R. A.; CARDOSO, E. C. M.; MEDEIROS, J. R. DE; FONSECA, C. F. DA; SCHAEFER, C. E. G. R. Organic carbon rich-soils in the brazilian semiarid region and paleoenvironmental implications. Catena, v. 212, n. July 2021, 2022.

SOUZA, L. C. DE; LIMA, H. V. DE; RODRIGUES, S.; KERN, D. C. Chemical and physical properties of an anthropogenic dark earth soil from Bragança , Para , Eastern Amazon. v. 46, n. 4, p. 337–344, 2016.

STOCKMARR, J. Tablets with spores used in absolute pollen analysis. Pollen et Spores, v. XIII, n. April, p. 615–621, 1971.

TADINI, A. M.; NICOLODELLI, G.; SENESI, G. S.; ISHIDA, D. A.; MONTES, C. R.; LUCAS, Y.; MOUNIER, S.; GUIMARÃES, F. E. G.; MILORI, D. M. B. P. Soil organic matter in podzol horizons of

the Amazon region: Humification, recalcitrance, and dating. Science of the Total Environment, v. 613–614, p. 160–167, 1 fev. 2018.

TOLONEN, K. Charred particule analyses. In: BERGLUND, B. E. (Ed.). . Handbook of Holocene Palaeocology and Palaeohydrology. New York: John Wiley and Sons Ltd., 1986. p. 485–490.

WANG, X.; AULER, A. S.; EDWARDS, L. L.; CHENG, H.; CRISTALLI, P. S.; SMART, P. L.; RICHARDS, D. A.; SHEN, C. C. Wet periods in northeastern Brazil over the past 210 kyr linked to distant climate anomalies. Nature, v. 432, n. 7018, p. 740–743, 9 dez. 2004.

WANG, X.; AULER, A. S.; EDWARDS, R. L.; CHENG, H.; ITO, E.; SOLHEID, M. Interhemispheric anti-phasing of rainfall during the last glacial period. Quaternary Science Reviews, v. 25, n. 23–24, p. 3391–3403, 2006.

WATLING, J.; IRIARTE, J.; WHITNEY, B. S.; CONSUELO, E.; MAYLE, F.; CASTRO, W.; SCHAAN, D.; FELDPAUSCH, T. R. Differentiation of neotropical ecosystems by modern soil phytolith assemblages and its implications for palaeoenvironmental and archaeological reconstructions II: Southwestern Amazonian forests. Review of Palaeobotany and Palynology, v. 226, p. 30–43, 2016.

WERNECK, F. P.; COSTA, G. C.; COLLI, G. R.; PRADO, D. E.; SITES, J. W. Revisiting the historical distribution of Seasonally Dry Tropical Forests: New insights based on palaeodistribution modelling and palynological evidencegeb. Global Ecology and Biogeography, v. 20, n. 2, p. 272–288, mar. 2011.

XAVIER, R. A.; SEABRA, V. S.; DAMASCENO, J.; DORNELLAS, P. C. Mapeamento geomorfológico da bacia do Rio Paraíba (PB) utilizando classificação baseada em objetos. Acta geográfica, v. 10, n. 23, p. 139–152, 2016.

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