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New Holocene pollen records from the Brazilian Caatinga

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ABSTRACT

We present two pollen diagrams from the semi-arid Caatinga of the Catimbau National Park, in Pernambuco and from a *Mauritia* palm forest in the Caatinga/Cerrado ecotone of southern Piauí, NE Brazil, spanning the last 10,000 cal. yrs BP and the last 1,750 cal yrs BP, respectively. These two records contain a signature of the local vegetation and permit the correlation of the pollen signal with regional climatic changes. The Catimbau record shows *Zizyphus* sp., a typical Caatinga taxon, in all three pollen zones indicating regional Caatinga vegetation and the predominance of local arboreal taxa adapted to high humidity from 10,000 to *ca.* 6,000 cal. yrs BP with a gradual tendency towards drier conditions revealed by a deposition hiatus between 6,000 to *ca*. 2,000 cal. yrs BP. This abrupt loss of sediments in both localities is interpreted as a consequence of the establishment of modern semi-arid climates. The subsequent return of humidity is signaled by increased sedimentation rates and ^{14}C date inversions in agreement with high precipitation, revealed by $\sigma^{18}O$ ratios in speleothems from NE Brazil. Modern sediments deposited in the last 500 years reflect local conditions with the maintenance of humidity by geological faulting and surfacing water tables.

Key words: paleoclimatology, palynology, Pernambuco, Piauí, caatinga vegetation.

INTRODUCTION

The Brazilian Caatinga appeared for the first time in the international scientific literature with the seminal study Flora Brasiliensis by Karl Friedrich von Martius in 1817, followed by various contributions on the physical and floristic characteristics of this semi-arid tropical ecosystem (Andrade-Lima 1953, 1977, Rizzini 1963, Rizzini and Mattos Filho 1992, Barbosa et al. 2006). Until recently, the Late Quaternary history of this vegetation had not been available due to a lack of palynological studies, which require organic-rich and unoxidized

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* Contribution to the centenary of the Brazilian Academy of Sciences.

sediments. These were later found in the Icatu River Valley, in the mid-São Francisco River, state of Bahia, by De Oliveira et al. (1999) and revealing continuous sedimentation in the last 11,000 years. The authors observed the predominance of rainforest taxa during the Pleistocene/Holocene transition, indicating a humid phase in the Early Holocene, with a gradual loss of humidity. According to the Icatu pollen record, it became clear that rainforest as well as palm forest (buritizal) decreased gradually in abundance in that valley until the mid-Holocene and was followed by the establishment of semi-arid climate at *ca.* 4,200 yrs BP.

Among other studies that contribute to the understanding of Holocene climates within the Caatinga is that of Behling et al. (2000), who analyzed the pollen signal in marine sediments deposited at the Jaguaribe River delta, in the continental platform, 90 km off the coast of Ceará. These authors show that the terrestrial signal started to decrease after 8,500 yrs BP, thus suggesting the establishment of semi-arid conditions. However, it is noteworthy the return of humid climates after *ca*. 3,200 yrs BP in high elevation regions of the semi-arid Caatinga domain of Ceará, Piauí and Paraíba (Pessenda et al. 2010) and in Serra do Maranguape, Ceará (Montade et al. 2014). In fact, the modern vegetation pattern within the Caatinga is predominantly xerophytic in the lowlands in contrast to the conspicuous presence of tropical forests containing Amazonian and Atlantic taxa in elevations higher than 1,000 meters, known as "Brejos de altitude", maintained by orographic rains which create unusual high rainfall patterns under lower temperatures within the semi-arid domain (Sales et al. 1998).

Other paleoclimatic analyses within the Caatinga region, derived from geochemical and geological data, support unstable climates during the Holocene, with a wetter early phase, followed by dryer conditions at *ca.* 4,000 yrs BP, intercalated with a strongly rainy period *ca*. 2,000 yrs BP (Cruz et al. 2009, Novello et al. 2012, Nace et al. 2014, Mendes 2016).

Despite the recent advances in our knowledge of the vegetation and climatic dynamics, the Caatinga ecosystem remains the least known in the literature in terms of its vegetational and climate evolution. In this present contribution, we provide two new Holocene pollen records from the semi-arid region of central Pernambuco and southern Piauí, both located in an area with the lowest precipitation levels in this ecosystem, known in Brazil as Sertão or Polígono da Seca (Drought Polygon), in order to contribute to the understanding of the vegetational, climate and ecological processes during the Holocene.

STUDY SITES

Pollen analyses were conducted in two localities in the Caatinga domain: Vale do Catimbau, Pernambuco and Bom Jesus, Piaui, shown on Figure 1.

In the first, sediments were collected from a peatbog 0.5 km long x 0.12 km wide in the Vale do Catimbau National Park, Arcoverde municipality, Pernambuco (8º29'26"S; 37º11'20"W), at 740 m elevation. The climate is semi-arid, with a well-defined wet season between February and August, mean annual precipitation of 700 mm, and mean annual temperature of 22.9 ºC. The geological setting of the Vale do Catimbau region is controlled by the Jatobá Basin, of Silurian-Devonian age (CPRM 1964), containing the Tacaratu Formation, composed of sandstones and conglomerates. The sedimentary rocks establish an important deep aquifer in a large section of northeastern Brazil. Geological faults in the Catimbau region (Gomes 1995), especially the São José Mountain range are responsible for surfacing waters conducive to peatbog formation (Nascimento 2008). The modern vegetation cover in Vale do Catimbau includes typical Caatinga genera such as the arboreal and herbaceous *Astronium*, *Cassia*, *Ceiba*,

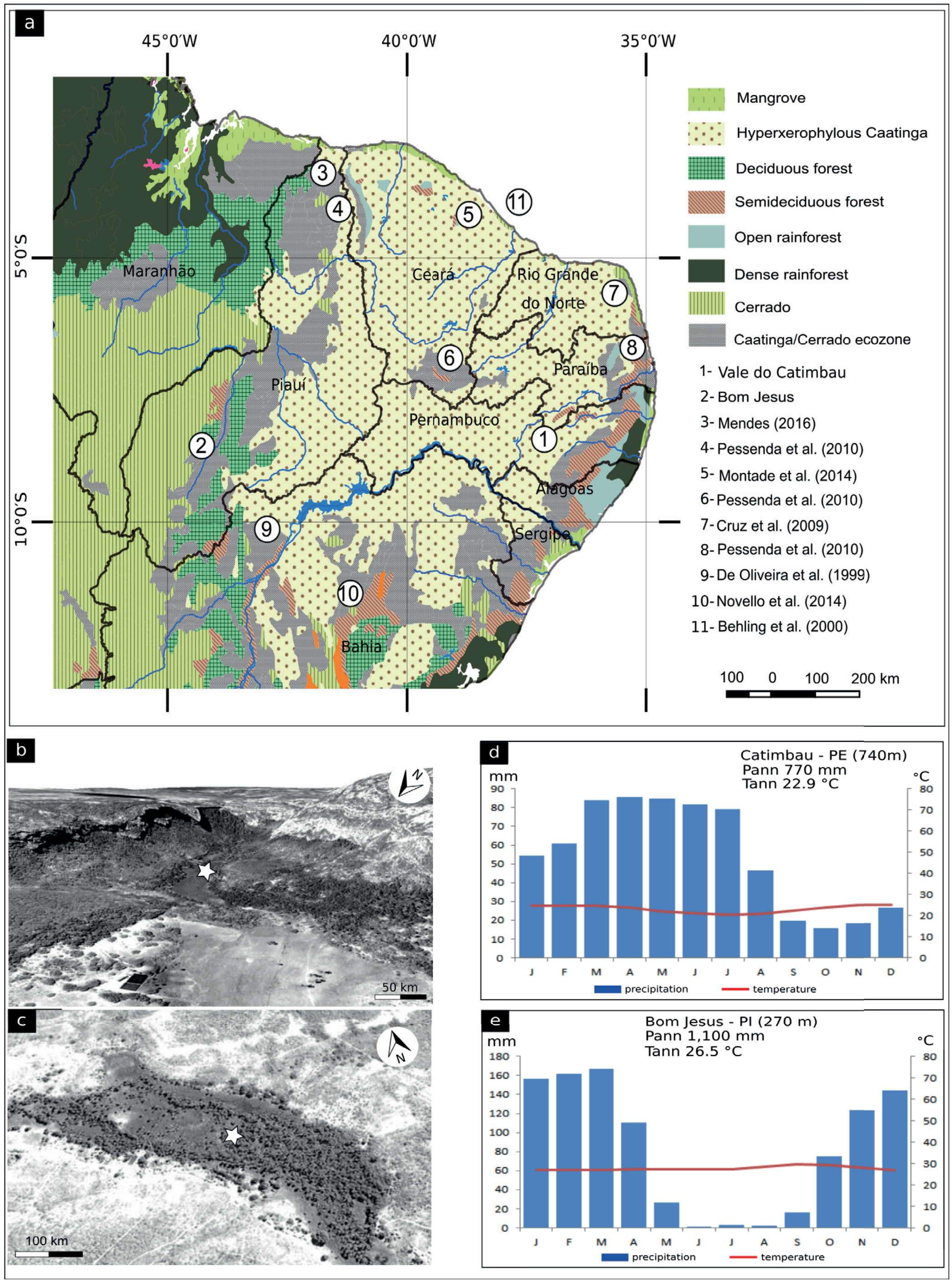

Figure 1 - (**a**) Location map of Catimbau (1) and Bom Jesus (2) sites in relation to important paleoclimatic studies, showing the vegetational distribution of NE Brazil, drawn by Q GIS 2.18 Las Palmas software. Satellite images for both sites are in (**b**) and (**c**), respectively and reveal the position of the sampled sites in the environment. Ombrothermic diagrams show mean monthly values of temperature and precipitation and annual precipitation (Pann) and temperature (Tann), for both sites (**d**) and (**e**) respectively, calculated for the last 45 years (data from the National Institute of Meteorology, available at: www.inmet.gov.br/portal). Paleocological studies discussed in the present work are: 3 – Parnaíba River (Mendes 2016); 4 – PARNA (Pessenda et al. 2010); 5 – Serra do Maranguape (Montade et al. 2014); 6 – FLONA (Pessenda et al. 2010); 7 – Rio Grande do Norte (Cruz et al. 2009); 8 – REBIO (Pessenda et al. 2010); 9 – Icatu River (De Oliveira et al. 1999); 10 – Diva de Maura and Torrinha Caves (Novello et al. 2012); 11 – GeoB 3104-1 (Behling et al. 2000).

Cereus, *Croton*, *Jatropha*, *Manihot* and *Tabebuia*. Nearby islands of Cerrado contain the *Krameria*, *Hymenaea*, *Senna*, *Guapira* and *Tocoyena* and in some humid areas, rainforest elements such as *Mauritia*, *Sauvagesia* and *Justicia* are common. In some areas *Orbignya* (*Attalea*) palms (babaçu) is predominant (Sales et al. 1998), especially around the peatbog sampled for the present pollen study.

The second site, at Bom Jesus, Piaui, is located at a Caatinga/Cerrado ecotone, thus reflecting a floristic mosaic composed of species belonging to those ecosystems. Organic-rich sediments, forming a superficial peatbog underlain by mineral sediments, were collected in a location named Veredas, (9°13'40.59"S and 44°28'0.92"W), part of an extensive *Mauritia flexuosa* palm forest. The sampling location is located within an ephemeral drainage system under a semi-arid climate with a wet season from October to April, mean annual precipitation of 1,100 mm and mean annual temperature of 26.5ºC, at 270 m elevation (EMBRAPA 2016). The Bom Jesus *Mauritia flexuosa* palm forests (buritizais) are located in humid areas where the surfacing water table creates waterlogged soils colonized by Amazonian and/or Atlantic arboreal taxa such as *Mauritiella aculeata*, *Acacia*, *Anadenanthera*, *Commiphora*, *Dalbergia*, *Piptadenia*, *Poeppigia*, *Copernicia*, *Geoffroea*, *Licania* as well as *Costus* herbs (Andrade-Lima 1981).

MATERIALS AND METHODS

At the Vale do Catimbau peatbog, a peat sediment column of 161,5 cm was retrieved with a Russian sampler (Belokopytov and Beresnevich 1955) in the northern portion of that basin in order to avoid sampling of disturbed sediments previously collected at the center of the bog by Nascimento (2008). At the Bom Jesus site, a 155 cm sediment sequence was obtained with a vibrocore sampler (Martin et al. 1995) in a palm swamp characterized by clayey/organic sediments.

After the opening of the tubes under laboratory conditions, sediments were described and subsampled. A total of 32 samples of one cm^3 were collected along the Catimbau core in various depth intervals (10 cm, 5 cm and 2.5 cm), while in the Bom Jesus sequence, were collected a total of 12 samples, within 10 cm depth intervals. All of them were chemically processed according to the Quaternary Palynology protocol described in Colinvaux et al. (1999): addition of *Lycopodium clavatum* (exotic marker) spores, followed by HF (hydrofluoric acid) treatment for silicates removal and acetolysis reaction for the destruction of organic matter in the samples as well as within the pollen. Residues were mounted on glycerine and pollen/spores and other palynomorphs were counted under light microscopy. Counts proceeded until a minimum of about 300 pollen grains or 100 to 200 grains for samples with low palynomorph preservation. Pollen sums were calculated based on all pollen taxa present and belonging to the different categories such as arboreal, shrub, terrestrial and aquatic herbaceous pollen grains. Percentage and concentration values of all taxa were calculated by TILIA, TILIAGRAPH software (Grimm and Troostheide 1994), and pollen zones were established by means of a similarity dendrogram by CONISS (Grimm 1987). Accelerated Mass Spectrometry (AMS) radiocarbon dating of selected samples was carried out by Beta Analytics Laboratory, Miami, Florida. All the calibrations were done with the software CALIB 7.1 (Stuiver et al. 2017), using the calibration curve ShCal13 (Hogg et al. 2013) and the age-depth models curves were done by Oxcal 4.3 (Ramsey 2008).

RESULTS

Lithology, radiocarbon dating and sedimentation rates are presented for both sites, followed by separate palynological results.

Peatbog sediments from Catimbau are composed of very dark sandy organic sediments with fine sand laminations at 122.5 cm and from 135 and 140 cm, while the Bom Jesus sequence showed the intercalation of clays and sands (Table I). Radiocarbon ages for the Catimbau sequence vary from 10,322 cal yrs BP to 152 cal yrs BP with dating inversion at around 1,800 cal yrs BP. The Bom Jesus sequence reached 1,749 cal yrs BP at the bottom depth of 100 cm depth, with inversions at *ca.* 1,700 cal yrs BP, at 154 cm depth (Table II).

The litology and radiocarbon dating results indicate very slow sedimentation rates varying from 0.009 to 0.233 cm year^{-1}, at Catimbau, as shown on Figure 2, although a significant deposition of 30 cm occurred between the inverted dates of 1,880 and 1,830 cal. yrs BP. The rapid deposition at *ca.* 1,800 cal. yrs BP at the Catimbau site is probably associated with a humid episode, with torrential rains that could have altered the horizontally layering of the sediments. A hiatus in sedimentation is clear between 6,440 and 1,778 cal. yrs BP in the Catimbau peat core, which appears to bear a correlation to the Mid-Holocene drying climates observed for the Caatinga ecosystem at *ca.* 4,500 cal. yrs BP. An age model based on previous analyses at the Catimbau site by Nascimento (2008) shows similar results, *i.e.* low sedimentation rates at *ca.* 2,000 yrs BP followed

TABLE I
Lithology of the Vale do Catimbau peat and Bom Jesus sequence.

Sites	Depth (cm)	Sediments description
Vale do Catimbau	0 – 135	Sandy peat, with sand lamination at 122,5 cm
	135 – 140	Sand lamination
	140 – 161,5	Sandy peat
Bom Jesus	0 – 16,5	Brown organic matter with plant remains
	16,5 – 42	Dense clay with roots
	42 – 47	Light brown sand
	47 – 101	Yellow sandy clay
	101 – 155	Banded gray clayey sands

TABLE II
Radiocarbon ages for the Catimbau and Bom Jesus samples. Calibrations were calculated by software CALIB 7.1 (Stuiver et al. 2017), ranges of 95,4% (2$^{\delta}$). Final calibrated ages were obtained from the median probability provided of the end calibration.

Site	Sample	Nr. Beta	Conventional Ages (BP)	Calibrated ages (yr cal. BP)	Calibrated ages range	
					from	to
Catimbau	30	390149	180 +/- 30	152	284	3
Catimbau	60	431967	1100 +/- 30	956	1055	920
Catimbau	80	390150	1880 +/- 30	1778	1796	1619
Catimbau	110	390151	1830 +/- 30	1714	1830	1709
Catimbau	120	431968	5700 +/- 30	6440	6531	6320
Catimbau	130	390152	6540 +/- 30	7416	7466	7327
Catimbau	137	431969	6570 +/- 30	7446	7509	7339
Catimbau	169	370007	9200 +/- 40	10322	10486	10229
Bom Jesus	38-40	360002	460 +/- 30	516	530	500
Bom Jesus	100	390147	1810 +/- 30	1750	1822	1628
Bom Jesus	120	390148	1560 +/- 30	1462	1475	1320
Bom Jesus	152-154	360003	1320 +/- 30	1247	1300	1180

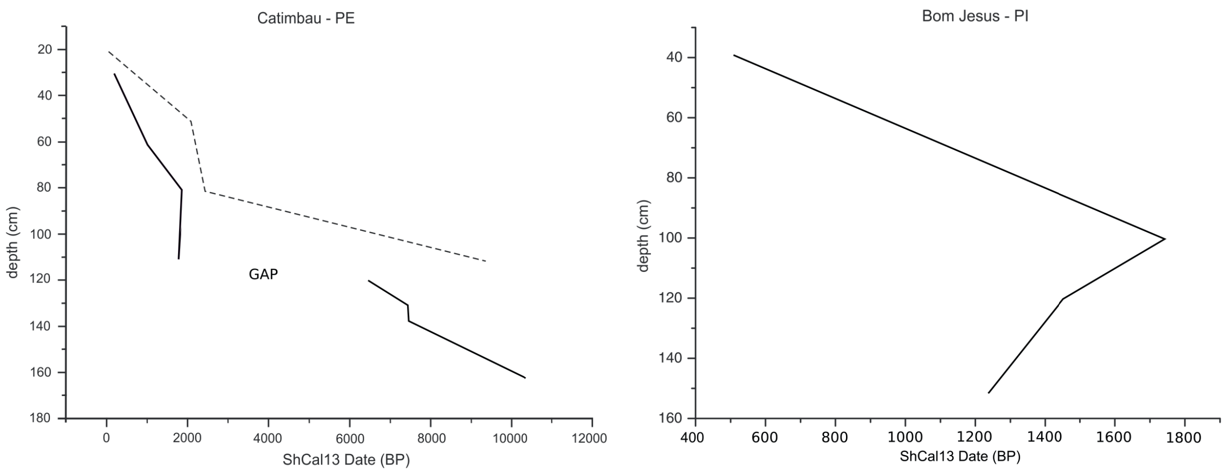

Figure 2 - Oxcal 4.3 (Ramsey 2008) calibrated age-depth models for the Vale do Catimbau and Bom Jesus peat sequences. The Catimbau data (this study) is given as a continuous line whereas the dotted line represents the age-depth models applied to Nascimento's data (2008).

by oscillating values. It is very likely that due to poor radiocarbon control the author was not able to detect the hiatus. On the other hand, deposition at the Bom Jesus site, also presented on Figure 2, reveals age inversions thus not allowing a thorough interpretation of its pollen data.

PALYNOLOGICAL ANALYSES- VALE DO CATIMBAU

Figures 3 and 4 show percentage and concentration pollen diagrams for different palynomorph categories, respectively. Percentage and concentration values for each taxon, given between parentheses, refer to the evolution of its representation from bottom to top of each pollen zone. In the palynomorph diagrams, aquatic herbs, pteridophytic and algal spores provide a clear signature of waterlogged conditions for the entire Catimbau deposition. These, in turn, are determined by geological fault lines allowing the surfacing of the underground water table.

CA-1 (160 – 111 cm; 10,330 cal. yrs BP – *ca.* 6,000 cal. yrs BP (extrapolated age) is characterized by fluctuating arboreal elements, both in percentage and concentration values, at the end of this zone. Maximum value of these components occurs at *ca.* 6,600 cal yrs BP. The most significant taxa, followed by their percent representation from bottom, middle to top of this zone, are represented by Arecaceae (5% - 4%), *Byrsonima* (4.6%- 5.4% to 0%), *Casearia* (1.5% - 4.5% to 1.2%), *Cecropia* (1% - 6% to 1.2%), Melastomataceae (1.5% - 15% to 1.2%), Myrtaceae (0.7%- 2.5% to 2%), *Piptadenia* (0.5% - 1.7% to 0%) and others. *Orbignya* (*Attalea*) palm pollen appeared in the record at an extrapolated age of *ca.* 9,000 cal. yrs BP represented by less than 6% of the total pollen sum, whereas *Ziziphus*, a xerophytic Caatinga indicator, fluctuated in this zone with values under 2%. Concentration values, *i.e.* number of grains per cubic centimeter of sediment (g/cc), of each taxa, follows the same trend observed in the percentage profile. These values shows a clear preponderance of humid adapted taxa in the Early Holocene, gradually decreasing in representation towards the Mid Holocene: Arecaceae (15724 -1010 gr/cc), Myrtaceae (1,429 – 2,511 to 167), *Cecropia* (2,859 – 5,718 to 502), Melastomataceae (2,654 – 10,191 to 606), Moraceae (2,534 – 326 to 502), *Ziziphus* (619 to 167). Pollen grains belonging to *Orbignya* (*Attalea*) are represented by 9,911 g/cc and are possibly a consequence of human influence on the local landscape.

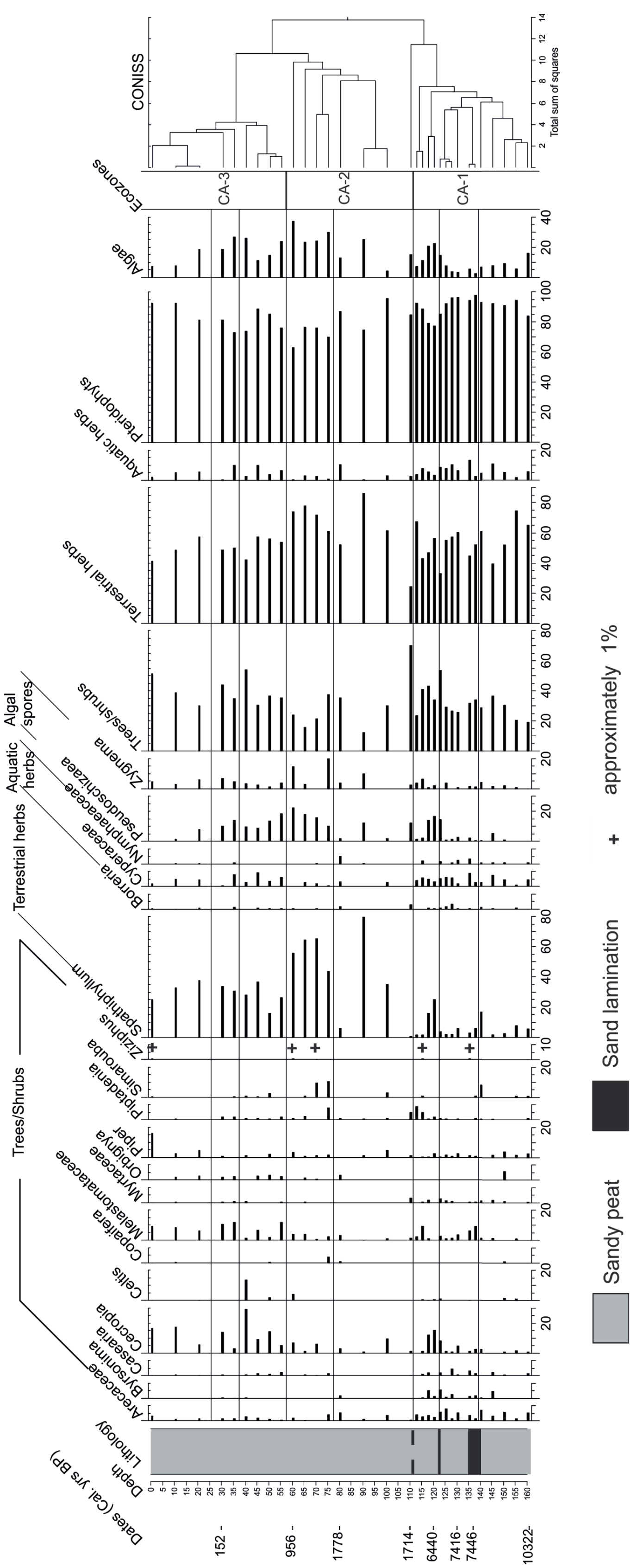

Figure 3 - Percentage pollen diagram of the Vale do Catimbau peat sequence, of selected taxa and sum of categories. Dotted line in the lithology column marks a sedimentary hiatus.

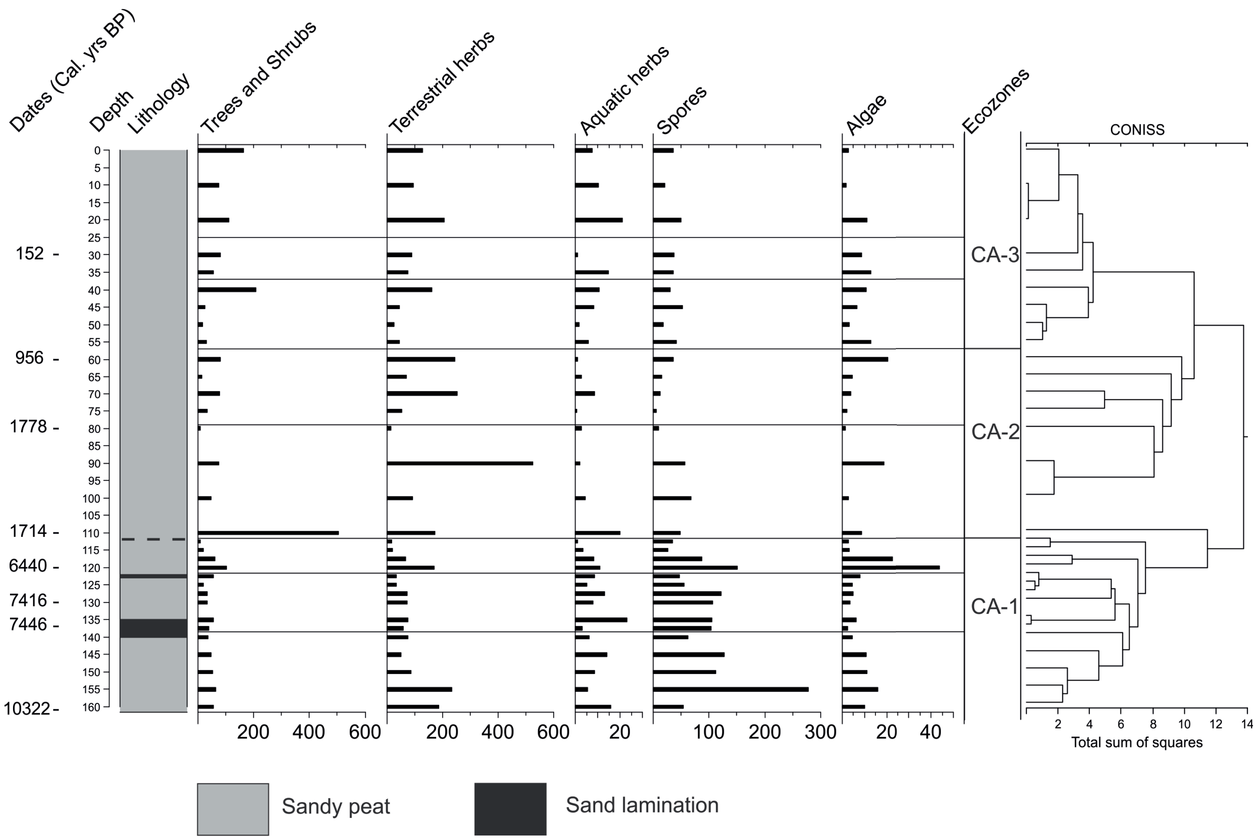

Figure 4 - Concentration pollen diagram of the Vale do Catimbau peat sequence of plant categories (x 1000). Dotted line at the lithology column marks a sedimentary hiatus.

CA-2 (110 – 57 cm; 1,714 – 956 cal. yrs BP). The position of sample 110 cm within the contact between reworked and non-reworked layers, as suggested by radiocarbon age inversion, did not allow it to be included in the Ecozone CA-1. It is noteworthy that the CONISS dendrogram separates this sample depth from all previous samples due to reduced similarity between them. CA-2 is subdivided into two sections: a reworked zone from 110 cm to 80 cm interval with date inversion, and a non-disturbed sequence from 79 to 57 cm (1,778 cal. yrs BP to 956 cal. yrs BP). The latter is characterized by the presence of *Copaifera* (0.75% - 4%), together with Arecaceae (5% to 2%), *Simarouba* (10% to 9%), *Celtis* (4%) in synchrony with a steady increase in *Cecropia* (3% to 7%), Melastomataceae (3% to 4%) and *Piptadenia* (<1% to 7%) while *Ziziphus* continued its local representation until present conditions fluctuating within 1% of the pollen sum. Another change in this zone is marked by high *Spathiphyllum* concentration values, a terrestrial herb found presently at the site in very moist rocky habitats next to the peatbog. In contrast to *Spathiphyllum*, other herbaceous groups such as Poaceae (Gramineae) and Asteraceae (Compositae) are found in smaller percentage and concentration values. *Orbignya* (*Attalea*) palm returns to the Catimbau record at 1,778 cal. yrs BP (80 cm).

Concentration values within this zone, from its beginning to its end, of arboreal taxa is mostly represented by non-*Orbignya* Arecaceae pollen (1,300 – 6,094), Melastomataceae (741 – 13,421), *Cecropia* (743 – 22,713), *Ziziphus* (663 – 1032), *Orbignya* (743 – 1327). Myrtaceae, which was already in decline in the previous zone, was found

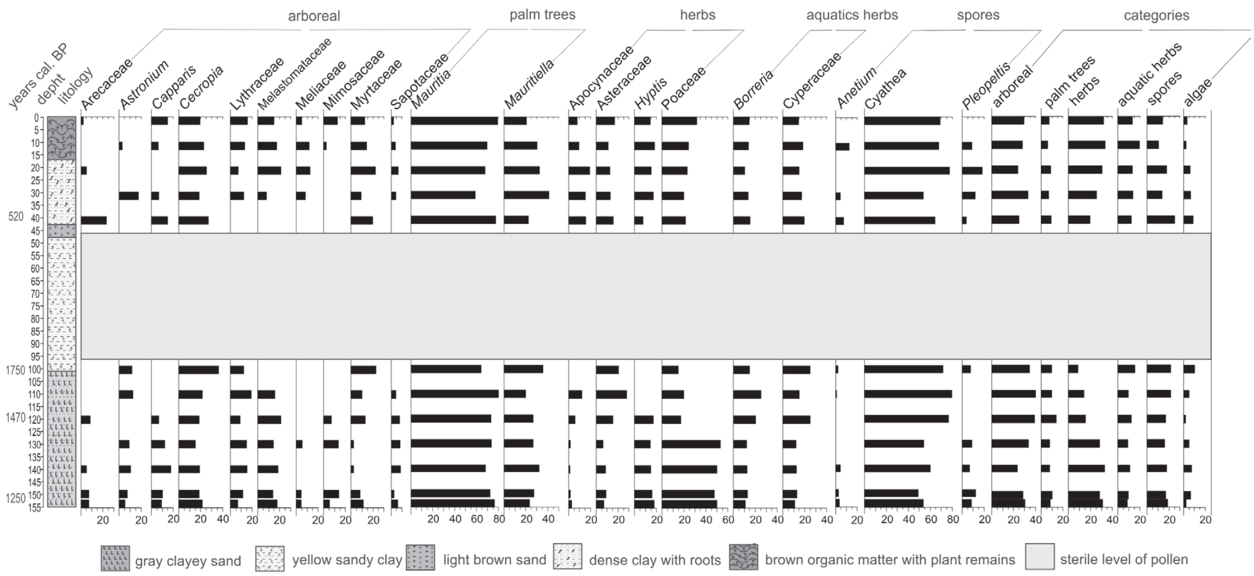

Figure 5 - Percentage pollen diagram of the Bom Jesus sediment sequence.

in only one sample with 261 g/cc. The herbaceous component is well-represented by Asteraceae (2,590 – 11,356) and Poaceae (7,433 – 29,940) whereas aquatic associations are defined mainly by *Borreria* (371 – 1,032), Cyperaceae (743 – 2,617) and ferns by *Cyathea* (1,486 – 3,097) and trilete spores (1,672 – 6,694).

CA-3 (56 – 0 cm; 956 cal. yrs BP – Present). The pollen content of zone CA-3 is represented by Arecaceae, fluctuating between 0.7% to 3%, *Casearia* (2.4% to 0.7% and 0.5%), *Celtis* (2% - 13.4% to 0.3%), Melastomataceae (12% to 9%), *Orbignya* (*Attalea*) in steady levels around 2.5 % and *Piptadenia* (2% - 0.2%). Successional elements are represented by *Cecropia* (5% to 29% and 16%) and *Piper* (2% - 4.4% to 16%). The presence of nearby Caatinga vegetation is given by *Ziziphus*, which continued to appear in steady low percentages (around 0.3%) as it did in the previous zone. Concentration values for selected arboreal taxa are given as follows: Arecaceae (1,250 – 10,221), *Cecropia* (4,385 – 51,106), Myrtaceae (1,000 – 350), Melastomataceae (10,215 – 28,805), *Orbignya* (2.088 – 9,911). Herbs are represented by Asteraceae (4,176 – 10,619 to 5,575), Poaceae (13,990 – 9,724 to 31,592) and aquatic plants by Cyperaceae (5,220 – 16,106 to 6,504) and ferns by *Cyathea* (30,486 – 1,351).

PALYNOLOGICAL ANALYSES - BOM JESUS

The percentage diagram of the botanical elements of the Bom Jesus (PI) *Mauritia* palm swamp is presented in two intervals, containing age inversions in its lower section (155-100 cm) and modern, undisturbed deposition ranging from 40 cm to 0 cm (Figure 5). Due to the low resolution of this record, coupled with the fact that it represents a reworked sedimentary record, CONISS zonation was not determined. Pollen percentage and concentration values given below for each taxon represent their overall distribution range within each sedimentary interval as follows:

Interval 155 -100 cm (1,250 – 1,750 yrs cal BP) is represented by the predominance of *Mauritia* (70% - 80%) and its associated taxon *Mauritiella* (24% - 36%), followed by other arboreal elements typically found in humid soils such as *Crecropia* (15% - 22%) and Melastomataceae (14 % - 20%). Herbaceous layer indicators are Poaceae (17% - 50%), Asteraceae (6% - 15%), *Hyptis* (14%

-18%). Aquatic herbs belong to *Borreria* (10% - 25%) and Cyperaceae (11% - 32%), whereas fern representatives are *Cyathea* (50% -80%), *Pleopeltis* (7% - 12%) and *Anetium* (3% - 4%).

The undisturbed interval containing the upper 40 cm of deposition (520 yrs cal. BP) is characterized by *Mauritia* (60% - 80%), *Mauritiella* (20% - 40%), other Arecaceae (2% - 24%), *Astronium* (3% - 18%), *Cecropia* (20% - 27%), Lythraceae (7% -15%), Melastomataceae (8% - 21%), Meliaceae (6% - 12%), Mimosaceae (2% - 12%), Myrtaceae (9% - 20%) and Sapotaceae (3% - 8%). Among the herbs, the pollen spectra contain Asteraceae (11% -17%), *Hyptis* (8% - 18%) and Poaceae (20% - 30%). The aquatic herb component is given primarily by *Borreria* (10% - 15%) and Cyperaceae (15% - 20%) and ferns by *Cyathea* (65% - 77%), *Pleopeltis* (4% - 18%) and *Anetium* (4% - 12%).

DISCUSSION

The Catimbau vegetation during the Holocene can be thought of as a local oasis-like ecosystem within a semi-arid domain maintained by tectonics. Underlain Silurian-Devonian sedimentary rocks function as a source of ground water in a deep aquifer (CPRM 1964) which surfaced possibly due to Mesozoic/Cenozoic geological faulting (Gomes 1995, Nascimento 2008). This geological feature might explain the overall abundance and a prolific representation of *Spathiphyllum* along the Catimbau record. This herbaceous taxon, restricted to humid rocks and soils (Croat 1988) within semi-arid regions, remained stable in the Catimbau site despite regional climatic fluctuations during the Holocene.

The occurrence of *Cecropia* in this period is significant. This arboreal taxon, known for its invasive habits and predominance in secondary vegetation, cannot survive in semi-arid climates and can therefore be used as an indicator of successional events under humid climates or in moist soils maintained by edaphic factors (Lorenzi 1998). Humid signals in both sites are given also by the presence of *Borreria* and Cyperaceae, in association with pteridophytic and algal spores. *Borreria*, although commonly found in terrestrial settings, has macrophytic species adapted to soils under prolonged flooding such as *B. eryngioides*, *B. quadrifaria* (Pott and Pott 1994), *B. saponariifolia* and *B. capitata* (Lorenzi 2000). Likewise, Cyperaceae is a large family comprising *ca* 4,500 species found mainly in waterlogged conditions (Souza and Lorenzi 2005).

Unlike the Late Pleistocene/Holocene and Early Holocene humid phase displayed by the Icatu record in the Bahian semi-arid Caatinga (De Oliveira et al. 1999), the pollen signal at Catimbau is of very local and not of regional amplitude. This restricted signal is controlled by a peatbog surrounded by a rocky amphitheater, where its abundant pollen signature, maintained by local trees and herbs, masks regional anemophilous sources. However, it is noteworthy the presence of *Ziziphus*, very likely to be *Z. joazeiro*, a well-known evergreen tree species of the xerophyhtic Caatinga of the Sertão region in NE Brazil, thus suggesting nearby semi-arid vegetation around this humid site, throughout the Holocene.

The tendency towards drying of the landscape after the Mid-Holocene shown regionally by the Icatu pollen record (De Oliveira et al. 1999) and by $\delta^{18}O$ ratios in cave speleothems for NE Brazil (Wang et al. 2004, Cruz et al. 2009, Nace et al. 2014, Mendes 2016), is possibly represented in the Catimbau record by the lack of sediment deposition after *ca.* 6,400 and prior to *ca.* 1,800 cal yrs BP. This was likely to be a consequence of lowering water tables under a regional and strong semi-arid climatic phase. However, it is possible that humid conditions, concomitantly with sediment deposition, persisted during the Mid-Holocene in the climatically closed system of Catimbau, shown by the presence of various moist-adapted taxa either side of the hiatus (*ca*. 6,400 yrs to 1714 cal. yrs BP).

This sedimentation hiatus is possibly correlated to a phase of generalized drying of that portion of NE Brazil as suggested by the Syntrace Climatic Model (Nace et al. 2014) and by the isotopic data from cave speleothems in State of Rio Grande do Norte (Cruz et al. 2009). In both studies, there is a clear tendency toward arid phases, reaching a peak at *ca.* 4,000 cal. yrs BP. Under this context the surfacing water table (Costa Filho and Demétrio 2005) at the Catimbau site had been lowered.

This Mid-Holocene climatic phase is possibly correlated with the return of a moist phase in the Early Holocene as detected by Novello et al. (2012), Nace et al. (2014), Mendes (2016). It is possible that the same climatic episode had occurred at Bom Jesus, which could explain the inverted ages as well as the high mineral content (sandy sediments) of its sequence, as well as loss of older deposits.

The increase of *Spathiphyllum* sp. and sedimentation rates between 2,000 and 1,500 cal yrs BP at Catimbau and Bom Jesus and the date inversions in both sites are suggestive of sediment transport and reworking under intense high energy precipitation. Such storm conditions have been reported for the same time period by Mendes (2016) and Viana et al. (2014).

After *ca.* 500 cal yrs BP towards modern times the pollen signal at the Catimbau site is characterized by a gradual decrease in taxa adapted to high levels of humidity such as aquatic herbs and algae. A semi-arid climatic pattern is also present in the Icatu record where a decline in the arboreal component is in synchrony with an increase of charred particles indicating higher natural or anthropogenic fire frequencies. Both dry scenarios are in agreement with the climatic phases given by Novello (2012), derived from isotopic data in cave speleothems in southern Bahia. These climatic scenarios are well supported by concentration values in the Catimbau pollen signal. One example of this trend is given by Myrtaceae which declined from 1,000 to 350 g/cc, however other elements expected to behave the same way such as *Cecropia*, Melastomataceae, Arecaceae and *Orbignya* (*Attalea*), followed a contrary pathway, and instead increased in the local landscape. The first two taxa are well known elements found in disturbed vegetation (Prather 2014, Shiels and González 2014, Rodríguez-Zorro et al. 2015), whereas the palm family, and particularly *Orbignya* (*Attalea*), are important taxa in cultural forests (Balée 2013).

The presence of *Orbignya* (*Attalea*) pollen in the Catimbau sediments was already attributed by Nascimento et al. (2009) to human manipulation of the vegetation at around 5,000 yrs BP. Our study shows the occurrence of the *Orbignya* (*Attalea*) pollen type as early as 9,000 cal. yrs BP, decreasing during the Mid-Holocene drying event and returning afterwards. Such distribution therefore might suggest Early Holocene human manipulation at the Catimbau site.

CONCLUSIONS

The pollen analysis carried out at the Catimbau site is indicative of an anomalous island of humidity amidst a semi-arid environment created and maintained by geological features such as the Mesozoic/Cenozoic fault systems that permitted the surfacing of ground water. This in turn has allowed this area to function as a refuge for arboreal and herb elements typically found in moist forest ecosystems such as *Cecropia*, *Cedrela*, *Simarouba*, *Piptadenia*, Melastomataceae, Myrtaceae, *Copaifera* as well as the conspicuous modern *Orbignya* (*Attalea*) palm.

The low geographical amplitude of the pollen signal obtained in this site, contrary to the Icatu sequence which appears to be in synchrony with regional climatic scenarios of NE Brazil, is still useful in determining the presence of nearby Caatinga by the fluctuating presence of *Ziziphus* pollen in all three zones of the Catimbau record.

The Mid-Holocene drying climatic signal, widely recognized by the Icatu pollen record and by $\delta^{18}O$ ratios in cave speleothems in NE Brazil, is likely to be represented by a long term sedimentation hiatus, lasting from 6,000 to 2,000 cal. yrs BP in the Catimbau.

The return of humid conditions both in the Catimbau and in the Bom Jesus site has left a signature in the sedimentation pattern of both locations, marked by higher sedimentation rates and radiocarbon ages inversions.

After *ca.* 500 cal yrs BP towards modern times the pollen signal at the Catimbau site demonstrates a gradual decrease in concentration values of taxa adapted to high levels of humidity such as aquatic herbs and algae. *Spatiphyllum*, for example, decreases from *ca.* 184,000 g/cc at 950 cal. yrs BP to *ca.* 78,000 g/cc in the modern surface of the deposit.

By and large, the Holocene records provided by these two new pollen diagrams, although representative of the local vegetation, do show the presence of *Ziziphus*, an important Caatinga indicator, that appeared to have tolerated a great deal of climatic change since the humid phases of the Early Holocene to the intensification of semi-arid climates since the Mid Holocene. However, such a pattern is very likely to be explained by its tolerance to wide precipitation ranges, varying from 315 mm to 1700 mm/year^{-1} (Gomes and Fernandes 1985), which is not expected to be found in most elements of the Caatinga flora.

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