Vegetation History and Archaeobotany
https://doi.org/10.1007/s00334-023-00930-4

ORIGINAL ARTICLE

A glimpse into shell mound builders' diet during mid-to-late Holocene on Marajó island

Lautaro Hilbert[1] · Daiana Travassos Alves[2] · Eduardo Góes Neves[1] · José Iriarte[3]

Received: 17 December 2022 / Accepted: 3 April 2023

Abstract
Shell mounds are anthropic intentional constructions produced by pre-Columbian fishing/gathering communities. They are generally composed of a primary layer of mollusc carapaces, fish bones and, in some cases, human burials. Our case study is the Tucumã shell mound located on western Marajó island. The site has two occupation components comprising the sequential formation of anthrosols: the shell mound layers buried under an Amazonian Dark Earth soil. We carried out phytolith analysis on a total of 37 samples to address the plant component of the Tucumã shell mound builders' subsistence strategies. Our results reveal the impact on the vegetation composition and plant dietary preferences throughout the occupation. Exceptionally, our research revealed the presence of domesticates such as maize (*Zea mays*) and squash (*Cucurbita* sp.) at ca. 4,000 year BP presenting the earliest evidence of these plants in the Marajó archipelago.

Keywords Shell mound builders · Eastern Amazonia · Mid Holocene · Maize · Phytoliths

Introduction

The Amazon basin is the largest rainforest in the world, encompassing approximately 6,500,000 km^2, an area greater than Europe. It incorporates a series of micro and macro-ecosystems such as lowland closed canopy rain forests, savannahs, inundated forests, and secondary forests (Condit et al. 1996). Far from the commonly referenced pristine tropical forest (Meggers 1971), some parts of the Amazon have human-constructed landscapes altered by ancient indigenous groups (Heckenberger et al. 2007). In several places along the Amazon River there is evidence of large pre-European occupations, as well as large-scale transformations of forest and wetland environments (Heckenberger et al. 2007). For instance, the late Holocene marajoara culture mound builders from eastern Marajó island are undisputed evidence for ancient Amazonian complex societies (Roosevelt et al. 1991; Schaan 2004). However, the human occupation of Marajo's western part is poorly understood. Our paper reports an archaeobotanical investigation of the mid-Holocene Tucumã shell mound from western Marajó, addressing plant consumption and food production. Although there have been a few recent advances (Hilbert et al. 2017; Lombardo et al. 2020; Furquim et al. 2021), the plant component of Amazonian mid-Holocene shell mound builders' diets has yet to be understood.

Shell mounds are intentional mound constructions built by pre-Columbian fishing, hunting (DeBlasis 2001) and gathering/horticultural communities (Scheel-Ybert 2003; Gaspar et al. 2008; Scheel-Ybert et al. 2010). Ranging from small mounds of two metres to larger ones up to 60 m high, they are composed of a primary layer of mollusc carapaces, fish bones, and, in some cases, human burials (Pugliese et al. 2018). Various functionalities of shell mounds have been identified, such as habitational purposes (Barbosa et al. 1994), funerary mounds (Fish et al. 2000), or monumental mounds (Fish et al. 2013). While this may be a broad classification of such occupations, it is noteworthy that shell mounds present regional-specific characteristics regarding the material culture, the constitutional structure of the sites,

Communicated by W. Out.

✉ Lautaro Hilbert
lmaxhilbert@yahoo.com.br

1 Museum of Archaeology and Ethnology, University of São Paulo, Av. Prof. Almeida Prado, 1466 - Butantã, São Paulo 05508-070, SP, Brazil

2 Department of Archaeology, Federal University of Pará, R. Augusto Corrêa, 01 - Guamá, Belém 66075-110, PA, Brazil

3 Department of Archaeology, University of Exeter, Laver Building, North Park Road, Exeter EX4 4QE, UK

Published online: 12 June 2023

and their functionality, highlighting their cultural context diversity.

Shell mounds have been reported in various locations in the Amazon, such as in Ecuador (Meggers et al. 1965), Colombia (Reichel-Dolmatoff 1972), Venezuela (Rouse and Cruxent 1963), Guiana (Evans and Meggers 1960), Bolívia (Lombardo et al. 2013) and Brazil (Pugliese et al. 2018). Even though the earliest information on the presence of Amazonian shell mounds in Brazil derives from historical and ethnographic accounts from the 18th and 19th centuries (Barbosa Rodrigues 1892), the first extensive survey in the Salgado region was carried out only in 1966, recording 62 archaeological sites, 42 classified as shell mounds (Simões 1981). As for the Marajó region, the Tucumã shell mound is amongst the 160 sites identified by the first systematic archaeological survey conducted in 2008 on western Marajó (Schaan et al. 2009).

The Tucumã shell mound comprises a dark soil area over a series of mound structures ca. 96 cm deep overall and spread over ~1,800 m^2 (Schaan and Silva 2013) dated between 4,425 and 4,245 and 1,693-1,523 cal BP (Hilbert 2017). Excavations revealed at least three cultural layers, comprising distinct cultural material, layers of gastropods and well-preserved bones (Schaan and Silva 2013, pp 72–73). In an examination of the stratigraphic layers of the Tucumã site, no burials and areas of activity that could be interpreted as housing were identified. Therefore, its functionality might have been that of a kitchen midden. Regarding its age, the site age falls within the Lower Amazon's Middle to Late Holocene occupations (Roosevelt 1995; Roosevelt et al. 1996) and the Amazon Atlantic coast groups of *Mina* pottery producers (Simões 1981; Schaan et al. 2009).

Our study provides data on the plant component of the Tucumã shell mound builders' subsistence strategies using phytolith proxies. A noteworthy fact is the presence of squash and maize phytoliths at the mound's base, suggesting the cultivation of these crops in the region for at least 4,000 cal BP and that mound builders were already engaged in incipient horticultural practices from the onset of the occupation, as previously assumed (Schaan 2004). Furthermore, our data support the broader Amazonian west-to-east maize dispersal based on archaeogenetic studies (Kistler et al. 2018) and indicate both maize and squash arrived in eastern Amazonia earlier than predicted (Kistler et al. 2018; Maezumi et al. 2018).

Study area

The Marajó macroregion (composed of the Marajó island and all adjacent smaller islands) encompasses an area of approximately 104,140 km^2 (Fig. 1) (IBGE 2022), about half the size of Great Britain. Climate is considered tropical humid with pronounced wet conditions from November to May and drier seasons from June to October (Sifeddine et al. 2001). The mean monthly precipitation ranges from 740 mm during the wet and 60 mm during the dry seasons, with an average annual temperature of 25 °C (Hermanowski 2014). Regarding its vegetation, the north-east Amazonian region comprises a mosaic of vegetation formation, including savannah (Nunes 2009; Hermanowski et al. 2012), evergreen tropical rain forests occurring along slopes and lowlands (Nunes 2009) and savannah/forest transition areas (Morellato and Rosa 1991).

Methods

Excavations were conducted in November 2015 based on the results from a previous fieldwork season (Schaan and Silva 2013). Schaan reports the area described as Excavation 4 (EU4) as the best-preserved regarding bioturbation and current human activities; according to her reports, this area was not damaged by a telephone tower built right on top of the southern portion of the shell mound (Schaan and Silva 2013). Accordingly, one 100 × 100 cm unit, three 50 × 50 cm in-site test pits, and one control test pit outside the shell mound's area (TP4) were excavated (Fig. 2). Soil samples were taken at 10 cm intervals, moving up the northern profile, and transferred into plastic sampling bags; the trowel was cleaned between samplings. In total, nine samples were taken from EU4, eleven from TP1, six from TP2, seven from TP3 and five from TP4. In-site test pits were excavated to investigate any variations in plant composition within the site; an off-site sample was collected to determine if there was any influence on vegetation in the vicinity of the shell mound during its occupation. For the sake of consistency, and given the matching results between EU4 and the three in-site test pits, we will only discuss EU4 and TP4 in this paper.

Phytolith processing and identification

Phytoliths from all samples were extracted using the wet oxidation method described by Piperno (2006) in the Archaeobotany Laboratory of the University of Exeter (UK).

Briefly, the process consists of a deflocculation stage in which 100 g of soil is mixed with 900 ml of 5% hexametaphosphate solution in a shaker for approximately 24 h

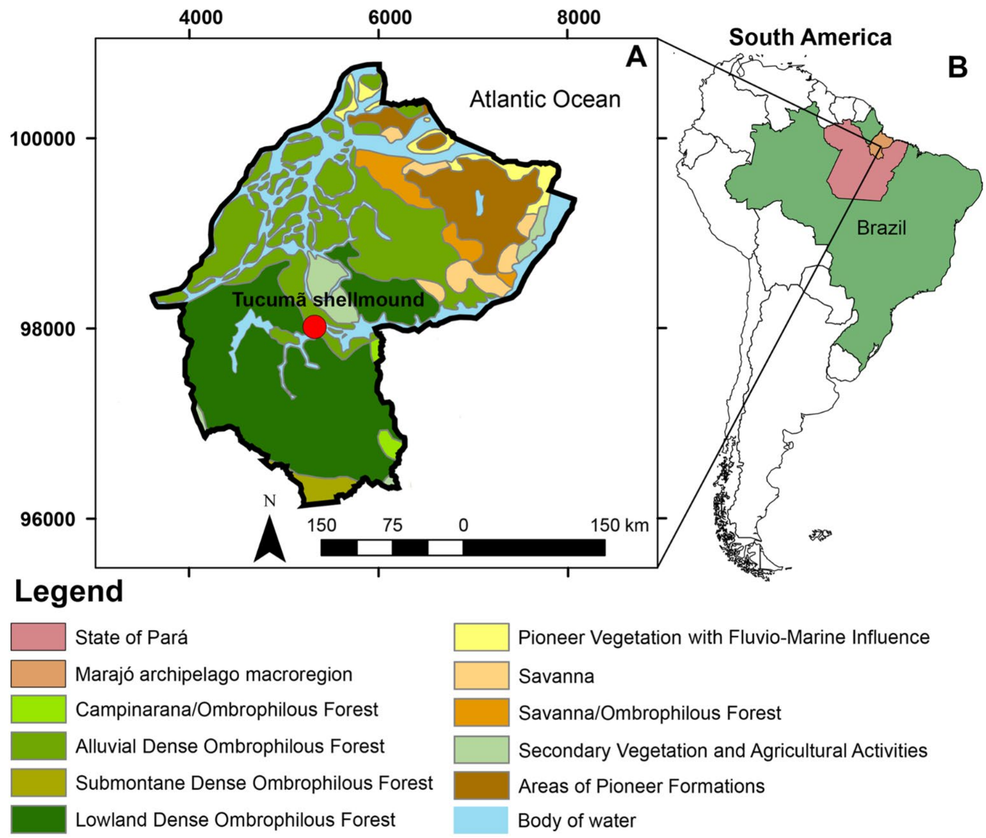


Fig. 1 Location of the Tucumã shell mound. (**A**) Marajó archipelago macroregion (UTM: 22 S 531,552 9,801,083). (**B**) Overview of South America highlighting the Pará state in Brazil. Vegetation definitions based on the Brazilian Institute of Geography and Statistics (IBGE) open-source ArcGIS base map files

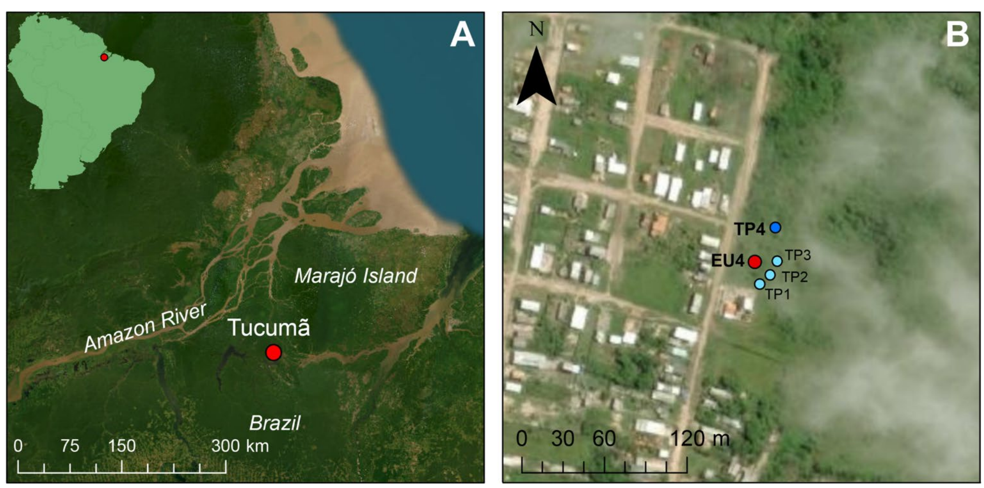


Fig. 2 Tucumã site location. (**A**) Map showing the location of the Tucumã site; (**B**) overview of the excavation unit and test pits. UTM coordinates: EU4, 22 S 531544 980161; TP1, 22 S 531546 9801041; TP2, 22 S 531553 9801047; TP3, 22 S 531558 9801057; TP4, 22 S 531558 9801079

to disaggregate the soil. A washing stage follows in which clays are removed using gravity sedimentation to ensure clean microscope slides. Next is a carbonate removal stage in which roughly 2 cm^3 of soil is transferred into separately labelled test tubes in which hydrochloric acid (HCl) is added to the samples to remove carbonates and iron oxides. This is followed by removal of organics from the soil using nitric acid (HNO_3), the samples in HNO_3 being heated to 100 °C for at least two hours. After the removal of organics, the samples are ready for the flotation stage. This process involves using a zinc bromide ($ZnBr_2$) solution with a density of approximately 2.30 g/cm^3 to separate phytoliths from the remaining sediment. The final stage consists of drying the samples and treating them with acetone. After at least 24 h, the samples are stored in accordingly labelled glass containers. Entellan™ was used to mount the phytoliths on the microscope slides. While fresh, Entellan™ enables the phytoliths to be rotated, leading to more convenient and accurate identifications.

Phytolith identifications were made using standard published material (e.g. Twiss et al. 1969; Pearsall et al. 1995; Boyd et al. 1998; Piperno and Pearsall 1998; Wallis 2003;

Chandler-Ezell et al. 2006; Piperno 2006; Iriarte and Paz 2009; Dickau et al. 2013; Watling and Iriarte 2013; Watling et al. 2016) and by direct comparison with the phytoliths from the reference collection of the Archaeobotany and Palaeoecology Laboratory in the Department of Archaeology of the University of Exeter. Phytoliths were identified, counted, and photographed under a Zeiss Axioscope 40 light microscope at 500× and 200× magnification. Measurements were conducted using Zen2 (blue edition version 2.0.14283.302) software, and objective calibration was done via a calibration slide. Phytolith slides were scanned at least three times at the standard 200 counts (Strömberg 2009; Pearsall 2015).

Apart from genus and species-specific phytoliths, the analysis included various other forms in the count, such as non-diagnostic Poaceae and non-diagnostic arboreal morphotypes. Furthermore, phytolith types produced by a broader range of plant taxa (higher taxonomic ranks), such as short and long polyhedral epidermal cells, hair bases and plain tracheid bodies (Piperno 2006), were excluded from the count. All samples (after the 200 phytolith count) were fully scanned for possible crop phytoliths. Ultimately, the resulting data were converted into percentage frequencies and plotted using C2 software (Juggins 2010).

Excavation results

The Tucumã shell mound comprises four layers (Fig. 3). In excavation 4 (EU4), Layer I (ca. 84–90 cm below surface) has a compacted sandy yellowish-brown soil (Munsell ref. 10YR 5/4) devoid of human remnants, corresponding to the site's natural stratum.

Layer II (ca. 37–84 cm below surface) corresponds to the pre-Columbian shell mound occupation, composed of whole and fragmented gastropod shells, potsherds, burnt clay, and dark yellowish-brown soil (10YR 3/4). A preliminary ceramic analysis indicates the sherds from this layer likely pertain to the Mina phase (Simões 1981), which would connect the Tucumã site with shell mounds from the Atlantic coast (Simões 1981). Additionally, the inferred chronological sequence of this layer is approximately 2,600 yrs BP: the base of the occupation (82 cm) was dated to 4,425-4,245 cal BP; the middle (75 cm) dates to 2,307-2,228 cal BP and the top dates to 1,695-1,647 cal BP.

Layer III (ca. 10–37 cm below surface) is composed of silt-clayed brown soil (10YR 3/3) filled mainly with potsherds instead of gastropod shell carapaces that are sparsely distributed throughout. Therefore, this layer likely corresponds to a renewed occupation of the area or a change altogether in subsistence strategies, dated to 1,629-1,569 cal BP (ca. 32 cm below surface). The pottery assemblage from

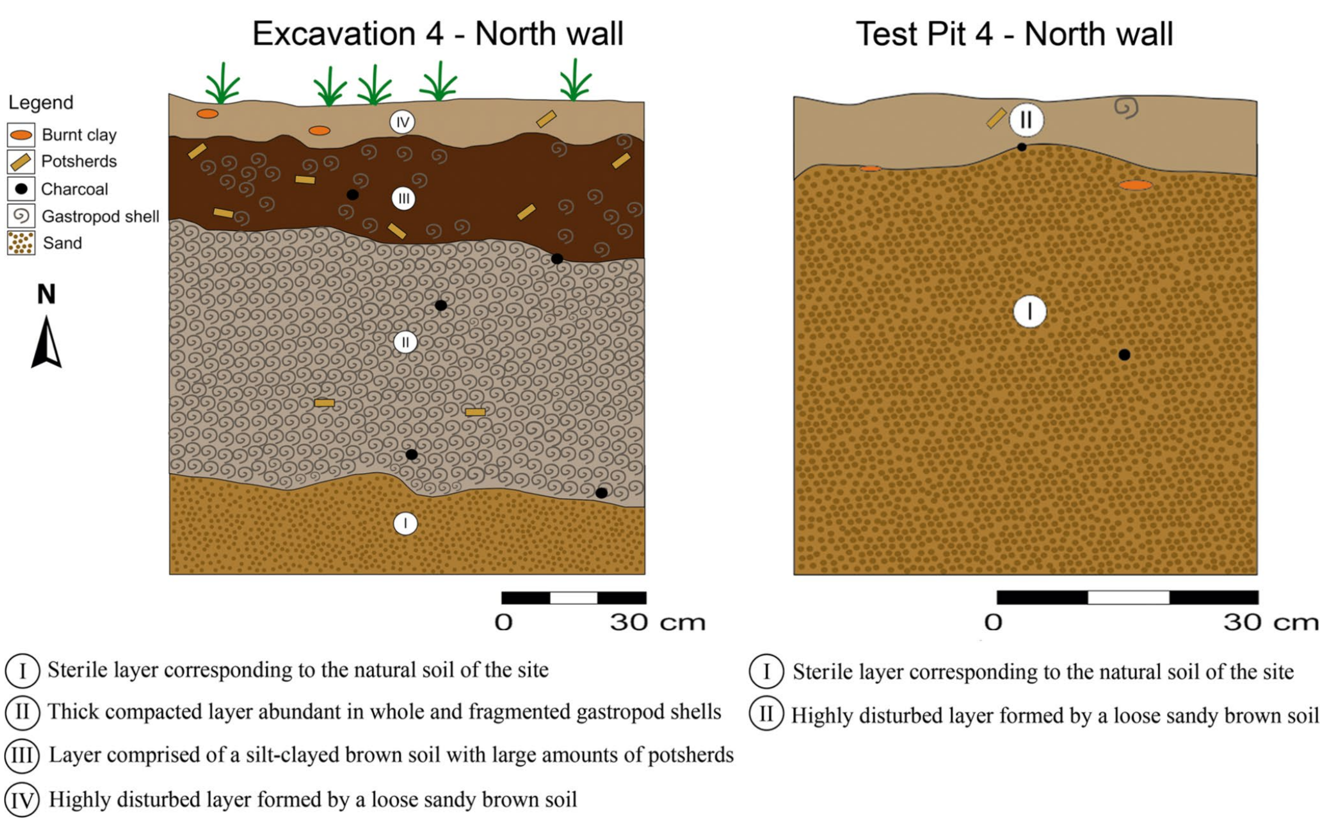


Fig. 3 North profile of Excavation 4 and Test Pit 4. (adapted from Hilbert 2017); image generated using Adobe Illustrator, Adobe Inc. 2019

Layer III corresponds to a distinct ceramic industry, corroborating the assumption of a different occupation. The ceramic analysis is currently being carried out, so further information will be available soon.

Layer IV (0–10 cm below surface) consists of the current surface level comprising highly disturbed soil due to the recent housing expanse in the area.

Test Pit 4 (TP4) revealed two layers: Layer I (ca. 10–50 cm below surface) presented a compacted yellowish brown (10YR 5/4) soil sterile in material culture. Layer II showed a loose sandy brown (10YR 3/3) soil abundant in crushed shells and small roots, akin to the surface layer identified in the overall shell mound's site area.

Overall, the excavations uncovered two distinct pre-Columbian cultural layers, which indicate two different occupations over time. The occurrence of diverse artefacts and the number of snail shells and bones determines these layers. The analysis of the stratigraphic layers indicates a long-term occupation, possibly with a slow deposition of cultural and faunal material in multiple mounds. The base of the shell mound and all the test pits were found over a compact latosol layer. The continuous occupation of the site is confirmed by the radiocarbon dates from EU4, shown in Table 1. Unfortunately, charcoal samples from TP4 were insufficient for dating.

Phytolith results

When comparing the test pits with EU4, all presented noticeable similarities. For example, we can observe a general decrease in arboreal morphotypes through the site's occupation, followed by an increase in herbs and grasses. Furthermore, all in-site test pits revealed the presence of maize exclusively in layer II. Additionally, palm proportions of cf. Mauritinae increase from layer II to layer III while cf. Attaleinae and phytoliths decrease in the same span. Given these matching results between EU4 and the three in-site test pits, for this paper we will focus our discussion only on EU4 and TP4 (An extended graph of the results is shown in ESM Fig. 1).

The phytolith diagram in Fig. 4 shows the relative frequencies of the phytolith assemblages from EU4 and TP4 (for more details on the recovered phytoliths, see ESM Table 1).

Arboreal phytoliths are dominant in Layer I, which precedes the shell mound builders' arrival. An increase in herbaceous and grass morphotypes at the expense of a decrease in arboreal ones follows the shell mounds' settlement (Layer II). Furthermore, Asteraceae, which are known human disturbance indicators (Piperno et al. 2015), exhibited a constant increase only after the beginning of the occupation. This pattern of a shift in the numbers of arboreal phytoliths in favour of grasses, herbs, and Asteraceae observed on TP4 and EU4 is likely a signal of forest clearance. During the following millennia of the mound builders' presence in the region, the immediate plant composition consisted of trees and palms, the latter slowly dominating the landscape. From the palm composition during this era, at least four possible taxa developed in the area: *Bactris*/*Astrocaryum* (Fig. 5-I), *Euterpe* sp. (Fig. 5-G), cf. Mauritinae (Fig. 5-J) and cf. Attaleinae (Fig. 5-K). Regarding domesticated crops during this occupation, Wavy-top rondels (Iriarte 2003) (Fig. 5-A) produced by maize (*Zea mays*) and Scalloped spheroids (Piperno et al. 2000) (Fig. 5-C) from squash (*Cucurbita* sp.) are present. Furthermore, commonly known foraging plants have been identified, such as possibly hackberries (*Celtis* sp. Figure 5-D), wild rice (*Oryza* sp. Figure 5-E) and likely soursop (Annonaceae Fig. 5-F).

Scalloped spheroid phytoliths from the squash rind were present in all units sampled. Measurement (ESM Table 2) analysis provided positive results for domesticated squash in most EU4 layers. Positive in layer II (50–60 cm, 60–70 cm and 70–80 cm), layer III (20–30 cm), and layer IV (0–10 cm). TP4 primarily generated negative results and positive only in layer IV (0–10 cm). Domesticated squashes produce larger (thickness and length) phytoliths; the criteria used for this research followed the investigations of Piperno et al. (2000) and Watling (2014). Squashes identified on the upper layers are likely from modern species. On the other hand, an unknown wild species conceivably produced squash phytoliths identified on lower levels of TP4.

A shift from the arboreal/palm composition occurred during the occupation associated with the third layer, in which palms were swapped for Asteraceae as the second most common phytolith identified. The lack of maize, neither cob nor leaf morphotypes, also characterizes this layer. Furthermore, this layer contained the only evidence of Heart-shaped phytoliths from cassava (Fig. 5-B). This evidence suggests a change in the subsistence system from a maize/squash-centric horticulture to a cassava/squash-centric one. Nonetheless, foraging species such as soursop, hackberries, and wild rice continue in this layer's phytolith assemblages,

Table 1 Radiocarbon dates for the Tucumã shell mound

Unit	Layer	Depth (cm)	Radiocarbon date (BP)	Cal yrs BP	Material	Reference
Ex4	III	32	1,720 ± 30	1,629-1,569 (94%)	Charcoal	Hilbert 2017
Ex4	II	41	1,730 ± 30	1,695-1,647 (92.5%)	Charcoal	Hilbert 2017
Ex4	II	75	2,160 ± 30	2,307-2,228 (94.5%)	Charcoal	I.D. Beta–361,794
Ex4	II	82	3,960 ± 30	4,425-4,245 (95%)	Charcoal	Hilbert 2017

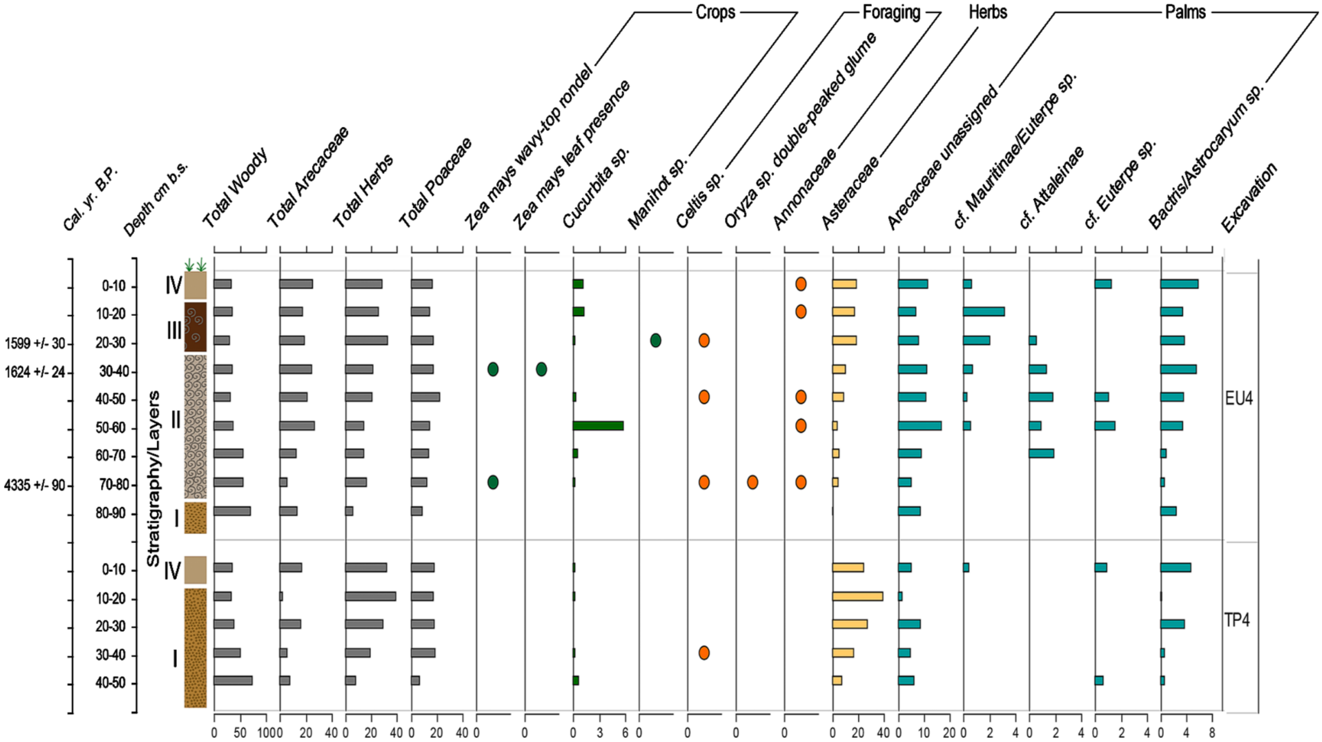


Fig. 4 Relative frequencies of phytoliths recovered in the Tucumã shell mound units. Horizontal bars represent percentages; circles correspond to presence of plant taxa lower than 1% in abundance

evidencing native elements of the post-shell mound inhabitants' diet.

The phytoliths recovered from the uppermost layer reflected the current vegetation assembly for the site's area. They correspond mainly with *Astracorayum* sp. palms (Tucumã), herbs, grasses, and various genera of dicotyledon trees.

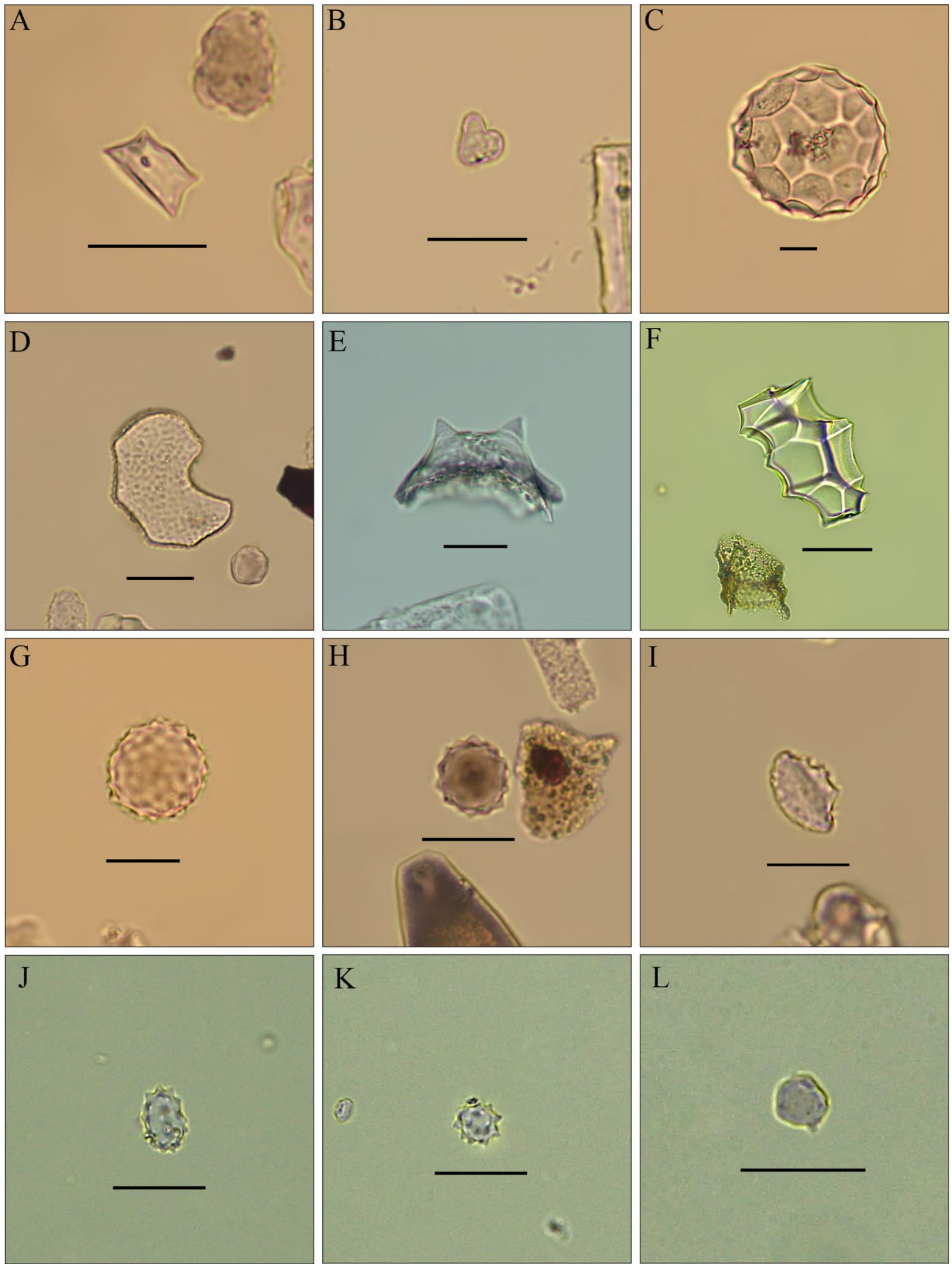
The control phytolith samples reveal a small window on the surroundings of the shell mound builders' long-term occupation. Overall, arboreal morphotypes decreased from the lower levels to the top. For instance, while herbs and grasses morphotypes increased, the arboreal morphotypes plummeted by about 42% during settlement. On the other hand, palm morphotypes fluctuate and only decrease considerably at the upper levels. Although the phytolith signature from TP4 reflects an in-situ result rather than a broader area, if these patterns are extrapolated to the general area, we suggest that open vegetation could have surrounded the mound during its occupation and that specific palm species, such as *Bactris*/*Astrocaryum*, were favoured by the shell mound occupants.

Discussion and conclusions

Located in the western part of the Marajó Archipelago, the Tucumã shell mound comprises two primary pre-Columbian layers distinguished by a typical shell mound structure and a second layer defined by dark brown soil with abundant potsherds. The radiocarbon dates provided by this study set the site's antiquity at 4,425-4,245 to 1,693-1,523 cal BP, placing it within the context of ancient shell mound builders of the eastern Amazon basin, and contemporaneous with the Mina pottery industry mounds (Simões 1981). Unfortunately, as previously stated, the site no longer exists, and the few vestiges, if any, are buried below a 30 m telephone tower.

This study provides a glimpse into the shell mound and post-shell mound inhabitants' diets, which included a mixture of crops and wild resources. It indicates mixed cropping and fruit tree management integrating their subsistence strategies following a broader mid-Holocene Amazonian pattern (Lombardo et al. 2020; Furquim et al. 2021). However, our data show a shift in the crops cultivated from maize to cassava, likely pointing to separate events during the sites' occupation. As aforementioned, phytoliths from the cob and leaf of maize were recovered exclusively in the shell mound layer (II), suggesting that it was commonly grown in the area from its first occurrence at ca. 4,000 year BP onwards. This is the earliest maize record for the Marajó

Fig. 5 Microphotographs of phytoliths identified and their taxonomic and anatomical associations. (**A**) *Zea mays* cob, WAVY-TOP RONDEL (EU4 30–40 cm); (**B**) *Manihot* sp. secretory cell, HEART-SHAPED (EU4 20–30 cm); (**C**) *Cucurbita* sp. rind, SCALLOPED SPHEROID (EU4 50–60 cm); (**D**) *Celtis* sp. seed/fruit, STIPPLED PLATE (EU4 20–30 cm); (**E**) *Oryza* sp. husk, DOUBLE-PEAK GLUME (EU4 40–50 cm); (**F**) Annonaceae leaf, SPHEROID FACETATE (EU4 40–50 cm); (**G**) cf. *Euterpe* sp. all plant parts, LARGE DENSE SPHEROID ECHINATE (EU4 50–60 cm); (**H**) Arecaceae all plant parts, GLOBULAR ECHINATE (TP4 30–40 cm); (**I**) *Bactris*/*Astrocaryum* all plant parts, CONICAL to HAT-SHAPED body (EU4 70–80 cm); (**J**) cf. Mauritinae/*Euterpe* sp. all plant parts, SPHEROID ECHINATE ELONGATE (EU4 40–50 cm); (**K**) cf. Attaleinae all plant parts, SPHEROID ECHINATE symmetric (EU4 40–50 cm); (**L**) Non Diagnostic Arboreal SPHEROID GRANULATE from all parts of the plant (TP4 30–40 cm); scale bars = 20 µm



archipelago, its presence formerly only conjectured (Brochado 1980; Roosevelt et al. 1991).

Interestingly, this evidence matches the proposed west-east maize dispersion pattern (~4,300 yrs BP), indicating that it likely disseminated across the Amazon from southwest to east after a change of the partially-domesticated to domesticated crop (Kistler et al. 2018). In addition, it corroborates the premise of a strong link between maize and anthrosol formation in Amazonia (Iriarte et al. 2020), broadening the anthrosol studies and reinforcing the diversity of land-use practices involved in maize cultivation and domestication. Furthermore, the possible clearing event observed in the phytolith records right after the arrival of the shell mound builders, alongside the presence of maize and squash from the beginning of the occupation, suggests a prior understanding and intention of managing a specific area for cultivation. These facts indicate that maize and squash were introduced in the region earlier than expected.

Palms were the most common plant resources the Tucumã shell mound builders exploited, showing a gradual increase in palm phytolith frequency in the archaeological units. The number of palm morphotypes identified is not surprising since palms have been among the most important plants used by Amazonian populations for over

10,000 years (Morcote-Ríos and Bernal 2001; Robinson et al. 2021). Our evidence suggests that palms constituted a significant part of layer III of the Tucumã occupation, particularly *Bactris*/*Astrocaryum*, considered Amazonian hyperdominants (Ter Steege et al. 2013). Accordingly, the site's name comes from the *Astrocaryum* sp. common name, tucumã. Tucumã used to cover the site area, showing this plant's ongoing importance in the region. Moreover, there is a shift in the proportions of cf. Attaleinae and cf. Mauritinae phytoliths from layer II to layer III. Both palms are disturbance indicators associated with anthrosol formation and intensive land use in SW Amazonia (Maezumi et al. 2022), and with construction materials within archaeological sites (Watling et al. 2020). Therefore, the abundance of cf. Attaleinae in the shell mound component replaced by cf. Mauritinae, in the post-mound one, evidenced a change in the preference for specific palms related to the broader cultural transition on the Tucumã Site; however this was not exclusively related to their consumption as foodstuffs.

Furthermore, palm fruits contain more protein and carbohydrates than maize (Newman 1990). Yet, the palms' general use could include as construction materials, fuel or medicines, given that the shell mound builders had a mixed economy. Therefore, the gradual increase in palm phytoliths recovered throughout the Tucumã occupation, and the swapping of maize with cassava in the upper layers, indicates a clear shift in management practices.

The reported shift in dietary practices observed between layers II and III could result from the increased wetter conditions reported for the late Holocene (Hermanowski et al. 2012). Assuming that the mound builders were cultivating maize in the lowland regions, the consequent decrease in land availability and resulting soil water saturation could have played a part in the change in cultivation strategies or even the abandonment of the site followed by a different occupation. Also, the observed decrease in arboreal morphotypes throughout the occupation is likely an in-situ occurrence and not necessarily due to the shift to wetter conditions. As previously stated for layer III, the absence of maize, on top of cassava cultivation and preferential care for certain palm species, indicates a change in diet followed by a different approach to manipulating the environment. Moreover, the observed increase in cf. Mauritinae morphotypes in layer III might also be a response to wetter conditions, pointing to coupled ecological and cultural factors affecting the palm signature in the site. Nevertheless, as with the previous occupation, the change in precipitation also affected the site's final abandonment, considering rainy conditions could have hindered its new horticultural practices.

Among the wild resources exploited by the shell mound builders, the phytolith data suggest the possible adoption of soursop (*Annona* sp.) and hackberries (*Celtis* sp.) in its diet throughout its occupation. While invariably recovered in the shell mound, the phytoliths related to the Marantaceae family could not be associated directly with araruta (*Maranta arundinacea*) or any other known root crop from this taxon. Still, the presence of phytoliths related to the root of this family could mean that the Tucumã inhabitants were foraging or managing some Marantaceae species.

Most archaeological investigations on the Marajó Archipelago have focused on the eastern portion (Schaan and Martins 2010). Little is known about the human occupation of the island's western portion (Schaan and Silva 2013). This investigation reports insights regarding the potential horticulture practices of the shell mound and post-shell mound occupations in the west Marajó Archipelago, including the earliest records of maize and squash in eastern Amazonia. Furthermore, the adoption of cassava and the shift in palm plants in the second cultural component indicate a distinct subsistence strategy to circumvent the environmental changes at the onset of the late Holocene. We highlighted these different plant management systems by the Tucumã occupants. Nonetheless, we highly encourage further archaeobotanical research on other multicomponent shell-mound sites to expand these results.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s00334-023-00930-4.

Acknowledgements The research was funded by the European Research Council project 'Pre-Columbian Amazon-Scale Transformations' (ERC-CoG 616179) to J.I. L.H. and E.G.N. are funded by The São Paulo Research Foundation (FAPESP) project 'Human-Environment Relationships in pre-Columbian Amazonia' (2020/02485-5; 2019/07794-9). D.T.A. is funded by the National Council for Scientific and Technological Development (CNPq) project 'Cultural Forests and territoriality in the Pre-Columbian Amazon Coast' (422288/2021-7). We thank Denise Schaan for her support at different stages of this work.

Author contributions L.H. designed the research. L.H. and D.T.A. conducted the archaeological excavation. L.H. carried out the phytolith analysis. L.H. and D.T.A. wrote the paper with help of E.G.N and J.I.

Declarations

Conflict of interest The authors declare no competing interests.

References

Barbosa Rodrigues J (1892) Antiguidades do Amazonas. Vellosia 2:1–40

Barbosa M, Gaspar MD, Barbosa DR (1994) A organização espacial das estruturas habitacionais e distribuição dos artefatos no sítio Ilha da Boa Vista I, Cabo Frio - RJ. Rev Mus Arqueol Etnol 4:31–38. https://doi.org/10.11606/issn.2448-1750.revmae.1994.109193

Brochado JP (1980) The social ecology of the Marajoara culture. University of Illinois, Urbana. MA Thesis

Boyd WE, Lentfer CJ, Torrence R (1998) Phytolith analysis for a wet tropics environment: methodological issues and implications for the archaeology of Garua island, West New Britain, Papua New Guinea. Palynology 22:213–228. https://doi.org/10.1080/01916122.1998.9989510

Chandler-Ezell K, Pearsall DM, Zeidler JA (2006) Root and tuber phytoliths and starch grains document manioc (*Manihot esculenta*), arrowroot (*Maranta arundinacea*), and llerén (*Calathea* sp.) at the Real Alto site, Ecuador. Econ Bot 60:103–120. https://doi.org/10.1663/0013-0001(2006)60[103:RATPAS]2.0.CO;2

Condit R, Hubbell SP, Foster RB (1996) Assessing the response of plant functional types to climatic change in tropical forests. J Veg Sci 7:405–416. https://doi.org/10.2307/3236284

DeBlasis PAD (2001) Da Era das Glaciações às Origens da Agricultura: Uma das mais antigas culturas do Território Brasileiro. Brasil 50 mil anos: uma viagem ao passado pré-colonial. Editado por Museu de Arqueologia e Etnologia, Universidade de São Paulo, Edusp, pp 12–26

Dickau R, Whitney BS, Iriarte J et al (2013) Differentiation of neotropical ecosystems by modern soil phytolith assemblages and its implications for palaeoenvironmental and archaeological reconstructions. Rev Palaeobot Palynol 193:15–37. https://doi.org/10.1016/j.revpalbo.2013.01.004

Evans C, Meggers BJ (1960) Archaeological Investigations in British Guiana, South America. Bureau of American Ethnology Bulletin 177. US Government Printing Office, Washington, DC

Fish PR, Fish SK, DeBlasis P, Gaspar MD (2013) Monumental shell mounds as persistent places in southern coastal Brazil. In: Thompson VD, Waggoner JC (eds) The archaeology and historical ecology of small scale economies. University Press of Florida, Gainesville, pp 120–140. https://doi.org/10.5744/florida/9780813042428.003.0007

Fish SK, DeBlasis P, Gaspar MD, Fish PR (2000) Eventos incrementais na construção de sambaquis, litoral sul do Estado de Santa Catarina. Rev Mus Arqueol Etnol 10:69–87. https://doi.org/10.11606/issn.2448-1750.revmae.2000.109378

Furquim LP, Watling J, Hilbert LM et al (2021) Facing change through diversity: resilience and diversification of plant management strategies during the mid to late Holocene transition at the Monte Castelo Shellmound, SW Amazonia. Quaternary 4:8. https://doi.org/10.3390/quat4010008

Gaspar MD, DeBlasis P, Fish SK, Fish PR (2008) Sambaqui (shell mound) societies of coastal Brazil. In: Silverman H, Isbell WH (eds) Handbook of South American Archaeology. Springer, New York, pp 319–335. https://doi.org/10.1007/978-0-387-74907-5

Heckenberger MJ, Russell JC, Toney JR, Schmidt MJ (2007) The legacy of cultural landscapes in the brazilian Amazon: implications for biodiversity. Philos Trans R Soc B 362:197–208. https://doi.org/10.1098/rstb.2006.1979

Hermanowski B (2014) Pleistocene and Holocene environmental changes in the brazilian Amazon region, PhD Thesis edn. University of Goettingen, Goettingen. https://doi.org/10.53846/goediss-4371

Hermanowski B, da Costa ML, Carvalho AT, Behling H (2012) Palaeoenvironmental dynamics and underlying climatic changes in southeast Amazonia (Serra Sul dos Carajás, Brazil) during the late Pleistocene and Holocene. Palaeogeogr Palaeoclimatol Palaeoecol 365–366:227–246. https://doi.org/10.1016/j.palaeo.2012.09.030

Hilbert LM (2017) Investigating Plant Management in the Monte Castelo (Rondônia-Brazil) and Tucumã (Pará-Brazil) Shell Mound Using Phytoliths Analysis. PhD Thesis, University of Exeter, Exeter. http://hdl.handle.net/10871/30060

Hilbert L, Neves EG, Pugliese F et al (2017) Evidence for mid-holocene rice domestication in the Americas. Nat Ecol Evol 1. https://doi.org/10.1038/s41559-017-0322-4. :1,693-1,698

IBGE (Instituto Brasileiro de geografia e Estatística) (2022) http://www.ibge.gov.br/home/. Accessed June 2022

Iriarte J (2003) Assessing the feasibility of identifying maize through the analysis of cross-shaped size and three-dimensional morphology of phytoliths in the grasslands of southeastern South America. J Archaeol Sci 30 :1,085 – 1,094. https://doi.org/10.1016/S0305-4403(02)00164-4

Iriarte J, Paz EA (2009) Phytolith analysis of selected native plants and modern soils from southeastern Uruguay and its implications for paleoenvironmental and archeological reconstruction. Quat Int 193:99–123. https://doi.org/10.1016/j.quaint.2007.10.008

Iriarte J, Elliott S, Maezumi SY et al (2020) The origins of amazonian landscapes: plant cultivation, domestication and the spread of food production in tropical South America. Quat Sci Rev 248:106582. https://doi.org/10.1016/j.quascirev.2020.106582

Juggins S (2010) C2 version 1.6.7. Software for ecological and palaeoecological analysis and visualization. School of Geography, Politics & Sociology, Newcastle University, Newcastle upon Tyne

Kistler L, Maezumi SY, Gregorio de Souza J et al (2018) Multiproxy evidence highlights a complex evolutionary legacy of maize in South America. Science 362. https://doi.org/10.1126/science.aav0207. 1,309-1,313

Lombardo U, Szabo K, Capriles JM et al (2013) Early and middle Holocene hunter-gatherer occupations in western Amazonia: the hidden shell middens. PLoS ONE 8:e72746. https://doi.org/10.1371/journal.pone.0072746

Lombardo U, Iriarte J, Hilbert L, Ruiz-Pérez J, Capriles JM, Veit H (2020) Early holocene crop cultivation and landscape modification in Amazonia. Nature 581:190–193. https://doi.org/10.1038/s41586-020-2162-7

Maezumi SY, Alves D, Robinson M et al (2018) The legacy of 4,500 years of polyculture agroforestry in the eastern Amazon. Nat Plants 4:540–547. https://doi.org/10.1038/s41477-018-0205-y

Maezumi SY, Elliott S, Robinson M et al (2022) Legacies of indigenous land use and cultural burning in the bolivian Amazon rainforest ecotone. Philos Trans R Soc Lond B 377:20200499. https://doi.org/10.1098/rstb.2020.0499

Meggers BJ (1971) Amazonia: Man and Culture in a Counterfeit paradise. Aldine-Atherton, Chicago

Meggers BJ, Evans C, Estrada E (1965) Early formative period of coastal Ecuador: the Valdivia and Machalilla phases. Smithsonian Contributions to Anthropology 1. Smithsonian Institution Press, Washington, DC. https://doi.org/10.5479/si.00810223.1.1

Morcote-Ríos G, Bernal R (2001) Remains of palms (Palmae) at archaeological sites in the New World: a review. Bot Rev 67:309–350. https://doi.org/10.1007/BF02858098

Morellato LP, Rosa NA (1991) Caracterização de alguns tipos de vegetação na região amazônica, Serra dos Carajás, Pará, Brasil. Rev Bras Bot 14:1–14

Newman A (1990) Tropical rainforest: a world survey of our most valuable and endangered habitat with a blueprint for its survival. Facts on File, New York

Nunes JA (2009) Florística, estrutura e relações solo-vegetação em gradiente fitofisionômico sobre canga, na Serra Sul, FLONA de Carajás - Pará. PhD Thesis, Universidade Federal de Viçosa, Viçosa. http://locus.ufv.br/handle/123456789/2510

Pearsall DM (2015) Paleoethnobotany: a handbook of procedures. Left Coast Press, Walnut Creek

Pearsall DM, Piperno DR, Dinan EH, Umlauf M, Zhao Z, Benfer RA Jr (1995) Distinguishing rice (*Oryza sativa* Poaceae) from wild Oryza species through phytolith analysis: results of preliminary research. Econ Bot 49:183–196. https://doi.org/10.1007/BF02862923

Piperno DR (2006) Phytoliths: a comprehensive guide for archaeologists and paleoecologists. AltaMira Press, Lanham

Piperno DR, Pearsall DM (1998) The silica bodies of tropical American grasses: morphology, taxonomy, and implications for grass systematics and fossil phytolith identification. Smithsonian Contributions to Botany 85. Smithsonian Institution Press, Washington, DC. https://doi.org/10.5962/bhl.title.103722

Piperno DR, Andres TC, Stothert KE (2000) Phytoliths in *Cucurbita* and other neotropical Cucurbitaceae and their occurrence in early archaeological sites from the lowland american tropics. J Archaeol Sci 27:193–208. https://doi.org/10.1006/jasc.1999.0443

Piperno DR, McMichael C, Bush MB (2015) Amazonia and the Anthropocene: what was the spatial extent and intensity of human landscape modification. in the Amazon Basin at the end of prehistory? Holocene 25. https://doi.org/10.1177/0959683615588374. 1,588-1,597

Pugliese FA, Zimpel Neto CA, Neves EG (2018) What do amazonian Shellmounds tell us about the long-term indigenous history of South America? In: Smith C (ed) Encyclopedia of global archaeology. Springer, Cham, pp 1–25. https://doi.org/10.1007/978-3-319-51726-1_3030-2

Reichel-Dolmatoff G (1972) The feline motif in prehistoric San Agustín sculpture. In: Benson EP (ed) The cult of the feline: A Conference in Pre-Columbian Iconography, October 31st and November 1st, 1970. Dumbarton Oaks Research Library and Collection, Trustees for Harvard University, Washington, DC, pp 51–68

Robinson M, Morcote-Ríos G, Aceituno FJ, Roberts P, Berrío JC, Iriarte J (2021) Moving South': late pleistocene plant exploitation and the importance of palm in the colombian Amazon. Quaternary 4:26. https://doi.org/10.3390/quat4030026

Roosevelt AC (1995) Early pottery in the Amazon: twenty years of scholarly obscurity. In: Barnett WK, Hoopes JW (eds) The emergence of pottery: technology and innovation in ancient societies. Smithsonian Institution Press, Washington, DC, pp 115–131

Roosevelt AC, Housley RA, Imazio da Silveira M, Maranca S, Johnson R (1991) Eighth millennium pottery from a prehistoric shell midden in the brazilian Amazon. Science 254. https://doi.org/10.1126/science.254.5038.1621. 1,621-1,624

Roosevelt AC, Lima da Costa M, Lopes Machado C et al (1996) Paleoindian cave dwellers in the Amazon: the peopling of the Americas. Science 272:373–384. https://doi.org/10.1126/science.272.5260.373

Rouse I, Cruxent JM (1963) Venezuelan archaeology. Yale University Press, New Haven

Schaan DP (2004) The Camutins chiefdom: rise and development of social complexity on Marajó island, Brazilian Amazon. PhD Thesis, University of Pittsburgh, Pittsburgh

Schaan DP, Martins CP (2010) Muito além dos campos: arqueologia e história na Amazônia Marajoara. Gknoronha, Belém - Parà

Schaan D, Silva EP (2013) Programa de Arqueologia e Educação Patrimonial nas Áreas de Influência. Direta e Indireta do Empreendimento Lt Ilha do Marajó

Schaan D, Martins C, Silva W, Portal V (2009) Inventário do Patrimônio Arqueológico. Marajó das Florestas e Santa Cruz do Arari-Ilha de Marajó/PA. UFPA/IPHAN

Scheel-Ybert R (2003) Relações dos habitantes de sambaquis com o meio ambiente: evidências de manejo de vegetais na costa sul-sudeste do Brasil durante o Holoceno Superior. Atas do IX Congresso da Associação Brasileira de Estudos do Quaternário e II Congresso do Quaternário de Países de Línguas Ibéricas

Scheel-Ybert R, Caromano CF, Cascon LM, Bianchini GF, Beauclair M (2010) Estudos de paleoetnobotânica, paleoambiente e paisagem na Amazônia Central e o exemplo do sudeste-sul do Brasil. Arqueologia Amazônica 2:909–935

Sifeddine A, Martin L, Turcq B, Volkmer-Ribeiro C, Soubiès F, Cordeiro RC, Suguio K (2001) Variations of the amazonian rainforest environment: a sedimentological record covering 30,000 years. Palaeogeogr Palaeoclimatol Palaeoecol 168:221–235. https://doi.org/10.1016/S0031-0182(00)00256-X

Simões MF (1981) Coletores-pescadores ceramistas do litoral do Salgado (Pará). Nota Preliminar. Museu Paraense Emílio Goeldi, Belém. http://repositorio.museu-goeldi.br/handle/mgoeldi/223

Strömberg CAE (2009) Methodological concerns for analysis of phytolith assemblages: does count size matter? Quat Int 193:124–140. https://doi.org/10.1016/j.quaint.2007.11.008

Ter Steege H, Pitman NCA, Sabatier D et al (2013) Hyperdominance in the amazonian tree flora. Science 342:1243092. https://doi.org/10.1126/science.1243092

Twiss PC, Suess E, Smith RM (1969) Morphological classification of grass phytoliths. Soil Sci Soc Am J 33:109–115. https://doi.org/10.2136/sssaj1969.03615995003300010030x

Wallis L (2003) An overview of leaf phytolith production patterns in selected northwest australian flora. Rev Palaeobot Palynol 125:201–248. https://doi.org/10.1016/S0034-6667(03)00003-4

Watling JG (2014) Environmental Impact of the Pre-Columbian Geoglyph Builders of Western Amazonia. PhD Thesis, University of Exeter, Exeter. http://hdl.handle.net/10871/16386

Watling J, Iriarte J (2013) Phytoliths from the coastal savannas of french Guiana. Quat Int 287:162–180. https://doi.org/10.1016/j.quaint.2012.10.030

Watling J, Almeida F, Kater T et al (2020) Arqueobotânica das ocupações ceramistas na Cachoeira do Teotônio. Bol Mus Para Emílio Goeldi Cienc Hum 15:e20190075. https://doi.org/10.1590/2178-2547-BGOELDI-2019-0075

Watling J, Iriarte J, Whitney BS et al (2016) Differentiation of neotropical ecosystems by modern soil phytolith assemblages and its implications for palaeoenvironmental and archaeological reconstructions II: Southwestern amazonian forests. Rev Palaeobot Palynol 226:30–43. https://doi.org/10.1016/j.revpalbo.2015.12.002