

**INVESTIGATING PLANT MANAGEMENT IN THE MONTE
CASTELO (RONDÔNIA- BRAZIL) AND TUCUMÃ (PARÁ-
BRAZIL) SHELL MOUNDS USING PHYTOLITHS ANALYSIS**

Submitted by Lautaro Maximilian Hilbert to the University of Exeter
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Lautaro Maximilian Hilbert

2017

ABSTRACT

Shell mound or sambaqui, as commonly named in Brazil, are anthropic intentional mound constructions made by complex hunter-gatherer fishing communities. Typically distributed along shorelines and inland regions of Brazil, these sites are arguably one of the earliest evidence of human presence in South America, with dates ranging from 910-660 to 10,179-9,708 cal. yr. B.P. As archaeobotanical investigations reported the presence of various plant resources in these sites, a debate that has received much attention in recent years is regarding the scale of which the shell mound builders managed these resources.

The Monte Castelo (9,495-9,137 cal. yr. B.P - state of Rondônia) and the Tucumã shell mound (4,425-4245 cal. yr. B.P. - state of Pará) will be the case studies of this research. The aim of this thesis is to use phytolith data from archaeological contexts in order to evaluate and discern the extent to which these mound builders managed plant resources.

The outcome of this study provides novel evidence revealing the management and consumption of wild and domesticated plants through the mid-Holocene. The data calls for an evaluation on the potential scale of horticulture practices by Amazonian shell mound builders as well as the relative contribution of each domesticated resources to the indigenous diet.

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It's been four years, four long years since I started my PhD research. Upon realising that after one year of work the initial project I intended to investigate had to be ultimately dismissed, I felt pressured to find a new subject or I would have to give up the PhD altogether. The initial failure led me to the most challenging years of my life. However, as it is mostly the case, opportunities will arrive accompanied by a string of unexpected circumstances. By the time of the abandonment of my initial project, Eduardo Neves and his team got the permits to excavate the Monte Castelo shell mound. Fortunately, my supervisor, José Iriarte got the opportunity to talk to Eduardo asking if they needed someone to investigate the microbotanical remains of this site. Fortunately, again, Eduardo was still on the fieldwork preparations and agreed to collect soil samples for me. If any of these circumstances had unravelled a couple of months sooner or even later, I would have missed this opportunity altogether and probably would not have finished this thesis. Now, it was up to me to make the best of what was given.

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LIST OF ABBREVIATIONS

b.d.	bellow datum
b.s.	bellow surface
ca.	circa
d.v.	dorsal view
MC	Monte Castelo
TUC	Tucumã
TP	Test Pit
v.v.	ventral view

“Big things have small beginnings”

Lawrence of Arabia (Best Picture, 1962)

INTRODUCTION

This thesis will address and evaluate the plant management of the shell mound archaeological sites of Monte Castelo (9,495-9,137 cal. yr. B.P.), Miller 2002 - state of Rondônia) and Tucumã (4,425-4245 cal. yr. B.P. - state of Pará), using phytolith remains. The focus on identifying and evaluating the plant-based dietary characteristics of these specific pre-Colombian settlements derives from the principle that the south and south-east Brazilian shell mound occupants are known to have had a broad-spectrum diet, derived from their utilisation of the environment (DeBlasis et al., 2007, Figuti, 1992, Gaspar, 1999, Lima, 1991). The mound inhabitants are referred to in modern dietary studies as fisher-hunter and plant gathering societies (Figuti, 1992, Figuti, 1993, Gaspar, 1999, Gaspar et al., 2008, Kneip, 2009, Rossetti and De Toledo, 2006, Scheel-Ybert, 2003, Scheel-Ybert et al., 2010). However, the presence of plant-processing tools at the Monte Castelo and Tucumã Amazonian mounds leads to the main question that guides this research: is it possible to comprehend the Amazonian mound inhabitants of Monte Castelo and Tucumã as part of a sustainable agricultural society?

Further on, this study will combine the archaeological discourse on the formation and development of these sites (DeBlasis et al., 2007) with an analysis of the plant domestication centres (Clement et al., 2010) in south-west lowland Amazonia (Clement et al., 2010, Piperno, 2011, Sanjur et al., 2002). Accordingly, to guide this thesis, a paleobotanical perspective will be taken, whereby the principles of botany and archaeology will be used to infer the plant dietary preferences of these ancient anthropogenic formations. Whenever possible, dates were calibrated using OxCal version 4.3 using the standard IntCal 13 calibration (<https://c14.arch.ox.ac.uk/oxcal/OxCal.html>).

The six chapters of this thesis are presented and summarised below. Chapter 1 presents, firstly, a synthesis of the discussions devoted to the Brazilian shell mound formation and the investigation done in the identification of plants remains. The relationship between the environment in which these structures are found and the faunal and floral remains suggests a particular selectivity process regarding climate and geoenvironmental domains (Bandeira, 2008, DeBlasis et al., 1998a, DeBlasis et al., 2014, DeBlasis et al., 2007, Gaspar et al., 2008, Neves, 1984, Scheel-Ybert, 2001, Wagner, 2009). Next, a description of the study area is presented to gather primary data on the utilisation of the environment by the shell mound builders. Parallel to the discussions on the dietary preferences of the mound builders, there will be a brief focus on the geophysics of the south-west Amazonian lowlands.

The objective of Chapter 2 is to present studies devoted to the likely domestication of plant species in the south-west Amazonian lowland study area: manioc (*Manihot esculenta*), peach-palm (*Bactris gasipaes*), chilli peppers (*Capsicum baccatum*) and squash (*Cucurbita maxima*). The Andean domesticated species that are assumed to have converged and influenced the technological array of the Monte Castelo mound (Neves and Pugliese, 2016) will also be considered.

The third chapter introduces the main tools used to address the research in question: the extraction, counting and measurement techniques applied to microfossils. Phytolith studies will be the main method utilised for the identification of the plant diversity for the Monte Castelo and Tucumã shell mounds. The decision to use microfossil remains derives from the fact that little conservation of macro and pollen remains occurs in tropical climate regions (Scheel-Ybert, 2001, Scheel-Ybert, 2003, Scheel-Ybert et al., 2010).

The fourth chapter will present the excavation results, stratigraphy, chronology and soil sampling procedures for each site investigated. The soil samples analysed for the Monte Castelo site derive from the 2014 excavation conducted by Eduardo Neves and his team. All soil samples investigated in this study were obtained from soil profiles of test pits and excavation units.

Chapter 5 will describe the phytoliths identified in this study. The results are described individually for each shell mound excavated. Phytolith abundance and measurements parameters will have sub-chapters of their own. Lastly, a

brief description is presented on the faunal remains identified for the Tucumã shell mound.

As a final point, the sixth chapter discusses the results derived from the data and information presented in the previous sections. The conclusions drawn from the Monte Castelo and Tucumã mounds about environmental utilisation will widen the current archaeological discussions in the understanding of the plant dietary practices of these pre-Columbian occupations.

CHAPTER 1

BRAZILIAN FRESH-WATER SHELL MOUND INVESTIGATIONS

This chapter provides an overview of the Brazilian shell mound investigations. The chapter is divided into two parts. The first part will concentrate on research regarding plant management by the shell mound population, micro remains and phytolith studies and the fresh-water lowland Amazonian mounds. The second part presents the lowland Amazonian study area and an analysis of previous research in the shell mounds.

1. SUMMARY ON BRAZILIAN SHELL MOUNDS

Shell mounds - or sambaqui (the name derived from the Tupi language meaning mound of shells), as they are termed in Brazil - are anthropic intentional mound constructions produced by complex pre-Columbian fishing-hunting communities. In general terms, sambaquis are sites composed of a primary layer of mollusc carapaces, fish bones and, in some cases, human burials in which anthropic artefacts made of shells, bones or stone are typically present. These sites present ranging sizes from small mounds of two meters and larger ones with up to 60 meters in high (DeBlasis , 2001). While this may be a broad way to classify these occupations, it is important to note that shell mounds do present regional specific characteristics in regards to the cultural

material, the constitutional structure of the sites, as well as its functionality, demonstrating the diversity of its related cultural contexts. For this thesis, the term shell mound will be used interchangeably when referring to the sambaqui archaeological sites.

The Brazilian shell mounds have a significant geographical amplitude being present in almost all of the coast and in some riverine areas. There are records of these structures by the coastal strip from Rio Grande do Sul to Bahia and from Maranhão to the coast of Pará, including the Lower Amazon (Gaspar, 1998). Additionally, most shell mounds are found in highly productive bay regions, estuarine areas (Gaspar et al., 2008) and near lakes (Bandeira, 2011).

Overall, most of the Brazilian shell mounds present dates ranging from 10,560-10,269 to 910-660 cal. yr. B.P. and are found from most of the Atlantic coast to the lowland Amazon region (Fig. 1.1). In regards to the age and location of the south and southeastern mounds, some of the earliest recorded dates derive from riverine sites, such as 10,560-10,269 cal. yr. B.P. for the Capelinha (Neves et al., 2005) and 10,503-9,898 cal yr B.P. for the Batatal-I site (Figuti et al. 2013). While most of the south and southeastern coastal mounds revealed dates ranging from 6,882-67,95 to 1,989-1,924 cal yr. B.P. (Lima et al., 2002), early Holocene sites such as the Algodão mound have presented dates as ancient as 8,988-8,478 cal yr. B.P. (Lima et al., 2002). The differences in the ages have led scholars (e.g. DeBlasis et al. 2007) to postulate that the discrepancies could be due to the early and mid-Holocene marine regression and transgression (Ab'Sáber , 1979, Angulo and Suguio, 1995, Colinvaux et al., 2000). Therefore, from the end of the Pleistocene most of the shell mounds were destroyed or submerged, presenting the lack of early shell-mound evidence for this region. While this does present a rather plausible argument, the presence of early sites such as the Algodão mound adds questions regarding the antiquity of coastal sites for the eastern Brazilian. Furthermore, as stated by Lima (1999/200 p. 316), there probably is not a single and homogeneous socio-cultural order along the Brazilian central-southern coast shell mounds but probably is the result of different systems (Lima, op cit.).

Regarding the antiquity of Amazonian in-land mounds, studies have revealed dates as early as 8,034-7,705 cal. yr. B.P. for Taperinha (Roosevelt , 1995) and 9,495-9,137 cal. yr. B.P. for the Monte Castelo shell mound (Miller , 2002). While for shell mounds from the coast of Pará, most dates stem from a

series of investigations done near the coast of Salgado by the Museu Paraense Emílio Goeldi team (Salgado Project) during 1968 and 1977. The results have revealed dates ranging from 3,842-3,649 cal. yr. B.P. for Ponta das Pedras to 6,662-6,021 cal. yr. B.P. for Uruá mound. Unfortunately, no other study has been made on the coast of Pará, and the data collected by the Salgado project did not contribute much to the understanding of human coastal adaptations in northern Brazil.

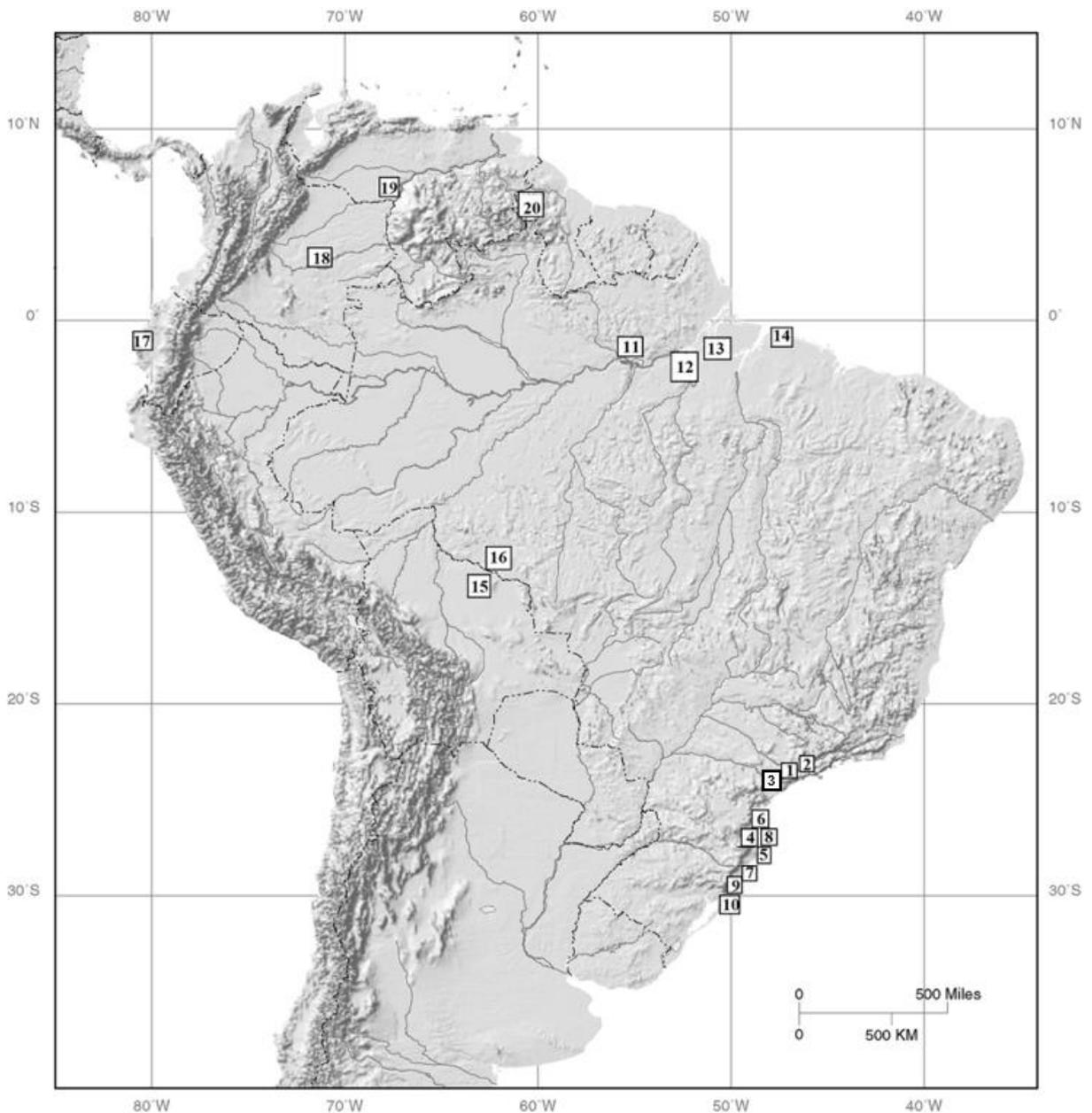


Figure 1.1. Shell mound mentioned in text. 1-10: South/ southeast mounds. 1-2: Fresh water mounds. 1: Ribeira do Iguape; 2: Capelinha. 3-10 coastal mounds. 3: Moraes; 4: Jabuticabeira; 5: Morro do Ouro; 6: Enseada; 7: Forte Marechal Luz; 8: Itacoara; 9: Marambaia I; 10: Figueira II. 11-14: South-east Amazonian lowland mounds. 11-13 fresh-water mounds. 11: Castália; 12: Taperinha; 13 Tucumã. 14. Salgado coastal mounds. 15-16 South-west Amazonian lowland mounds. 15. Llano de Moxos; 16: Monte Castelo. 17 Peruan mound; 18. Colombian mound; 19: venezualan mound; 20: Guinean mound (DeBlasis, 2005, DeBlasis et al., 2007, Evans and Meggers, 1960, Hilbert, 1959, Lombardo et al., 2013, Pereira, 2013, Reichel-Dolmatoff, 1972,

Roosevelt and Housley, 1991, Rouse and Cruxent, 1963, Scheel-Ybert, 2003, Simões, 1981, Wesolowski, 2009).

In Brazil, shell mounds were described in the sixteenth century by early European explorers (e.g. Agassiz and Agassiz, 1868, Cardim, 1583 [2009], de Acuña, 1641 [1986], De Carvajal et al., 1541 [1941], de Heriarte, [1964]). Since the nineteenth century the study of shell mounds has been continuous in Brazilian archaeological literature (Fig. 1.2) (Gaspar, 1999).

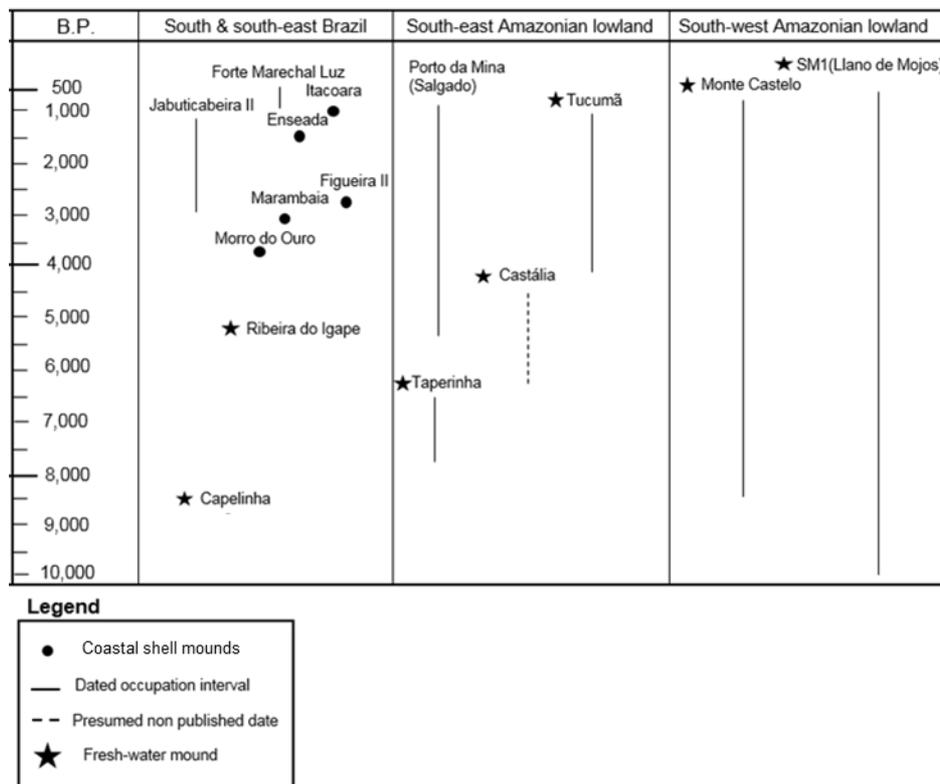


Figure 1.2. Chronological chart for the cited shell mounds south/south-east America, south-east Amazonian lowland and south-west Amazonian lowland (DeBlasis, 2005, DeBlasis et al., 2007, Evans and Betty, 1960, Hilbert, 1959, Lombardo et al., 2013, Pereira, 2013, Reichel-Dolmatoff, 1972, Roosevelt et al., 1991).

1.1. South and Southeastern Brazilian Shell Mound Studies

Despite the fact that shell mounds have been identified and referenced for over a century (Barbosa Rodrigues, 1892, Hartt, 1885, Hartt and Agassiz, 1870, Penna, 1876), the study of these sites in Brazil has not been done homogeneously (DeBlasis et al., 1998b). The first modern archaeological research probably began around the 1950's. These investigations (Empeaire, 1955, Empeaire and Laming, 1956, Faria, 1952) were mostly concentrated in the south and southeast regions with a focus on the states of São Paulo and Paraná (DeBlasis et al., 1998b). The main contribution of these researchers comprises the result of a series of radiocarbon dates which provided for a

chronological framework for the middle to late-Holocene coastal landscape occupation (DeBlasis et al., 1998b). During the 1960's, with the onset of new interpretive approaches, researchers have mostly described the shell mounds as debris of successive episodes of an occupation of simple mobile fisher-gatherers (Beck, 1972, Garcia, 1972, Kneip, 1977, Prous et al., 1977, Rauth, 2007). The lack of thorough investigation of these sites led to a rather simple perspective throughout the sixties and seventies (DeBlasis et al., 1998b). This scenery gradually changed during the 1980s and 1990s with the onset of extensive investigation on sites of Rio de Janeiro and most recently on Santa Catarina (Wagner et al., 2011).

When analysed as a whole, the shell mounds studies carried out in the South, and Southeast coast of Brazil allows the establishment of evidence to support the claims for complex fisher-hunter-gatherer societies (Arnold, 1996, DeBlasis et al., 1998b, Escórcio and Gaspar, 2012, Gaspar et al., 2011, Koyama and Thomas, 1981, Price and Brown, 1985).

Various functionalities for the shell mound have been identified (Barbosa et al., 1994, DeBlasis et al., 1998a, Duarte, 1968, Fish et al., 2000, Gaspar, 1996a). For example, the evidence for long continuous occupation has been reported by Tiburtius (1966), who has identified features in the Conquista site that seem to have served for housing purposes, presenting this mound as a habitational shell mound. Additionally, housing structures have been observed in the Ilha da Boa Vista shell mound (Barbosa et al., 1994) and in the Espinheiros site in which shell platforms appear to have been built for habitational purposes (Afonso and De Blasis, 1994).

Further evidence of functionality of southern and southeastern shell mounds is given, for example, in the Jaboticabeira II site (Fish et al., 2000). Investigations on this site has revealed the presence of various burial pits, hearths, and postholes starting on the surfaces of successive mound levels, providing evidence for both exclusive funerary function and incremental building-up of the mound (Fish et al., 2000)

Another example of functionality could be attributed to larger shell mounds, in which its function is to provide spatial and cultural landmarks (DeBlasis et al., 1998b). The dependence of the mound builders upon coastal, and lagunar resources might have led these communities to a higher degree of territorial circumscription, which might grant some of the bigger mounds to a

sole function to display such situation, as observed in the case of the northern shores of Rio de Janeiro (Deblasis 1998b).

Furthermore, differential treatment of the dead (Fish et al., 2000), ideological exchange (Lima and Mazz, 1999), and social and gender hierarchy (Escórcio and Gaspar, 2012) have also been recognised. In conclusion, all the data seems to support the notion that complex fisher-hunter-gatherer society constructed the south and southeastern shell mounds.

1.2. Amazoninan Shell Mounds Studies

The Amazon basin (Fig. 1.3) encompasses approximately 6,500,000 km² (Miles et al., 2004). It is composed largely of lowland regions, flanked by the Andean mountain ranges to the west and the Guiana Shield to the north (Miles et al., 2004). The Amazon basin includes territory belonging to nine nations: Brazil, Peru, Colombia, Venezuela, Ecuador, Bolivia, Guyana, Suriname and French Guiana; it represents over half of the planet's remaining rain forests over an area larger than Europe (Heckenberger et al., 2007). Divided into a series of ecosystems, the Amazon forest consists of: *terra firme* rain forest composed of closed canopy vegetation; savannahs occurring in regions with annual rainfall under 2000 mm; inundated forests supported by seasonally flooded riverine habitats (Miles et al., 2004); and secondary forest composed of pioneer community occupying areas where forest has been cleared (Condit et al., 1996).

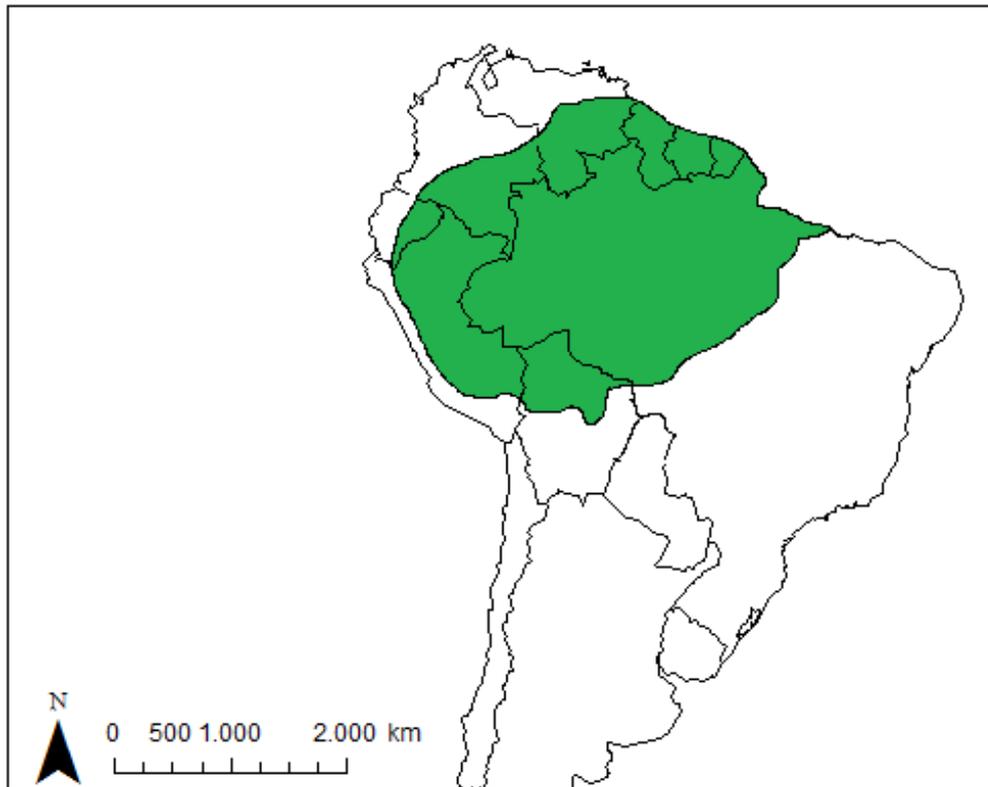


Figure 1.3. Amazon basin.

Rather than the commonly referenced pristine tropical forest, some regions in the Amazon are claimed to be a constructed landscape, dramatically altered by ancient indigenous groups (Heckenberger et al., 2007). Occurring in several areas along the Amazon River with evidence of large pre-European occupations and large-scale transformations of forest and wetland environments (Heckenberger et al., 2007), the presence of shell mound structures in the Amazon region has been described in various locations, such as Ecuador (Meggers et al., 1965), Colombia (Reichel-Dolmatoff, 1972), Venezuela (Rouse and Cruxent, 1963), Guiana (Evans and Meggers, 1960) Brazil (Simões, 1981) and Bolivia (Lombardo et al., 2013).

The earliest available information on the presence of shell mounds for North Brazil (State of Pará) derives from historical and ethnographic accounts of the 18th and 19th centuries (Barbosa Rodrigues, 1892; Ferreira Penna, 1876). These reports have stated the presence of mounds from the Trombetas river bank, passing through the lower Amazon, down the Tocantins and the Marajó archipelago reaching the northeast coast of the Salgado area, which in turn stretches from the Bay of Marajó to The mouth of the river Gurupi (da Silveira and Schaan, 2005). However, It was only in 1966 that researchers linked to the National Program of Archaeological Research (PRONAPA) carried out a first

and extensive survey in the Salgado region. The results of this study registered 62 archaeological sites, of these 46 were classified as shell mounds (Simões , 1981).

The shell mounds investigated were mostly classified as being oval, ranging from 25m by 30m and 130m by 170m with stratified deposits of mollusc shells, a small amount of fish bones and crustaceans and low quantity of terrestrial faunal bones (Simões, 1981). From the mounds excavated, only two presented burials in them, one in the Ponta de Pedras (5,446-4,866 cal. yr. B.P.) and one in the Porto da Mina (6,317-5,475 cal. yr. B.P.) shell mound (Simoes, 1978, 1981). Additionally, the carbon samples collected from these two mounds yielded one of the oldest radiocarbon dates for the Amazon region at the time, placing the *Mina* phase as the earliest in Brazil and between the earliest of the Americas (Simões, 1981).

While the work of the PRONAPA researchers was pioneer in the Salgado region, the overall available data did not lead to a conclusion on the coexistence between the settlements or an assessment of the intensity of the occupation in the same site (Silveira and Schaan, 2005), as well as the distribution of areas of activity within the site.

The description of south-east and south-west Amazonian shell mounds is included because of their importance to the archaeological knowledge about cultural development in Amazonia. The sites also provide comparable data to help comprehend the formation and development of the Monte Castelo and Tucumã shell mounds.

In the south-east Amazon, one of the most renowned sites is the Taperinha shell mound. This site was first identified by Charles F. Hartt in 1870 and revisited later in 1987 by Anna Roosevelt (Roosevelt and Housley, 1991). The mound is located near the River Tapajos and the city of Santarém (Fig. 1.4). This region became important around the tenth century, when the Tapajos Chiefdom arose (da Silveira and Schaan, 2005). Taperinha is classified as a circular mound containing circa 48 different strata composed of soil, mollusc shells, charcoal, bones, lithic artefacts (hammerstones and grinders) and ceramic fragments (Roosevelt et al., 1991 p.1622); no designation on the nature of the structure was provided (for example, habitational or monumental). The macro remains identified in this site suggest the consumption of essentially three species of molluscs: *Castalia ambigua*, *Paxyodon ponderosus* and

Triplodon corrugatus, as well as turtles and fish (Roosevelt et al., 1991). The most important aspect of this site is the presence of pottery associated with layers dated to 8,050-7,705 and 7,995-7,675 cal. yr. B.P., which represents the oldest occurrence of ceramics in the Americas (Roosevelt et al., 1991). To date there has not been any archaeobotanical study on the site.

In the south-west Amazon, the presence of early Holocene mounds indicates the successful human adaptation to seasonally flooded savannah and forest ecotones (Lombardo et al., 2013). Recently Lombardo et al. (2013) identified and analysed three early and middle Holocene shell mounds in the Llanos de Moxos (Fig. 1.4). The stratum of approximately 150 cm below the current surface of the savannah was dated to 10,774-10,510 cal. yr. B.P., which placed these sites in the early Holocene and revealed the oldest western Amazonian occupation to date (Lombardo et al., 2013). As with most shell mounds, the stratigraphic matrix of the Llano de Moxos sites had a predominance of mollusc carapaces (various species of apple snails *Pomacea* spp.), with a wide range of fragmented vertebrate faunal remains including brocket deer (*Mazama* sp.) and marsh deer (*Blastocerus dichotomus*), as well as the fish, reptiles and birds which composed part of the diet of its inhabitants (Lombardo et al., 2013). Pottery, bone tools and human bones were dated to the late Holocene (Lombardo et al., 2013). No archaeobotanical investigation was carried out at these sites.

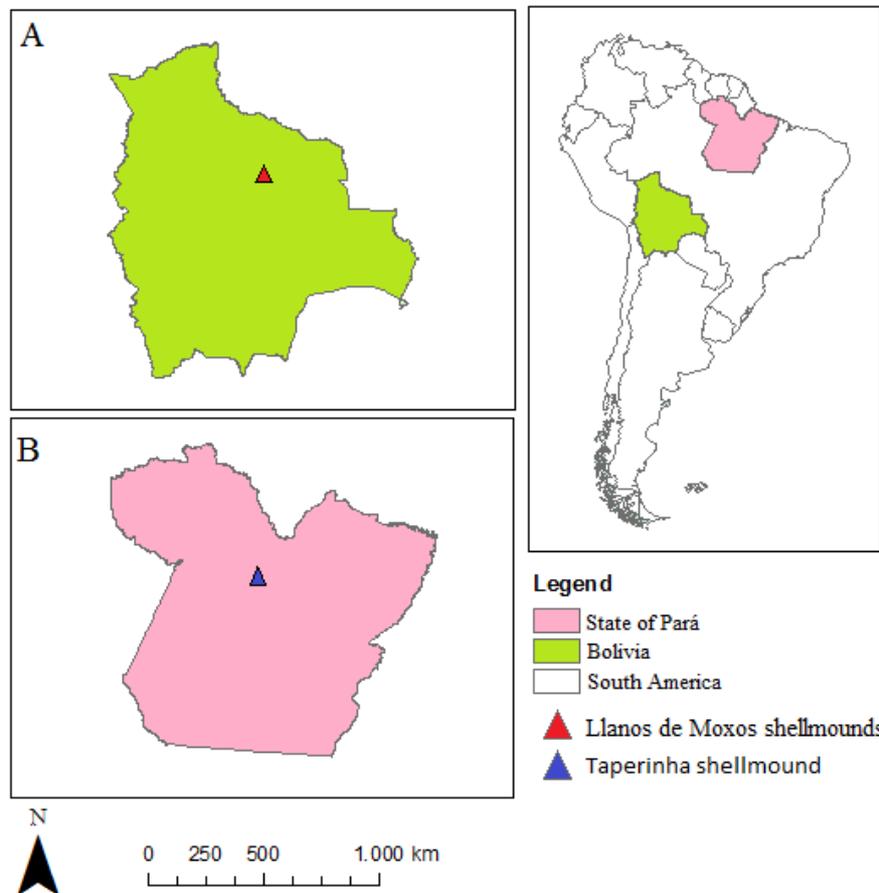


Figure 1.4. Delimitation of south-east and south-west Amazonian shell mounds. Triangles indicate relative location. **(A)** Bolivia, Llano de Moxos sites; **(B)** Brazilian state of Pará Taperinha shell mound.

1.3. Differences Between South/Southeastern and Amazonian Shell Mounds

As previously stated, the definition of shell mound used in this thesis will be that of sites composed of a primary layer of mollusc carapaces, fish bones and, in some cases, human burials in which anthropic artefacts made of shells, bones or stone are typically present (DeBlasis, 2001). While this is a general form of classification for these sites, it is important to note that shell mounds do present regional specific characteristics in regards to the cultural material, the constitutional structure of the sites, as well as its functionality, demonstrating the diversity of its related cultural contexts. Accordingly, if taken by its definition, the northern and southern coastal mounds are notably similar. Both sites have a stratigraphic matrix based on mollusc carapaces, with the presence of fish bones, stone tools and in some cases, burials.

However, in the case of northern and northeastern shell mounds, the main characteristic which differs them from the southern and southeastern sites is the presence of pottery. This feature brings to question the relationship

between the shell mound builders of this two regions in regards to the context of identity between South American mound builders. It is possible that pottery, as well as the zooliths of the south and southeastern mounds, comprise a marker of the social identity of these major shell mound groups (Gaspar and Silveira, 1999). Furthermore, the pottery found in northern shell mounds are amongst the oldest in the Americas.

In contrast to the southern Brazilian shell-mound studies, the coast of Pará has had limited investigations, with the PRONAPA team performing most of the research in this region. This limitation hinders a clear comparison between shell mounds from the north of the country and the southern/southeastern region. Additionally, as previously stated, the data collected by the Salgado project did not contribute much to the understanding of the human coastal adaptations. Nonetheless, researchers have tried to establish, based on what is known about the southern and northern shell mounds, a supposed correlation between all the sites in the country (Gaspar 2000a, Gaspar and Imazio 2000). However, it does not seek to understand the regional aspects that characterise the shell mounds of the Amazonian Atlantic Coast, from systematic excavations and the detailed analysis of the archaeological record. This divergence reflects the lack of studies that can base the theoretical constructions of the researchers on shell mounds of the North coast (Silveira and Schaan, 2005). While the significant number of sites in this region can offer substantial support for understanding the process of occupation and settlement of this part of the populations that inhabited the Amazonian Atlantic coast, the lack of investigation in this region is inversely proportional to its area.

1.4. Diet of the Shell-Mound Builders

Considering the dynamics of the shell mound builders' socio-cultural system and the Holocene coastal dynamic (Guimarães, 2013), these sites have increased in frequency along the inland from the south/south-eastern coast of Brazil (da Silveira and Schaan, 2005). This increase is associated with the spread of the basic subsistence system of the mound inhabitants which was based on fishing, gathering and hunting (da Silveira and Schaan, 2005).

The only source of information about the shell mound societies derives from the mounds and the burials found within them (Scheel-Ybert, 2003). It is

therefore important to note that the amount of remains deposited depends on both the type of food and its potential preservation quality (Gaspar, 1999).

Due to the abundance of mollusc remains and the likelihood of their preservation, it was initially conjectured that the diet of the mound builders was composed mainly of gastropods and bivalves (Gaspar et al., 2008). Biomass and zooarchaeological studies in both northern and southern mounds have proposed an assorted diet composed largely of fish (Figuti, 1992, Figuti and Klökler, 1996, Gaspar et al., 2008, Hilbert, 2011, Silveira and Schaan, 2005, Miller 2002). The exploitation of the environment also included fauna such as seagulls, penguins, seals, turtles and crustaceans (e.g. da Silveira and Schaan, 2005, Figuti, 1992, Figuti, 1993, Kern, 1991, Lima and Mazz, 1999, Lima, 1991).

But the presence of plant processing tools such as grinding stones, mortars, pylons and milling utensils also suggests the handling and consumption of various types of plants (Miller, 2002, Kneip, 2009, Scheel-Ybert, 2003, Scheel-Ybert et al., 2010). Shell mound builders are usually referred to as fisher-hunter-gatherers (Gaspar, 1991, Gaspar, 2003), and despite the frequency of the aforementioned tools in these sites (DeBlasis et al., 1998a, Kneip, 1980, Kneip, 1994, Tenório, 1995), few authors have suggested that plant gathering, plant management and the use of domesticated plants (e.g. Tenório, 1995; Scheel-Ybert, 2001, Scheel-Ybert, 2013) could have been practiced by the shell mound people (Boyadjian, 2007, Boyadjian, 2012, Kneip, 2009, Scheel-Ybert, 2001, Scheel-Ybert, 2003, Scheel-Ybert and Solari, 2005). This research hiatus is mainly the result of the conservation level of macrobotanical remains in a humid tropical environment, where carbonised vestiges are almost the only remains to survive (e.g. Scheel-Ybert et al., 2010).

To date, only in some rare cases, macrobotanical remains such as artefacts made of wood or fibres have been recovered in shell mounds (Afonso and De Blasis, 2016, Peixe et al., 2007). Overall, the study of macro plant remains has identified, predominantly, palm nuts (Gaspar et al., 2008, Kneip, 2009, Lima and Mazz, 1999, Scheel-Ybert, 2001, Scheel-Ybert, 2003, Scheel-Ybert et al., 2010) and roots and tubers (such as *Dioscorea* sp. - yams). The latter has mainly been interpreted as a complement to a diet mainly based on marine resources (Lima, 1999, Scheel-Ybert, 2003).

Even though plant gathering by the southern and southeastern populations has always been implicitly recognised (Scheel-Ybert et al., 2010), it has tended to be seen as a negligible or secondary activity. Recent studies from several areas indicate that in addition to an economy essentially based on fishing and the exploitation of aquatic resources, plant food had a greater importance than previously assumed (Scheel-Ybert, 2001, Scheel-Ybert, 2013). Anthracology data and bioanthropological analyses of oral pathologies suggest that tubers of some species of *Dioscorea* and *Cucurbita* sp. could represent part of an incipient agriculture by the shell mound builders (Bianchini and Scheel-Ybert, 2012b). However, in regards to northern Amazonian mounds, investigations regarding the cultivation and the consumption of plants remain, to date, poorly understood.

1.4.1. Microremains and phytoliths studies in Brazilian shell mounds

The study of archaeobotany is considered a young field in Brazil (Scheel-Ybert, 2013). Due to the low survival rate of macrobotanical remains in tropical humid environments (Scheel-Ybert et al., 2010), only a few sites in dry and/or specific regions such as in Central Brazil, Amazonian caves, rock shelters (Kipnis, 2002, Magalhães, 1997, Roosevelt et al., 1996, Scheel-Ybert and Solari, 2005, Shock, 2010) and waterlogged remains in shell mounds (Heredia and Conceição Beltrão, 1980, Peixe et al., 2007, Santos et al., 2000) have produced a suitable amount of plant vestiges (Scheel-Ybert, 2013). As a result, recent studies (Boyadjian, 2007, Boyadjian, 2012, Pereira, 2013, Wesolowski, 2009, Wesolowski et al., 2007) have relied on microfossil remains to better understand the shell mound formation.

Boyadjian (2007, 2012) analysed phytolith and starch grain remains recovered from dental calculus of two southeastern Brazilian mounds (Moraes and Jabuticabeira II). The elevated number of starch grains over the amount of phytoliths led her to conclude that the inhabitants had a probable diet based on tuber, roots and maize (*Zea mays*). Furthermore, her investigations found no difference in the relationship between sexes (Boyadjian, 2007). While the identification of phytoliths were mostly of Poaceae (grasses) morphotypes, their presence in the dental calculus were associated with medicinal practices (Boyadjian, 2012).

Studies on dental calculus were also made by Wesolowski (2007). A study of five distinct skeletal series (53 burials altogether) belonging to four south-east Brazilian coastal shell mounds (Morro do Ouro, Enseada, Forte Marechal Luz and Itacoara) was carried out to compare the inhabitants' dietary preferences with dental wear. The identification of phytoliths revealed the presence of grasses, palms and *Araucaria* nuts (Euphorbiaceae, Panicoideae, Bambusoideae, *Araucaria angustifolia*, Marantaceae, Bromeliaceae and Arecaceae) while the identification of starch grains suggested the existence of palm species, yam and maize (Wesolowski et al., 2007). The occurrence of yam granules in only two skeletal series, which also had a higher prevalence of caries, suggests that increased consumption of such tubers is one of the factors involved in the manifestation of this type of tooth decay in the group (Wesolowski et al., 2007). Therefore, the higher frequency in caries, combined with lower variability of starch grain and phytolith morphotypes, suggests an intensive and concentrated consumption of fewer plant species. It could also be indicative of an incipient horticulture practice. On the other hand, a greater variability in starch grain and phytolith frequencies and low caries occurrence from three skeletal series could suggest a greater emphasis on plant gathering rather than horticulture (Wesolowski, 2007 p.205).

In regards to sediment analysis, Pereira (2008) studied phytoliths of two southern coastal mounds (Marambaia I and Figueira II), focussing on understanding the environment in which the mounds were formed. The identification revealed the presence of palm trees, grasses and sedges. The findings were interpreted as an advance of the savannah over the coastal line (Pereira, 2008 p.95) and no discussion regarding plant manipulation was made.

Due to the low preservation of macrobotanical remains in tropical regions, researchers have adopted the study of microfossils in order to address questions regarding plant manipulation and consumption. The advances in microfossil studies have provided reliable data in the field of shell mound investigations in Brazil (e.g. Wesolowski, 2007, Boyadjian 2012). In conclusion, while shell mound builders are considered fisher hunter-gatherers, complementary studies in phytoliths and starch grains show great potential to reveal new aspects of the still misunderstood subsistence system of the shell mound population.

2. THE SOUTH-WEST AMAZONIAN LOWLAND STUDY AREA

The Monte Castelo shell mound is located in the state of Rondônia, inside the Biological Reserve of Guaporé which covers an area of approximately 6.000 km² (Fig. 1.5) (IBGE, 2017). The vegetation is classified as a transitional ecotone of dense rain forest consisting mostly of palm trees (e.g. *Orbignya speciosa*, *Euterpe precatoria* and *E. oleracea*) with expansion of grass savannah fields (INMET, 2017).

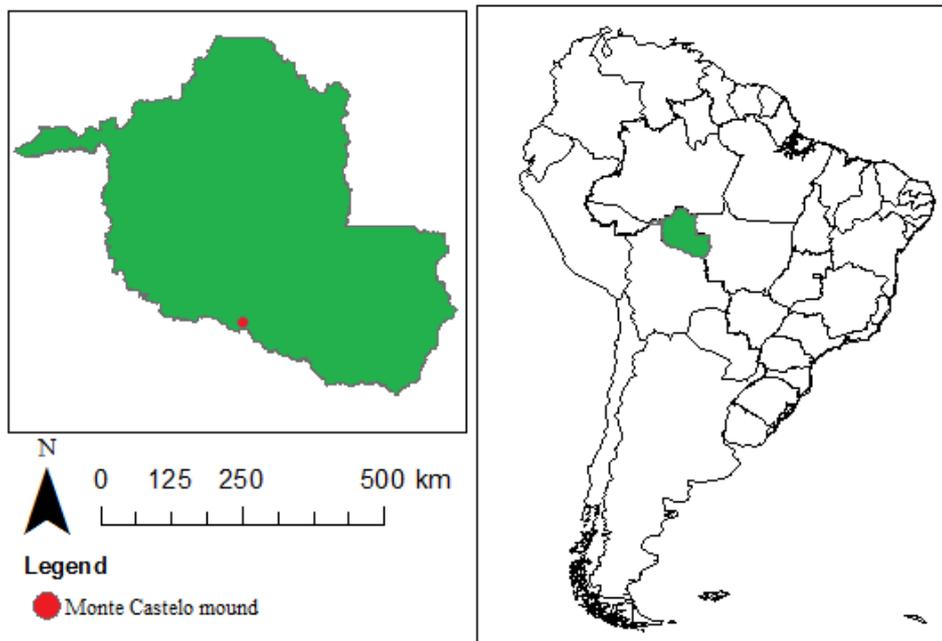


Figure 1.5. The Monte Castelo shell mound (12°33'13.57"S - 63° 5'46.35"O).

The seasonality of regional precipitation in the Amazon is influenced by several factors (e.g. Inter-Tropical Convergence Zone, Atlantic Sea Surface Temperatures and evapotranspiration of the rain forest) (Fu et al., 2001, Liebmann and Marengo, 2001, Marengo et al., 1993, Marengo et al., 2001, Nobre and Srunkla, 1996). The modulation of regional precipitation patterns in the south-west Amazon is currently determined by a May to October dry season and a wet season from November to April, with an overall annual precipitation of between 2.200 and 2.300mm (240 mm/month) (Duarte et al., 2002, Duarte, 2006).

2.1. The South-West Amazonian Occupation in the Early and Mid-Holocene

In the last two decades the archaeology of lowland South America has advanced in the characterization of the Amazonian occupation for the Pleistocene-Holocene transition (Neves, 2012b). Archaeological occupation, such as at the site of Abrigo do Sol in the state of Mato Grosso, near the basin of the Novo River (tributary of the Guaporé River), presents one of the oldest presumed dates for this area (18,381–17,435 cal. yr. B.P. Miller 1987 p. 63-4).

For the state of Rondônia, the antiquity of human occupation is corroborated by the presence of sites of circa 13,700 B.P. along the basin of the Jamari River (Meggers et al., 2002). In addition, the presence of Amazonian anthropogenic soils at the Jamari and Madeira River allegedly represents a long process of demographic occupation of approximately 7,000 B.P. (Kipnis et al., 2010) and 5.500 B.P (Zimpel Neto, 2009).

Likewise, the south-west Amazon is a testimony to the occupants who built the geoglyphs (Saunaluoma and Schaan, 2012). Interestingly this type of occupation was probably contemporary with the later shell mound settlement of this region, since the Monte Castelo site presented dates ranging from 9,495-9,137 to 910-660cal. yr. B.P. (Miller, 2009) and the state of Acre geoglyphs have dates that can be traced back to 2,751-2,214 to 660-565 cal. yr. B.P. (Saunaluoma and Schaan, 2012).

South-western Amazonian archaeology embodies, currently, the only evidence of a significant continuity of human occupation in the early Holocene, with relatively continuous records for its entirety (Almeida, 2013, Araujo et al., 2005, Neves, 2012a, Zimpel Neto, 2009). For the centre and south-eastern Amazon lowland region, researchers have considered the possibility of an occupational hiatus during the middle Holocene (Araujo et al., 2005), but this fact might be related to a bias in the formation and preservation of archaeological records or the methodologies applied to archaeological surveys rather than an absence of occupation (Neves, 2012a).

Discernibly the archaeology of the upper Madeira River has proved to be a significant source of data about the continuity of human occupation in the Amazon region and surrounding areas (Miller, 2009, Miller, 1987a, Miller, 1987b, Miller, 1992, Neves, 2012a). The dense, well-marked archaeological layers existing in the Monte Castelo shell mound correspond to the first signs of occupation in the Brazilian south-west Amazon (Miller, 2002). This region is

considered to be the centre of origin of domesticates such as manioc (*Manihot esculenta*) (Olsen and Schaal, 1999, Olsen and Schaal, 2001) and peach palm (*Bactris gasipaes*) (Clement et al., 2010), and it is where the first Amazonian anthropogenic soils emerged, in the Jamari River (Zimpel Neto, 2009). Additionally, because of the long sequence of human occupation, the state of Rondônia is assumed to be one of the probable centres of origin of various languages from different linguistic trunks, such as the Tupi-Guarani (Eriksen, 2011, Neves, 2012a, Rodrigues, 1958).

2.2. The Monte Castelo Shell Mound (RO-08-PN)

The Monte Castelo Amazonian fresh water mound (RO-08-PN) is regarded as one of the most important sites in the Amazon basin (Miller, 2002). It is situated near the confluence of the Branco River with the Guaporé River in the county of São Francisco do Guaporé, located in the state of Rondônia, northern Brazil (Fig. 1.6).

While economic exploitation and the intense real estate valuation leading to the expansion of cities figures as one of the most common causes of destruction of shell mound archaeological evidence in Brazil (Wagner, 2009), the location of the Monte Castelo site in the Biological Reserve of Guapore (IBDF, 1982) has assured the integrity and conservation of this archaeological heritage.

The archaeology of the upper Madeira River has proved to be a significant source of information on the processes of continuity and change that operated in the human occupation of the Amazon region and surroundings (Miller, 2002). Located next to the Branco River, a tributary of the Guaporé River (also known as Itenez in Bolivia), this area is currently sparsely occupied by riverine communities (Miller, 2002). Miller first described the mound in 1983. The Monte Castelo shell mound (Fig. 1.6) is classified as “a basal elliptical shell mound” with an area of approximately 145 x 105 m at the foot of the “island” (Miller, 2002 p.105). This site was revisited only 30 years later by a team led by archaeologist Edurado Neves (University of São Paulo).



Figure 1.6. Monte Castelo shell mound. **(A)** Photograph from the archaeological excavation made by Miller in 1983 (Miller 2002); **(B)** Recent photo of the mound taken by Neves in 2013 (Neves 2013).

Radiocarbon dates provided by Miller placed the beginning of the occupation of the site at 9,495-9,137 cal. yr. B.P., exposing the long-term human presence in the area (Miller, 2002). Miller presented the data from what he called Cut 4 (*corte 4*) (Fig. 1.7), interpreting the stratigraphy to a depth of 7m to reveal almost continuous settlement in three different occupations (2002 p.104).



Figure 1.7. Stratigraphy evidenced by cut-4. Interpretation of Miller's records from 1983 (modified from Miller 2002 p.104).

The sequence of cultural development reconstructed from Miller's surveys and excavations permitted the identification of an initial Hunter-Gatherer pre-ceramic occupation between 700-685cm designated by him as Cupim phase (9,495-9,137 to 7,970-7,682 cal. yr. B.P.). After a short "sterile" layer at the 685-670 cm interval, the pre-ceramic Sinimbú phase developed from 670-275cm (7,431-6,979 to 5,271-4,584 cal. yr. B.P.). The following layers between 275-220cm (10-15cm), exhibited silt and sandy non-archaeological sediment with organic intrusion, interpreted as a Sinimbú-Bacabal blend phase. Lastly, from 220cm to the top of the occupation the Bacabal phase (4,813-4,087 to 910-660 cal. yr. B.P.) occurs (Miller, 2002).

The only published data regarding the dietary preferences from the Monte Castelo shell mound was presented by Miller (2002, p 113). The exploration of the environment by the mound builders included the hunting and gathering of local fauna and flora, along with a possible adoption of manioc cultivation., though no solid data for this assertion was given.

It is necessary to emphasise that in the Amazon the oldest ceramic production contexts are regularly associated with shell mound builders (Neves, 2014). Examples are Taperinha (south-east lowland Amazon), with dates that reach 8,034-7,705 cal. yr. B.P. (Roosevelt et al., 1991), the Mina phase sites on the Atlantic coast Amazon, dated up to 6,317-5,475 cal. yr. B.P. (da Silveira and Schaan, 2005), and the Bacabal phase in the south-west Amazon with dates of 4,813-4,087 cal. yr. B.P. (Miller, 2002). A comparison between these ceramics indicates that the artefacts were manufactured in substantially different technological and stylistic contexts (Neves and Pugliese, 2016). This leads to the assumption that there were distinct and perhaps independent cultural change centres in the mid-Holocene, given the abundance of resources and the cultural diversity of the Pleistocene-Holocene transition (Neves and Pugliese, 2016, Neves, 2006, Neves, 2012a).

The Monte Castelo mound is part of these ancient contexts of ceramic production in the Amazon basin (Fig. 1.8). According to Miller (2002 p 106), in an archaeological package which dates back to about 4,813-4,087cal. yr. B.P., ceramic remains were found associated with the Bacabal phase, whose decorative elements are characteristic of some of the earliest known pottery in the New World (e.g. Puerto Hormiga in Colombia and Valdivia, Ecuador) (Neves and Pugliese, 2016). The study of these correlations indicates probable cultural exchange between producers of Andean ceramic technology and the Amazon during the Middle Holocene. This leads to the assumption that domesticated species from the Andes, such as squash (*Cucurbita* sp.), could similarly be exchanged.



Figure 1.8. Ceramic fragments of the *Bacabal* phase (Miller, 2002).

Miller's 1983 excavations could not be fully completed on account of a malaria* incident, and only in 2014 was this mound revisited. Archaeologist Eduardo Neves coordinated a group of researchers in order to attain specialized data and spatial distribution maps of the sites in the vicinity of Guaporé River (Neves and Pugliese, 2016). To date, there is no published data regarding microbotanical analysis for this site. The site not only represents a window on the Early and Late Holocene human occupation of the south-west Amazon, but also encompasses the area of distribution of the wild relatives of major modern crops (e.g. manioc and chilli peppers).

The chronological data collected by Miller in 1983 and the material culture gathered revealed three main occupational components on the Monte Castelo mound, respectively (Fig. 1.7): 3rd) Ceramic Shell-Mound Component: Bacabal phase, 4,813-4,087 to 910-660 cal. yr. B.P., 2nd) Pre-Ceramic Shell-Mound Component: Sinimbu phase, 7,431-6,979 to 5,271-4,584 cal. yr. B.P. and 1st) Pre-Ceramic and Pre-Shell-Mound Component: Cupim phase 9,495-9,137 to 7,970-7,682 cal. yr. B.P. (Miller, 2002 p. 104).

* Malaria is a mosquito-borne infectious disease widespread in tropical and subtropical regions ORGANIZATION, W. H. 1992. World malaria situation 1990. World Health Statistics Annual (WHO), 45, 257-266.

Thus, hypotheses were established specifically correlated to these contexts, in order to explore the direct questions about each one of these components. These questions will make up the scope of the proposed research for this site and will also be addressed in relation to broader studies that have been carried out in the contexts of the South American lowlands. The questions are:

I Could the various phases of the shell mounds be related to changes in the manipulation of plant resources?

II Could the archaeological layers display progressive evidence of intense exploitation of plant taxa in the Early to Late Holocene, which could lead to their eventual domestication?

2.2.1. Renewed archaeological research at the Monte Castelo shell mound

The proposal of analysing phytolith vestiges from the Monte Castelo mound is part of an interdisciplinary project coordinated by archaeologist Eduardo Neves, from the University of Sao Paulo. The project in which this thesis is included is entitled: Cultural Diversity Emergence in the South-western Amazon: A Regional Approach in the Guapore River Basin (*A Emergência da Diversidade Cultural no Sudoeste da Amazônia: Uma Abordagem Regional na Bacia do Rio Guaporé*). This project aims to understand what were the factors underlying the emergence of Amazon cultural diversity by proposing archaeological investigations in the basin of the Guaporé, in the Brazilian Amazon.

The archaeological excavation of the Monte Castelo mound took place from January the 10th to the 26th in 2014. Units of 1 x 1m were opened in selected areas of the site and artificial layers of 10cm were excavated. To each one of the artificial levels individual provenance numbers were registered (for more details see chapter 3). Due to the increased rain, the excavations were stopped at 460 cm below the current surface level. (Fig. 1.9). Soil samples from each artificial layer, including from identified burials associated with macro remains, were extracted and sent to the University of São Paulo for curation and analysis.



Figure 1.9. Archaeological excavation of the Monte Castelo shell mound in January 2014 (Neves and Pugliese, 2016).

The phytolith soil samples extraction and subsequent identification will be made in the archaeology department of the University of Exeter, United Kingdom. Myrtle Shock is processing the macro remains and carrying out the zooarchaeological analysis.

2.3. Paleoclimate and Past Floral Assemblage of the Study Region

The transitional dynamics between forest and savannah vegetation over the southern portion of the Amazonian rain forest are fundamentally important in providing insights over the millennial time scales of paleoclimate and therefore increasing an understanding of rain forest biodiversity (Mayle et al., 2000).

For the Last Glacial Maximum (LGM) ($\cong 20,000$ B.P.) drier conditions have been suggested by the pollen and lake level records from south-west Amazonia, as well as from the Andes and the eastern Colombian Cordillera (de Freitas et al., 2001, Hooghiemstra and Ran, 1994, Mayle et al., 2000, van der Hammen and Hooghiemstra, 2003). Nonetheless, de Freitas et al. (2001), while analysing carbon isotopes of soil organic matter data from soil samples along a 200 km transect between Rondônia and Amazonas State (Brazil), found no evidence for savannah expansion between 24,592-24,262 and 12,009-11,774 cal. yr. B.P. and thus postulated a dominance of forest vegetation, during the last part of the last glaciation to the early Holocene. Considering that a probable

savannah-like vegetation uniformity (Absy et al., 1991, Sifeddine et al., 2001) for the entire Amazon basin cannot be qualified (de Freitas et al., 2001 p.44), authors have implied a grassland expansion occurring as a localized (Martinelli et al., 1996) late phenomenon (de Freitas et al., 2001).

Alongside the changes brought from the correlations of the climatic forcing that ended the Pleistocene (Burbridge et al., 2004), palaeoecological records present the Holocene as a generally warmer period with a temperature increase of 5-6°C in comparison to the later period (Berrio et al., 2002, Burbridge et al., 2004, De Toledo and Bush, 2007, Seltzer et al., 1998).

For south-west Amazonia, along with changed atmospheric and moisture regimes and the rise in the temperature, a savannah expansion is generally accepted (Behling and Hooghiemstra, 2000, de Freitas et al., 2001, Mayle et al., 2000, Mourguiart and Ledru, 2003, Rigsby et al., 2009). Accordingly, de Freitas et al. (2001) reports that in the early to mid-Holocene (12,009-11,774 and 3,401-3,364 cal. yr. B.P.) the dry and warmer period is corroborated with the expansion of savannah islands in the north Rondônia/Amazonas state border (de Freitas et al., 2001). Likewise, Mourguiart and Ledru (2003) report the shift from cloud forest to open grass-dominated ecosystems in the eastern Bolivian Andes between 15,317-15,114 and 5,275-5,041 cal. yr. B.P. Also, Burbridge et al. (2004) suggest that the Laguna Chaplin seasonally flooded the savannahs continued to dominate low-lying areas around it from 13,430-13,301 to 1,894-1,821 cal. yr. B.P. Finally, reports of a prolonged low-stand in Lake Titicaca between 10,763-10,701 and 4,236-4,152 cal. yr. B.P. (Baker et al., 2001, Cross et al., 2000, Paduano et al., 2003, Seltzer et al., 1998) and also at the Bolivian Altiplano seem to corroborate with the aforementioned dry conditions of the early and mid-Holocene (Rigsby et al., 2009). Although no evidence for drier conditions comes from marine records in the Amazon (Maslin and Burns, 2000) or from lowland Amazonian lakes (Colinvaux et al., 2000), the research done by Behling and Hooghiemstra (1999), Mayle et al. (2000), Burbridge et al. (2004), and Toledo and Bush (2007) regard north and south-west Amazonia as having experienced a dry period that consequently replaced forests with savannah biomes.

For the late Holocene, Amazonian records include not only wetter conditions for the whole region (Berger and Loutre, 1991) but also a progressive increase of insolation as a consequence of the southerly migration of the

Intertropical Convergence Zone (ITCZ) (Burbridge et al., 2004, Haug et al., 2001). Additionally, the late Holocene (4,516-4,425 cal. yr. B.P.) modern rain forest communities for the south-west Amazonian territory are conjectured to have been established after 3,833-3,721 cal. yr. B.P. (Bush et al., 2004a, Bush et al., 2004b, Mayle et al., 2000).

Conclusively, the savannah-to-forest ecotones shift is in accordance with the increased snow accumulation on Sajama Mountain of the late Holocene (Thompson et al., 1998). It also accords with reports of forest development around Laguna Chaplin by Mayle et al. (2000), as well as the forest expansion after 3,401-3,364 cal. yr. B.P. in Rondônia-Amazonas state borders (de Freitas et al. 2001), the rising water levels in Lake Titicaca 4,516-4,425 cal. yr. B.P. (Baker et al., 2001), the expansion of cloud forest in the Bolivian Andes after 4,516-4,425 cal. B.P. (Mourguiart and Ledru, 2003), and the Laguna Chaplin reduction in open savannahs and an expansion of forest, likely a mixture of rain forest and dry forest species (Burbridge et al., 2004). Consequently in the Brazilian lowlands, increasingly wetter conditions during the late Holocene are suggested to have favoured the development of human populations after long-lasting dry periods during the mid-Holocene (Araujo et al., 2005).

3. THE SOUTH-EAST AMAZONIAN LOWLAND STUDY AREA

The Tucumã shell mound is located in the Marajó archipelago, in the county of Melgaço, encompassing an area of 6.774 km² (Fig. 1.10) (IBGE, 2017). The evolution of the current Amazon landscape and its plant distribution has been particularly influenced by the by: 1) the late Pleistocene and Holocene climate changes (e.g. Cordeiro et al., 2008, de Freitas et al., 2001, Pessenda et al., 1998, Sifeddine et al., 2001); 2) tectonic events (e.g. Rossetti and Valeriano, 2007, Rossetti et al., 2008, Rossetti and De Toledo, 2006); and 3) relative sea level variations (Behling and Hooghiemstra, 2000, Behling and Hooghiemstra, 2001, Cohen, 2009).

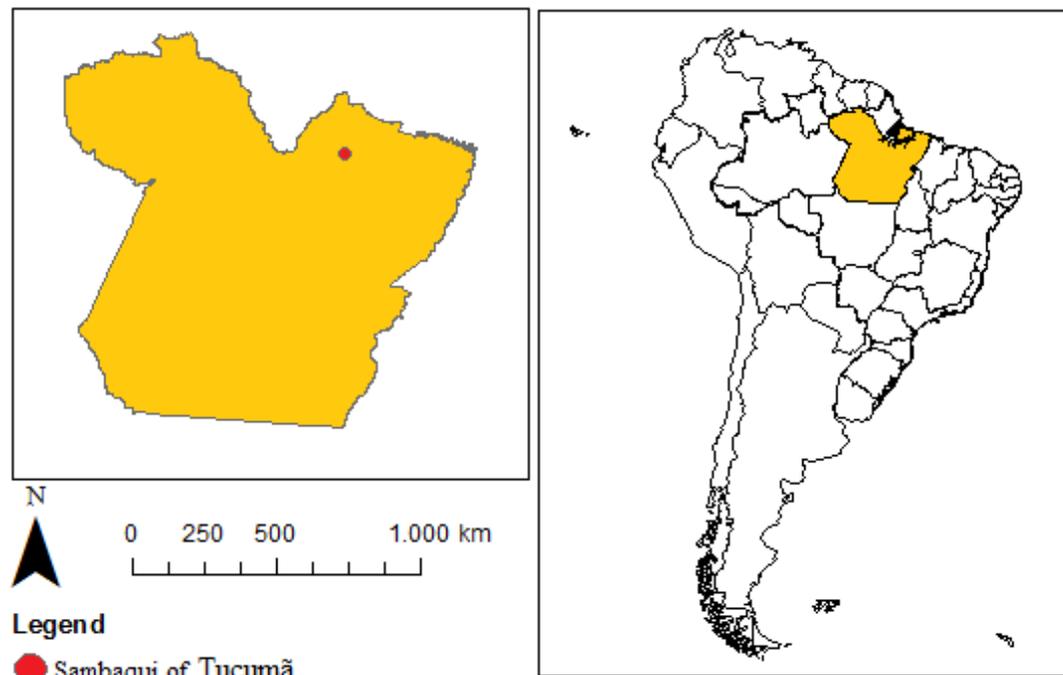


Figure 1.10. The Tucumã shell mound ($1^{\circ}47'58.79''\text{S} - 50^{\circ}42'58.72''\text{O}$).

The south-east Amazonia climate is considered tropical humid (Aw, Köppen) with pronounced wet conditions from November to May and drier seasons from June to October (Sifeddine et al., 2001). The mean monthly precipitation climate station accounts for 740 mm during the wet season, and 60 mm during the dry season, with an average annual monthly temperature of 25°C (Hermanowski, 2014). The seasonality of regional precipitation in the Amazon is influenced by several factors, such as the north-south migration of the Inter-Tropical Convergence Zone due to fluctuating Atlantic Sea Surface Temperatures (SST), moist trade winds from the tropical Atlantic, evapotranspiration from the forest, and the coupled onset and intensity of Amazon convection (Fu et al., 2001, Liebmann and Marengo, 2001, Marengo et al., 1993, Marengo et al., 2001, Nobre and Srunkla, 1996, Mao et al., 2013).

3.1. Previous Studies in the Marajó Archipelago

The first reports on archaeological sites in the Amazon basin refer to the second half of the nineteenth century (Agassiz and Agassiz, 1868, Hartt and Agassiz, 1870, Penna, 1876). Initially, the arrays of cultural interest of that time were the anthropomorphic urns identified along the Maracá River in the state of Amapá (Göldi, 1900, Penna, 1876), the ceramics from the Santarém Tapajó culture

(Barbosa Rodrigues, 1892) and the burial complex of Miracanguera (Barbosa Rodrigues, 1892).

There were, however, some descriptions of large shell mounds used as housing and burial sites in the eastern portion of the Marajó archipelago (Schaan and Martins, 2010). Funerary urns and ceramic containers decorated with complex sections, drawings and paintings aroused the curiosity of researchers (Hartt, 1871; Penna, 1885), but little was known about the pre-colonial occupation of the western portion (Schaan and Silva, 2013). One of the first systematic archaeological survey, in the western area, was conducted between July 2008 and February 2009 (Schaan et al., 2009b), when archaeologists identified over 160 archaeological sites (including ceramic, litho-ceramic, and shell mound sites) and 31 areas of occurrence of anthropic material (Schaan et al., 2009).

In recent decades, Brazilian archaeologists, leading research groups with international experts from various subjects, have contributed to the increasing body of knowledge concerning ancient Amazonian populations. Among others are: Hilbert and Hilbert (1980), McEwan; et al (2001), Gomes (2002), Schaan (2004, 2011), Neves (2006), Lima (2008), Guapindaia (2008), Heckenberger and Neves (2009), Pereira (2004). Yet the knowledge of prehistory in this vast Amazon region remains inversely proportional to its size.

3.2. The Tucumã Shell Mound

The Tucumã shell mound (Fig. 1.11), located in the county of Melgaço, consists of a vast area of dark soil, exposed ceramic and shell mound structures, approximately 96 cm below the current surface (Schaan and Silva 2013). The recent real estate expansion in the region resulted in a charge of depredation of archaeological sites by the local population. To assess the impact of real estate expansion on this site, archaeological survey teams were formed in 2009 (Schaan and Silva 2013). The mound, now under protection, was revisited in 2013 by a team of archaeologists led by Schaan and Silva, who aimed to salvage and thoroughly document this occupation.



Figure 1.11. Tucumã shell mound. (A) Overview of the mound (damaged portion); (B) Archaeological excavation presenting the initial mound occupation (Schaan and Silva 2013).

The archaeological excavations consisted of two 1x2m and four 1x1m in previously designated areas. The excavations were made in order to investigate areas of activities in different parts of the site and to understand the dispersion related to the mound occupation and its correlation with the subsequent pottery occupation (Schaan and Silva 2013).

The excavations revealed the occurrence of at least three distinct cultural layers, determined not only by the occurrence of different artefacts, but also by the presence of gastropod shells and well-preserved bones, which may indicate three different occupations over time (Schaan and Silva 2013 p.72-73). Regarding the faunal and botanical remains, the excavations revealed the presence of bivalves, fish and mammal bones, and charred wood.

Radiocarbon dates for the Tucumã mound placed the site at 2,307-2,228 to 1,693-1,523 cal yr. B.P. (Schaan and Silva 2013), despite the fact that similar sites in the Lower Amazon and the Amazon Atlantic coast (Roosevelt, 1995, Roosevelt et al., 1996, Schaan et al., 2009a, Simões, 1981) presented dates between 7,000 and 4,000 B.P. The dates for the Tucumã mound were not selected from the base of the occupation. Thus, to further confirm the expectations regarding the antiquity and continuity of the settlement, this study recovered radiocarbon samples from the lower and upper portion of this mound.

Conceivably, each of the different occupations could have had a distinctive approach to the management of the environment. Thus, hypotheses were established specifically correlated to these contexts. The questions are:

I Could the early shell mound builders during the mid-Holocene dry climatic conditions (Behling and Hooghiemstra, 2001, de Freitas et al., 2001,

Hermanowski et al., 2012) combined their fishing and gathering practices to an incipient horticulture practice?

II Could the humid climate conditions of the late Holocene (Hermanowski et al., 2012) and the increase of tropical forest taxa (Colinvaux et al., 2000) have influenced the gathering practices of the Tucumã mound builders?

The multicomponent mound formation at Tucumã is similar to the Monte Castelo mound, and together they offer an excellent research opportunity to correlate the different West and East anthropic adjustments to the Holocene Amazonian lowland environment configurations. While the Monte Castelo shell mound represents a continuous formation from early to late Holocene, on the other hand, the Tucumã mound establishes comparison due to the individual formation pattern and possible unique subsistence practices.

3.2.1 Excavation at the Tucumã shell mound

The opportunity to analyse soil samples gathered from the Tucumã mound arises from the collaboration from this thesis interest with archaeologist Denise Schaan. The Program: Archaeology and Educational Heritage in Areas of Direct and Indirect Influence of the Undertaking Transmission Line in the Marajó Island (*Programa de Arqueologia e Educação Patrimonial nas Áreas de Influência Direta e Indireta do Empreendimento LT Ilha do Marajó*), coordinated by Denise Schaan and Wagner Fernando da Veiga e Silva, included the Tucumã mound excavation in October 2013. The archaeological excavation of the Tucumã mound proceeded as follow: initially, test pits were made in order to circumscribe and identify areas of interest within the midden; subsequently, from the information gathered, six excavations proceeded (Fig. 1.12).

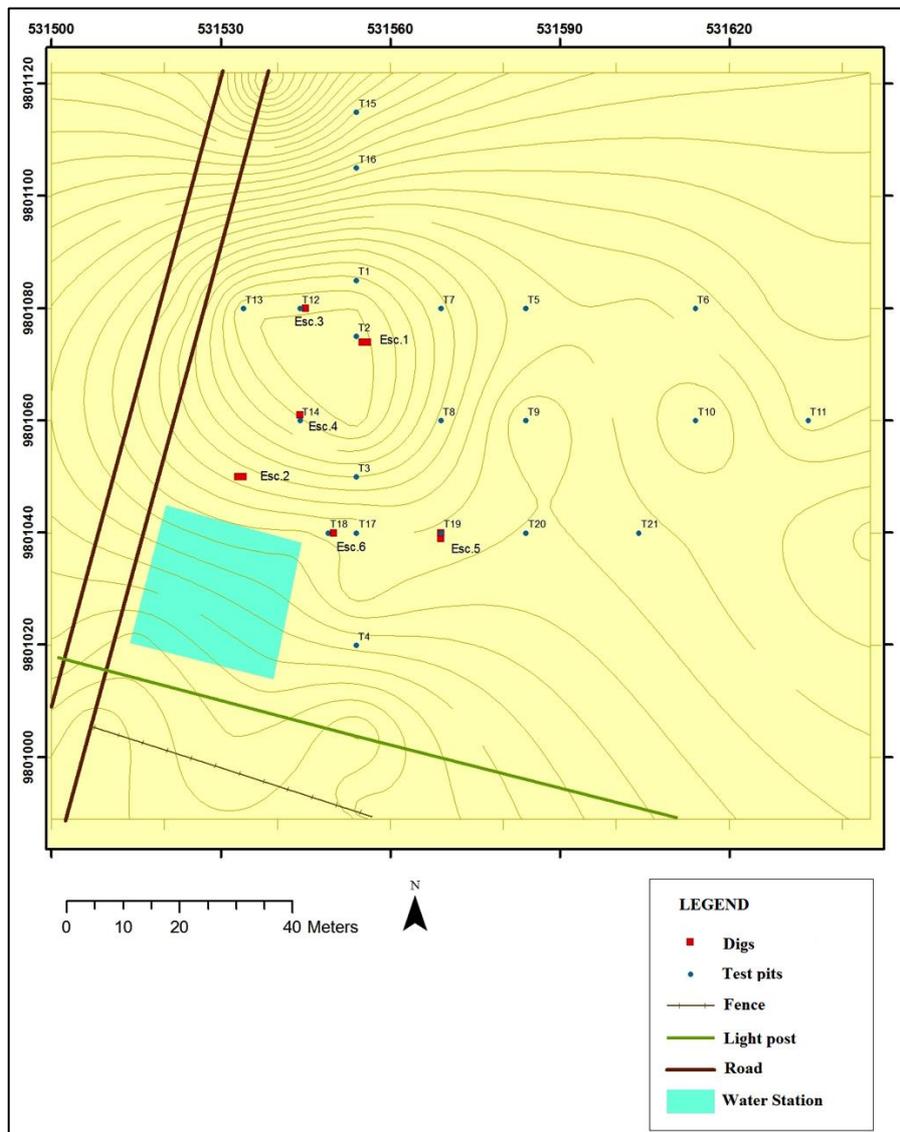


Figure 1.12. Site sketch with location of test pits and excavations (Schaan and Silva 2013).

Units of 1 x 1m and 1 x 2 m were opened in selected areas of the site and artificial layers of 10cm were designated for the extraction of soil samples. The material culture of Excavations 1 and 2 presented decorated pottery fragments and shell tempered pottery in the uppermost layers of the site. The presence of crosshatch-zoned (typical in pottery from the Mina phase – Simões, 1981) pottery was identified amidst the shell mound occupational layers (30 cm).

Excavation 4 presented the most complete stratigraphic assortment, with the conjectured three occupations (Fig. 1.13).

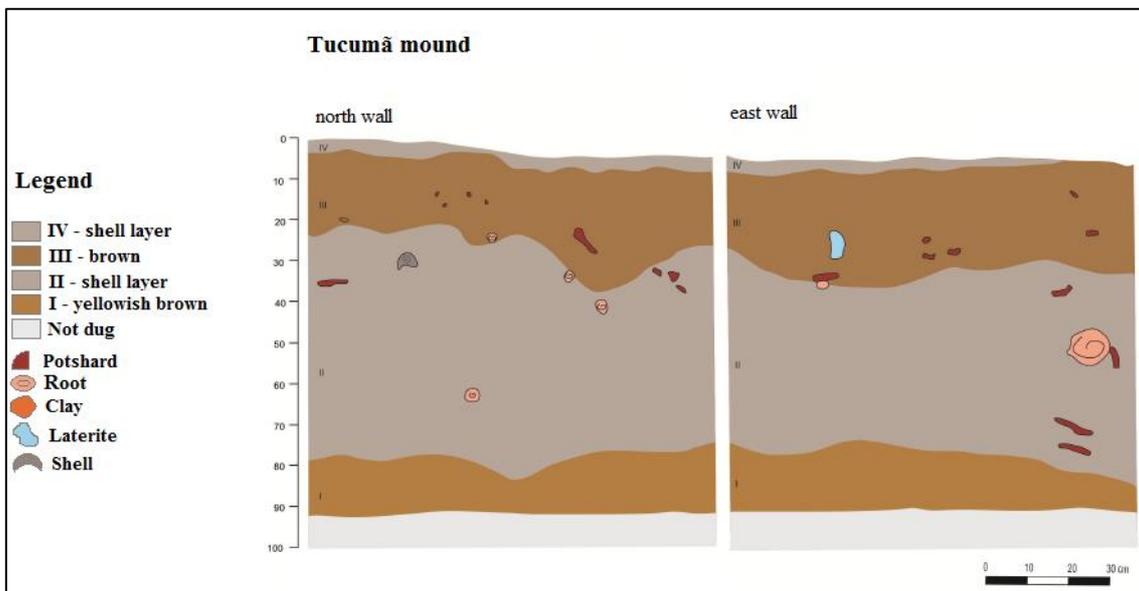


Figure 1.13. Northern and eastern sections of the Excavation 4 (Schaan and Silva 2013).

The presence of crosshatch zoned pottery associated with faunal vestiges was identified in the bottom of the mound occupation (86 cm) (Fig. 1.14). As well as presenting the whole stratigraphic assortment, Excavation 4 revealed pottery throughout the occupation and had little or no disturbance. Thus, for this thesis, Excavation 4 was reopened, and soil samples for phytolith analysis were recovered for analysis.



Figure 1.14. Profile and material culture gathered from Excavation 4. (A) Profile; (B) crosshatch zoned pottery; (C) Associated crosshatch zoned pottery and zoological remains; (D) up layer pottery (Schaan and Silva 2013).

Excavation 5 presented clay, faunal remains, and decorated ceramic with burn marks accumulated over the shell mound occupation at 30 cm (Fig. 1.15). Due to this unique pattern, continuity of the excavation was halted for future broader investigations.



Figure 1.15. Excavation 5 (Schaan and Silva 2013).

Similarly to the Taperinha mound, in which crosshatch zoned pottery was found in association with the mound occupation, the Tucumã shell mound could present a duplicate to the oldest American known archaeological evidence of early ceramic manufacture.

3.3. Paleoclimate and Past Floral Assembly of the Study Region

Currently the south-east Amazonian region comprises a mosaic of floral assemblies, such as: 1) savannah biome, composed of families such as Poaceae, Myrtaceae, and Asteraceae (Hermanowski et al., 2012, Nunes, 2009); 2) evergreen tropical rain forest, occurring along slopes and in the lowlands (IBAMA, 2007), composed largely of Melastomataceae, Anacardiaceae, Moraceae, Meliaceae, Alchornea, *Aparisthium*, Euphorbiaceae and Arecaceae (Nunes, 2009); and 3) transition between forest and savannah, characterized by a successional forest dominated by *Aparisthium* and *Erythroxyllum* (Morellato and Rosa, 1991). The transformation of the south-east Amazonian environment during the late LGM is considered to have been determined by colder conditions due to the rare

occurrence of tropical rain forest taxa and larger numbers of cold adapted taxa, such as *Myrsine*, *Ilex*, *Hedyosmum*, *Euplassa* and *Podocarpus* (Hermanowski et al., 2012).

At the onset of the Holocene (11,400–10,200 B.P.) the decrease in the number and taxa of cold plants indicates warmer conditions; wetter conditions are corroborated by the increase of *Nymphaea* in the region (Hermanowski et al., 2012).

In the early to mid-Holocene, (10,200–3,400 B.P.) the marked reduction of tropical forested area and savannah arboreal species, with the expansion of Poaceae taxa, indicates a change to dry climatic conditions (e.g. Behling and Hooghiemstra, 2000, de Freitas et al., 2001, Hermanowski et al., 2012, Pessenda et al., 1997). The late Holocene, (3,400 B.P to present) is marked by the increase of tropical forest taxa (Colinvaux et al., 2000) due to the return of more humid climate conditions extending to the present day (Hermanowski et al., 2012).

CHAPTER 2

LOWLAND AMAZONIAN PLANT DOMESTICATION

This chapter presents an overview of plant domestication for the lowland Amazonian region. Firstly, an attempt to classify and list domestication levels is presented. Next, centres of domestication are discussed. Lastly, domesticated and incipient domesticate species thought to have originated in the lowland Amazon are listed.

1. SYNTHESIS ON PLANT DOMESTICATION

Domestication is a complex evolutionary interspecific process in which one species leads a second towards genetic and physiological changes that distinguishes the latter taxa from their wild ancestors (Purugganan and Fuller, 2009). While examples of domestication are not restricted to humans, e.g. fungal species have been domesticated by ants (Schultz and Brady, 2008) and beetle (Junqueira et al., 2011), the attention of this thesis will be anthropological domestication of plant species.

Whereas early domestication is characterized by promoting the expression of selected phenotypes, the process leads to acquisition of traits that are often similar between plants of the same population, i.e. usually, both wild and domesticated types belong to one biological species, sharing a common primary gene pool (Cai and Morishima, 2002, Clement, 1999). Cultivation, and

consequently the domestication of plants, is one of the most important technological innovations in human history (Purugganan and Fuller, 2009). Probably originating around 15,000-12,000 B.P. it is believed to have given rise to most existing human cultures, along with craft specializations, art, social hierarchies, writing and urbanization (Cohen, 2009, Diamond, 2002, Flannery et al., 1969, Hancock, 2012, Purugganan and Fuller, 2009, Richerson et al., 2001, Stiner, 2001).

1.1. Domestication Level

Plant domestication occurs from a continuous selection process which terminates in fixation, through successive bottleneck and management of characteristics (genetic) that distinguish the domesticate from its wild progenitor (Clement et al., 2010, Pickersgill, 2007). During the course of domestication, different levels can be identified (Clement, 1999, Clement et al., 2010, Harlan, 1992, Rindos, 1984), respectively: wild population, incipiently domesticated (e.g. *Inga* spp., *Eugenia uniflora*), semi-domesticated (e.g. *Capsicum baccatum* var. *baccatum*) and domesticated population (e.g. *Manihot esculenta*, *Zea mays*, *Bactris gasipaes*) (Clement, 1999).

A wild population is classified as those plants that evolved without direct human interference (Clement 1999). An incipiently domesticated population is one that has gone through an early selectiveness event, in which only a portion of the genotypic characteristic of its wild ancestry has been maintained, thereby decreasing its phenotypic expressions (Rindos 1984, Clement, 1999). A semi-domesticated population is one that has gone through further enhancements of its traits. At this point the morphological diversity has been encouraged by an accumulation of promoted alleles selected by humans (Clement, 1999, Doebley, 2004). A domesticated population is one that has been further thoroughly selected and has co-evolved with human modified landscapes, granting them a almost symbiotic relationship (Clement, 1999, Harlan, 1992). For this study cultigens will be used as a synonym of domesticated species.

Besides the progression from wild to fully domesticated, the modification of landscape (i.e. land domestication) additionally imposes environmental pressures which plants with the according genetic selective advantage may use. Plants that advance in human modified land are classified as incidentally

co-evolved (e.g. weeds); these plants can, if induced, undergo a domestication process (Rindt 1984, Harlan, 1992, Clement, 1999).

1.2. Domestication Pattern

The most common changes resulting from wild plants becoming domesticates are: 1) loss of dispersal mechanisms, 2) increase in size, 3) increased morphological variability, 4) changes in plant habit, 5) loss of seed dormancy, 6) loss of chemical or mechanical protection, and 7) photoperiodism. These characteristics constitute the domestication syndrome (Hancock, 2012, Harlan, 1992, Pickersgill, 2007, Purseglove, 1968, Schwanitz, 1957). They generally reduce the domesticate's ability to survive in the wild, thus making it dependent on human management for its growth and reproduction (Pickersgill, 2007).

The loss of dispersal mechanisms often involves the loss of an abscission zone (Pickersgill, 2007), as observed in modern cultivars of American wild rice (Kennard et al., 2002), pearl millet (Poncet et al., 2002), wheat (Watanabe and Ikebata, 2000) and maize (Doebley 2004), which have lost the abscission zones within the inflorescence which cause shattering in their wild relatives (Ji et al., 2006). Increase in size is usually noticeable in the part of the plant harvested (Pickersgill, 2007), such as fruits and tubers (Cong et al., 2002). The increased morphological variability is also especially marked in the part of the plant used by humans (Pickersgill, 2007), such as domesticated chilli peppers and tomatoes which vary in fruit shape and colour, as well as in size; domesticated potatoes vary in colour and in the shape of the tuber (Boster, 1985).

The changes in plant habit are usually adaptations associated with germination. Manioc (*Manihot esculenta* ssp. *esculenta*) presents epigeal* germination whereas its immediate wild progenitor (*M. esculenta* ssp. *flabellifolia*), together with other closely related wild species, has hypogeal** germination (Pujol et al., 2005). This adaptation thrives under conditions of slash-and-burn agriculture (Elias et al., 2004, Salick et al., 1997). The loss of

*The epigeal seedlings of domesticates have aerial photosynthetic cotyledons that promote rapid early growth (Pujol et al., 2005).

**Hypogeal seedlings can regenerate from buds in the axils of the cotyledons and cataphylls, because these survive underground when above-ground parts are burned (Pujol et al., 2005).

seed dormancy is usually associated with rapid uniform germination (Pickersgill, 2007). This trait is necessary if a stand of a crop is to be established before there is competition from weeds and also if domesticates in the stand are to mature at the same time (Foley, 2001, Pickersgill, 1981, Wilson and Heiser, 1979). The loss of chemical or mechanical protection (Pickersgill, 2007) is usually concomitant to domesticates such as sweet cassava that have completely or partially lost the secondary metabolites that protect their wild relatives against herbivores (Purseglove, 1968). Photoperiodism is associated with the domesticate's adaptation to different day lengths (Diamond, 2002). The first potatoes to reach Europe produced tubers only in short days, but 200 years later clones adapted to long days had developed (Simmonds, 1976).

1.3. Review on Centres of Plant Domestication

The study of domestication centres is of major interest to plant geneticists, archaeologists and biogeographers. The understanding of the broad area of a given crop can help not only to expand plant genetic variability by the introduction of wild relative variances, but also support a knowledge of archaeological migration patterns and population dynamics (Hancock, 2012).

Carl Linnaeus in 1753 presented one of the first studies related to identification of crop domestication centres (Linnaeus, 1753). Later, in the 19th century, the work of Alphonso de Candolle refined the studies with the "Origin of Cultivated Plants" (de Candolle, 1855). In the early 20th century, through the onset of basic genetics, plant geneticist Nikolai I. Vavilov made a thorough study of the Centre of Diversity and introduced the "Centers of Origin of Cultivated Plants" (Vavilov, 1926), his work establishing seven main geographical centres (figure 1): 1) Mediterranean centre, 2) Middle East, 3) South America, 4) central America, 5) east Africa, 6) south west Asia, and 7) China (Vavilov, 1926). In the late 20th century, the centres proposed by Vavilov were refined by further research (e.g. Sauer, 1952) and the addition of the Centre of Origin and Non-centres (Harlan, 1971).

From the three centres proposed by Harlan in 1971, to six (Cowan et al., 2006a) then eight (Smith, 2006) in the early 21st century, the recent advances in the fields of archaeobotany, in particular studies of microfossils (e.g. starch grain and phytolith studies), have remodelled the picture of crop origins (Fuller

et al., 2014) by suggesting approximately 13 to 24 centres (Purugganan and Fuller, 2009, Fuller et al., 2014) (Fig. 2.1).

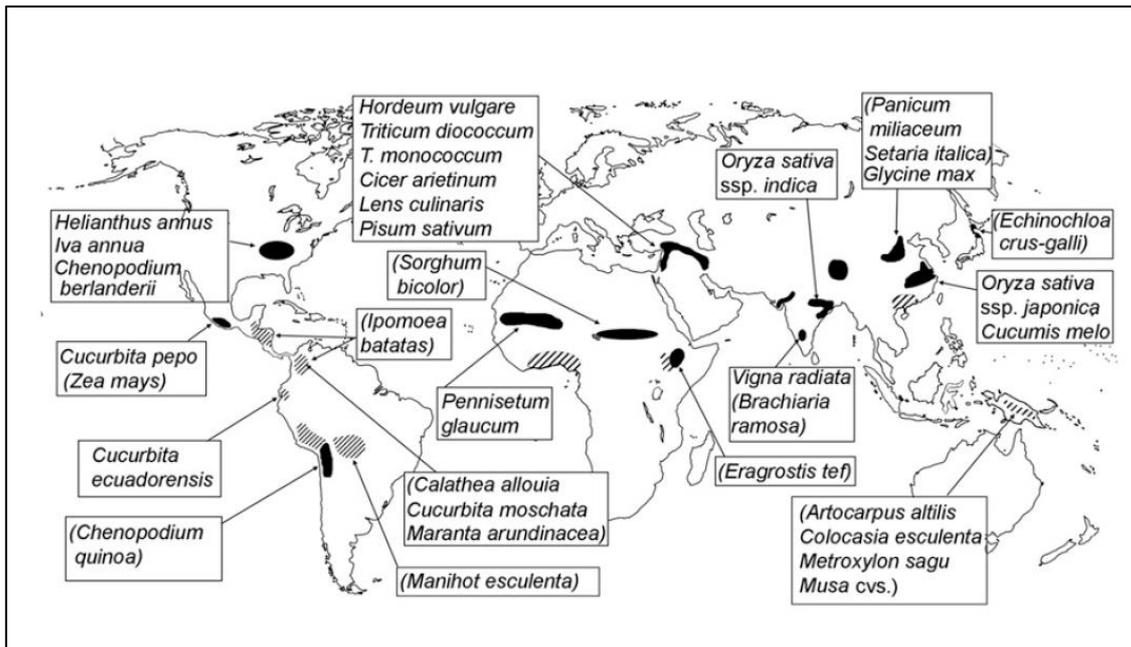


Figure 2.1. Map of centres of domestication. Black areas indicate key areas of early seed crop domestication and hatched regions have an early focus on vegetable. (Image: Fuller et al., 2014).

These recent advances have been largely attributed not only to the increased number of researchers but also to a broader and more specialized range of recognized plant taxa (Fuller et al., 2014). From a proposed North American centre (Smith 2006), to new evidence from the tropics of Central and South America (Arbuszewski et al., 2013, Iriarte, 2009, Pearsall, 1984, Piperno, 2011, Piperno and Pearsall, 1998a), to studies in West Africa, South India and the Ganges valley, pointing to an independent development of agriculture (Fuller, 2007), to a study of independent New Guinean crops (Denham, 2011), recent research has shown how advances in archaeobotany in conjunction with other fields of science (e.g. biology, archaeology and geology) can identify plausible locations of early agriculture and domestication practices, when applied to past human occupation sites in distinct regions (Fuller et al., 2014).

2. LOWLAND AMAZONIAN PLANT DOMESTICATION

Beginning soon after the end of the Pleistocene (ca. 11,400 B.P.), human occupation of the Neotropics began to change from sparsely distributed and short term occupations to longer sedentary periods, and more frequent revolving to specific locations (Piperno, 2011). This change in occupational patterns led to intentional alteration of the environment by creating clearings in forests and/or burning them (Pearsall, 1984). It also induced the development of tool kits in order to exploit and manage plants (Gnecco and Aceituno, 2006, Mora, 2003b, Ranere et al., 2002, Ranere et al., 2009).

Archaeobotanical information indicates that food production began in a number of localities in tropical Central and South America during the early Holocene (ca. 11,000 and 7,600 B.P.), not long after the Neotropical climate and vegetation underwent profound changes associated with the end of the LGM (Pearsall, 1984, Piperno, 2011). It was already recognized that numerous New World plant domesticates originated in Neotropical forests (Harlan, 1971, Harris, 1972, Sauer, 1952), establishing the lowland Neotropical forest as an early and independent centre of agricultural origins (Pearsall, 1984).

Recognising single or multiple domestications or even hybrid origins in a precise area of origins for New World crops is often less clear for a number of reasons (Piperno, 2011). Such as the existence of wild congeneric populations that could potentially be a progenitor species on the basis of shared morphological attributes, or the lack of hybridization barriers (e.g. manioc, squash, the ancestor of maize [teosinte], sweet potato, yams and cotton) present some of the difficulties in pinpointing these centres in both Meso and South America (Piperno, 2011). Recent development in the analysis of protein and DNA-based molecular markers have shed some light on these issues (Piperno, 2011), especially in the case of some major root, seed, and tree crops (Piperno, 2011) such as manioc (Olsen and Schaal, 2001), various species of squashes (Sanjur et al., 2002), South American cotton (Westengen et al., 2005) peanuts (da Cunha et al., 2008) and peach palm (Rodrigues et al., 2005).

The centres of origin for many South American crops, such as the major root and seed crops, appear to be located in seasonal types of lowland tropical forest, as well as in lowland wet forests and mid elevation moist forest habitats (Fig. 2.2). It would be difficult to designate a single circumscribed centre or core

area of agriculture (Piperno, 2011). Molecular and botanical studies, however, together with an increasing amount of archaeobotanical data, have elucidated patterns revolving around single (e.g. manioc, maize and peach palm) and multiple (lima bean) domestication events for the continent (Matsuoka et al., 2002, Olsen and Schaal, 2001, Piperno, 2011, Rodrigues et al., 2005).

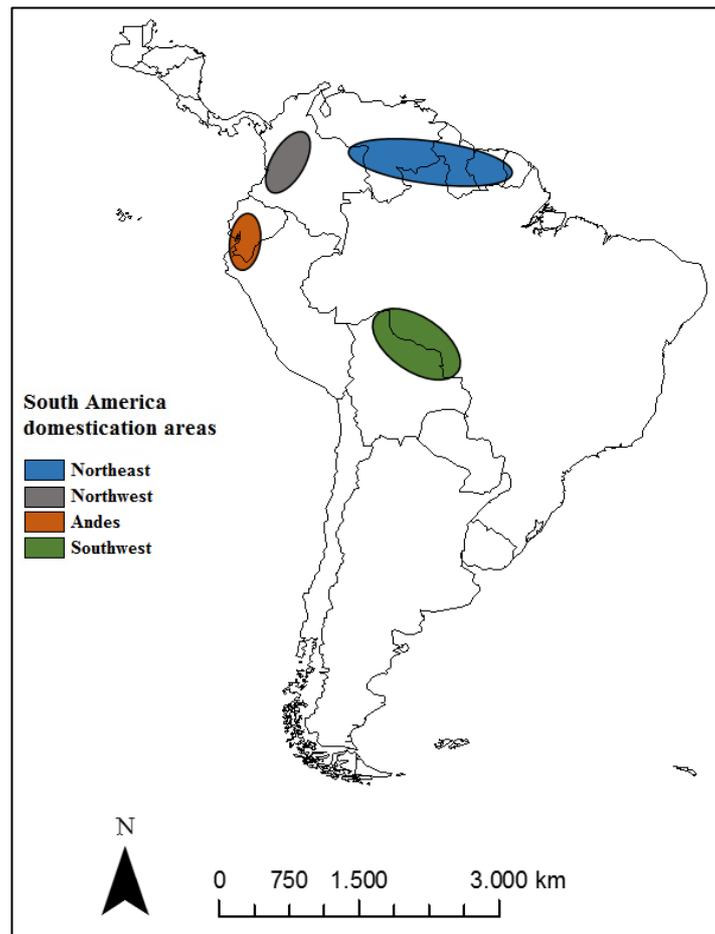


Figure 2.2. Postulated domestication areas for various tropical crops in South America. Coloured circles designate areas where it appears that more than one or two important crops may have originated. Northeast domesticates: yam (*Dioscorea trifida*), Cocoyam (not confirmed species) and leren (not confirmed species). Northwest domesticates: *Cucurbita moschata* (squash), *Canna edulis* (achira), cocoyam (*Xanthosoma sagittifolium*), leren (*Calathea allouia*) and sweet potato (not confirmed species). Andes domesticates: jackbean, Cotton and squash (*Cucurbita ecuadorensis*). Southwest domesticates: Manioc (*Manihot esculenta*), peanuts (*Arachis hypogaea*), chille peppers (*Capsicum baccatum*), squash (*Cucurbita maxima*) and peach palm (*Bactris gasipens*) (for more details and sources used in the figure, see Piperno, 2011).

In addition, there is archaeological data to support the idea that certain crops were commonly grown together after food production was established (e.g. maize, manioc, squashes, chilli peppers and sweet potato). The data present spatially different conjectured areas of origin, showing that the crops did

not initially spread together; this suggests that early patterns of dispersal probably did not involve significant population movements, or diffusion of crops in packages. Therefore, as the lowland northern and southern South American domestication zones are separated by large distances, and as several plants native to these areas were taken under cultivation and domestication, one may interpret at least two to three independent areas of food production (Piperno, 2011).

Current archaeological data has revealed that domestication of plants in the different centres of the New World presumably began in the early Holocene (Iriarte, 2009). Evidence of domestication stems from lower Central America to northwestern South America comprising of Panama Ecuador and Colombia (Fig. 2.3) (Denham et al., 2016). Microbotanical studies indicate that human manipulation of neotropical plants species included, mainly, squashes and gourds (*Cucurbita moschata*, *C. ecuadoriensis*, *C. maxima*) arrowroot (*Maranta arundinacea*), manioc (*Manihot esculenta*), yams (*Dioscorea* spp.), maize (*Zea mays*) and rice (*Oryza* sp.) which resulted in their domestication in early to mid-Holocene (Aceituno and Castillo, 2005, Dickau et al., 2007, Hilbert et al., 2017, Piperno, 2006a, Pohl et al., 2007).

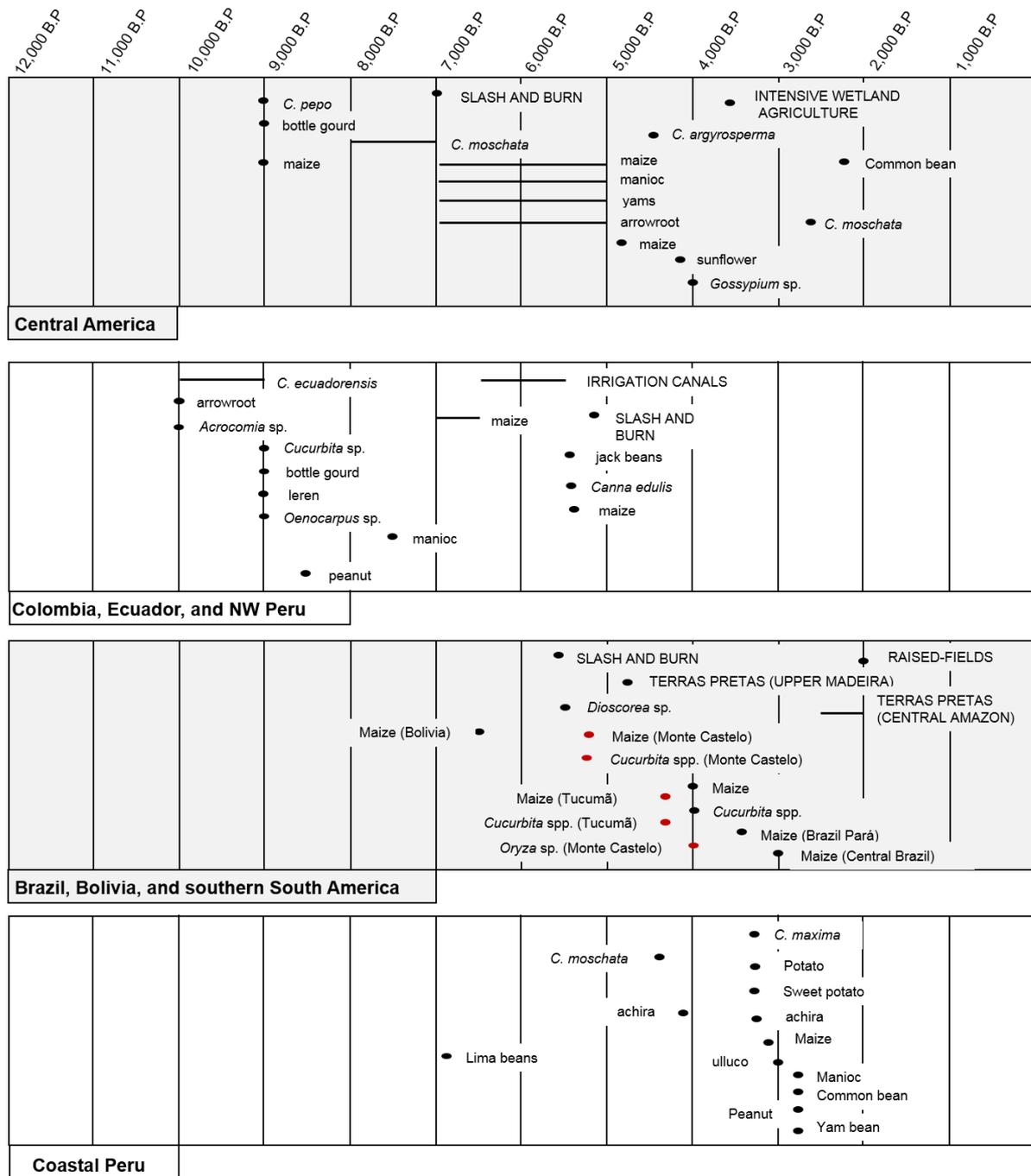


Figure 2.3. Summary of the chronology from the earliest appearance of domesticated plants and food-producing practices in different regions of Central and South America; references and dates are given in Appendix 1 (modified from Iriarte 2007 p.173).

2.1. Lowland Domestication Centre

The Monte Castelo mound and Tucumã shell mound are located in the Amazonian lowland. This area, therefore, provides the focus for the following

description. The conjectured species assumed to be domesticated will be examined, with especial attention given to the south-west domestication centre.

2.1.1. *Manihot esculenta* Crantz ssp. *esculenta*

Cassava (Fig. 2.4) is a staple perennial root crop shrub of the Euphorbiaceae family, derived from the *Manihot* genus. The most recent taxonomic revision of the genus, carried out over 40 years ago, recognizes 98 species distributed throughout the Neotropics (Rogers and Appan, 1973). Considered as one of the most important domesticated plants originating from Amazonia (Clement, 1999), cassava is the sixth major food crop produced globally (Clement et al., 2010, Hancock, 2012).



Figure 2.4. *Manihot esculenta* Crantz ssp. *esculenta* as illustrated by Marcgraf (1648 p.55).

Studies of current chloroplast DNA, nuclear ribosomal DNA and amplified fragment length polymorphisms (Fregene et al., 1997, Olsen and Schaal, 2001, Roa et al., 1997) support the hypothesis that manioc is derived from populations of *M. esculenta* ssp. *flabellifolia* (Pohl), native to the south-western rim (northern Mato Grosso, Rondônia and Acre states, in Brazil) of the Amazon lowland (Léotard et al., 2009, Olsen and Schaal, 1999, Olsen and Schaal, 2001). The postulated time of divergence of this domesticate occurred probably before 9,688-9,562 cal. yr. B.P. (Mühlen et al., 2000).

Regarding archaeological data, cassava has been registered in sites from Mesoamerica, such as the Tehuacan Valley, Tamaunlipas (3,068-2,986 and 2,306-2,151 cal. yr. B.P. Callen 1967), the Gulf coast of Mexico and Belize, between 729-691 and 5,286-5,052 cal. yr. B.P. (Pohl et al., 1996, Pope et al., 2001), in the Casma valley in Peru (4,516-4,425 cal. yr. B.P. Perry, 2002b, Towle, 1958, Ugent et al., 1986) and the Aguadulce Rock Shelter in Panama

(Piperno et al., 2002). In Colombia and Venezuela, archaeological artefacts suggested to have been used in the processing of manioc have been found (4,516-4,425 cal. yr. B.P.) (Roosevelt, 1980).

2.1.2. *Bactris gasipaes* Kunth ssp. *gasipaes*

Peach palm (Fig. 2.5) is a caespitose palm from the Arecaceae family (Arias and Huete, 1983). Considered to be the only domesticated palm species (Clement, 1988), the current economic use of this plant is mainly related to the extraction of heart of palm and, secondarily, for its fruits (Clement, 1988).



Figure 16.5. *Bactris gasipaes* ssp. *gasipaes* as illustrated by Marcgraf (1648 p.62).

Recently Araujo et al. (2013), analysing the chloroplast sequences of peach palm and its different variants concluded that in regards to the divergence of the domesticated specimens from the wild ones, the data suggested only one domestication event from two plausible domestication scenarios (Araújo et al., 2013): 1) along the Ucayali River, in which the already cultivated peach palm was dispersed throughout western Amazonia, north-western South America and southern Central America, and 2) along the Madeira River basin, in which the cultivated palm was dispersed along this river towards eastern Amazonia (Araújo et al., 2013).

Ethnohistorical reports reveal that peach palm was already widespread at the time of the European contact (Patiño, 1963). Archaeological macro remains (carbonized endocarps) have been identified from two sites in the lowlands of Costa Rica (2,330-2,183 and 1,563-1,533 cal. yr. B.P. Corrales -Ulloa and Mora-Urpi, 1990) and one site in the Pacific lowlands of Colombia (2,200 B.P. Romero -Picón, 1996); for the Amazon lowlands, endocarp fragments were

identified at Aguazul, in eastern Colombia (1,048-957 cal. yr. B.P. Morcote - Ríos and Bernal, 1998). Microbotanical remains are currently restricted to pollen grains identified at Abeja, on the Caqueta River in Colombia (705-677 cal. yr. B.P. Mora et al., 1991). While the postulated time of divergence of this domesticated occurred probably during the early Holocene (Clement, 1988), archaeological research has identified peach palm remains only in the late Holocene (Corrales-Ulloa and Mora-Urpi, 1990, Morcote-Ríos and Bernal, 2001, Romero-Picón, 1996)

2.1.3. *Capsicum baccatum* L. var. *baccatum*

The *Capsicum* genus (Fig. 2.6) is composed of 27 species, being five domesticated and 22 semi-domesticated and wild ones (Reifschneider, 2000).

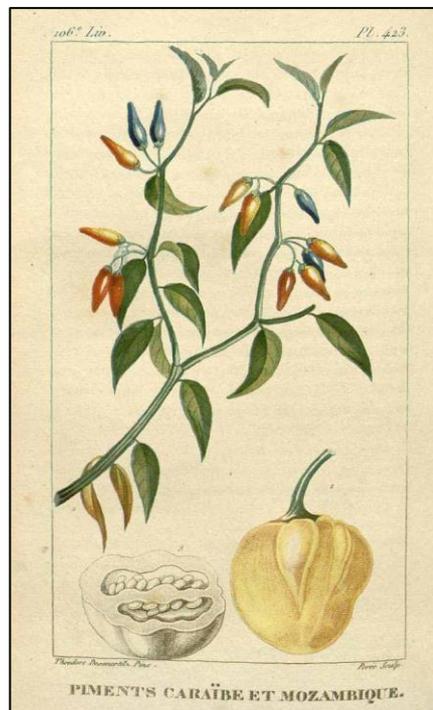


Figure 2.6. *Capsicum baccatum* as illustrated by J.T. Descourtilz (Descourtilz, 1828).

The distribution records are derived mainly from herbarium research (Eshbaugh, 1975). The records indicate that the wild *C. baccatum* var. *baccatum* has a fairly restricted distribution, which at the present time is confined almost entirely to southern Peru and Bolivia (Eshbaugh, 1975).

Archaeological macro remains of *C. baccatum* var. *pendulum* have been identified in the Huaca Prieta sites, dating from about 2,715-2,500 cal. yr. B.P., and the Punta Grande from about 2,715-2,500 cal. yr. B.P. (Pickersgill, 1969).

Microfossil (starches and pollen) remains have been identified in the Los Mangos site, Venezuela, from about 934-921 to 535-515 cal. yr. B.P. (Perry et al., 2007). Additionally, chilli pepper starches have been identified in the Bahamas at the Three Dogs site (934-921 cal. yr. B.P.), in Peru at Waynuna, (Preceramic site 4,516-4,425 cal. yr. B.P.), in Panama at Zapotal, (Early Ceramic coastal shell-midden – 5,590-5,485 cal. yr. B.P.) and Aguadulce (Late Preceramic 6,409-6,320 cal. yr. B.P.) and in Loma Alta, Ecuador (Perry et al., 2007).

2.1.4. *Cucurbita maxima* Duchesne ex Lam ssp. *maxima*

Composed of approximately 12 to 14 species, the plants of the genus *Cucurbita* (Fig. 2.7) are found in northern, central and southern parts of the American continent (Sanjur et al., 2002).



Figure 2.7. *Cucurbita maxima* ssp. *maxima* as illustrated by Blanco Castro (Blanco Castro, 1837).

Mitochondrial DNA analysis has grouped *C. maxima* ssp. *andreana* with *C. maxima* ssp. *Maxima*, forming a well-defined clade in which the subspecies *andreana* has been identified as the probable wild ancestor of *maxima* (Sanjur et al., 2002). Currently, wild *C. andreana* populations can be identified in southern Argentina and in the Bolivian lowlands (Ferriol et al., 2004). One of the

few archaeological studies is based on macro remains identified in the Peruvian coastal sites (4,960-4,860 cal. yr. B.P. - Lira-Saade, 1995).

2.1.5. *Arachis hypogaea* L.

The *Arachis* genus is native to South America and comprises 80 described species including the cultivated peanut (*A. hypogaea* – Fig.2.8) (Moretzsohn et al., 2013). It is found throughout Brazil, Argentina, Bolivia, Paraguay and Uruguay (Moretzsohn, 2013). Except for *A. hypogaea*, which is allotetraploid, most species of the *Arachis* genus are diploid (Leal-Bertioli et al., 2017). Given the evidence presented by genetic data, *A. hypogaea* most probably originated from the hybridization of two wild species (*A. duranensis* and *A. ipaënsis*) from the eastern part of the Andes, in an area covering south-eastern Bolivia and north-western Argentina (Bertioli et al., 2016, Kochert et al., 1996, Seijo et al., 2004). While the wild species of peanut are conjectured to be endemic to south-eastern Bolivia and north-western Argentina, the earliest archaeological evidence comes from Peru.



Figure 2.8. *Arachis hypogaea* as illustrated by Marcgraf (1648 p.37).

Peanut macro remains from the Zaña Valley, Peru (Dillehay et al., 2007), dated to 9,535-9,475 cal. yr. B.P., showed distinctive phenotypic characteristics when compared to modern domesticated and known wild species (Dillehay et al., 2007). This indicates the probability of a pre-domestication cultivation of this plant and its transport out of its area of origin before it acquired the domesticated traits (Piperno, 2011). Additionally, peanut starch grains, identical

to those of the modern species, were recovered from human teeth dating back to 9,257-9040 cal. yr. B.P., in the Ñanchoc Valley in northern Peru (Piperno and Dillehay, 2008).

2.1.6. *Dioscorea trifida* L.

The *Dioscorea* (Dioscoreaceae family – Fig. 2.9) genus is composed of 644 species (Govaerts et al., 2007), characterised by a wide range of species from highly dispersed geographical origins worldwide (Montaldo, 1991, Stephens, 2006). Yam plants are propagated vegetatively through their tubers (Montaldo, 1991). The economically important species in this genus are *D. alata*, *D. cayenensis*, *D. mummularia*, *D. opposita*, *D. rotundata*, *D. transversa*, *D. esculenta*, *D. bulbifera*, *D. pentaphylla* and *D. trifida* (Lebot, 2009).



Figure 2.9. *Dioscorea* sp. as illustrated by Marcgraf (1648 p.29).

The species of *Dioscorea* present a vast spectrum of origin, encompassing Southeast Asia, western Africa and tropical America (Nascimento et al., 2013). For the lowland Amazon, *D. trifida* was probably the first species of yam cultivated by European immigrants (Bousalém et al., 2010, Lebot, 2009). Regarding its centre of origin, wild-type species of *D. trifida* have been identified in French Guiana (Bousalém et al., 2010), placing this species in the likely northeast lowland Amazonian domestication area (Piperno 2011). However, molecular investigations are needed to verify the relationships between these possibly wild ancestors and the cultivated forms (Nascimento et al., 2013).

Disocorea starch grains and macro remains have been identified in various archaeological sites, such as the Cauca Valley in Colombia (8,493–

8,313 cal. yr. BP Piperno, 2011), and the Aguadulce rock shelter in Panama (6,497-6,447 cal. yr. B.P.- Piperno, 2011), the Morro do Ouro shell mound in South Brazil (4,784-4,416 cal. yr. B.P.- Wesolowski, 2007) and the Forte shell mound in Southeast Brazil (6,180-5,630 cal. yr. B.P. Scheel-Ybert, 2013).

2.2. Species of Interest

This sub-section will concentrate on wild rice species (*Oryza* spp.) and domesticated maize (*Zea mays*). South American historical and ethnographic accounts referenced wild rice consumption by natives, but despite the evidence provided by these accounts, the consumption of wild rice and its role in pre-Columbian subsistence has not been fully investigated (Hilbert et al., 2017 in press). Seeing that the Monte Castelo shell mound is included in the domestication area previously discussed in this chapter, and considering the large number of rice species growing in the wetland region, it is feasible that the occupants of the shell mound could have manipulated wild rice. Additionally, domesticated maize has been described in various ethnographic accounts for the South American continent, and is evident in various archaeological sites throughout the American continent (e.g. Piperno, 2011). Thus, a focus on this major crop is presented below.

2.2.1. *Oryza* spp. L.

The *Oryza* genus consists of 22 known wild species. Four of them are endemic to South America (Fig. 2.10). These include one diploid ($2n = 24$, AgpAgp) *O. glumaepatula* and three tetraploids ($2n = 48$, CCDD) *O. alta*, *O. grandiglumis* and *O. latifolia* (Fig. 2.11) (Judziewicz et al., 2000, Sanchez et al., 2013). South American wild rice species are all aquatic emergent macrophytes that grow along rivers, lakes and wetland margins. They include annual, biannual, and perennial species with seedling recruitment occurring during the dry season and a short reproductive phase starting directly after the flood peak (Bertazzoni and Damasceno-Júnior, 2011).

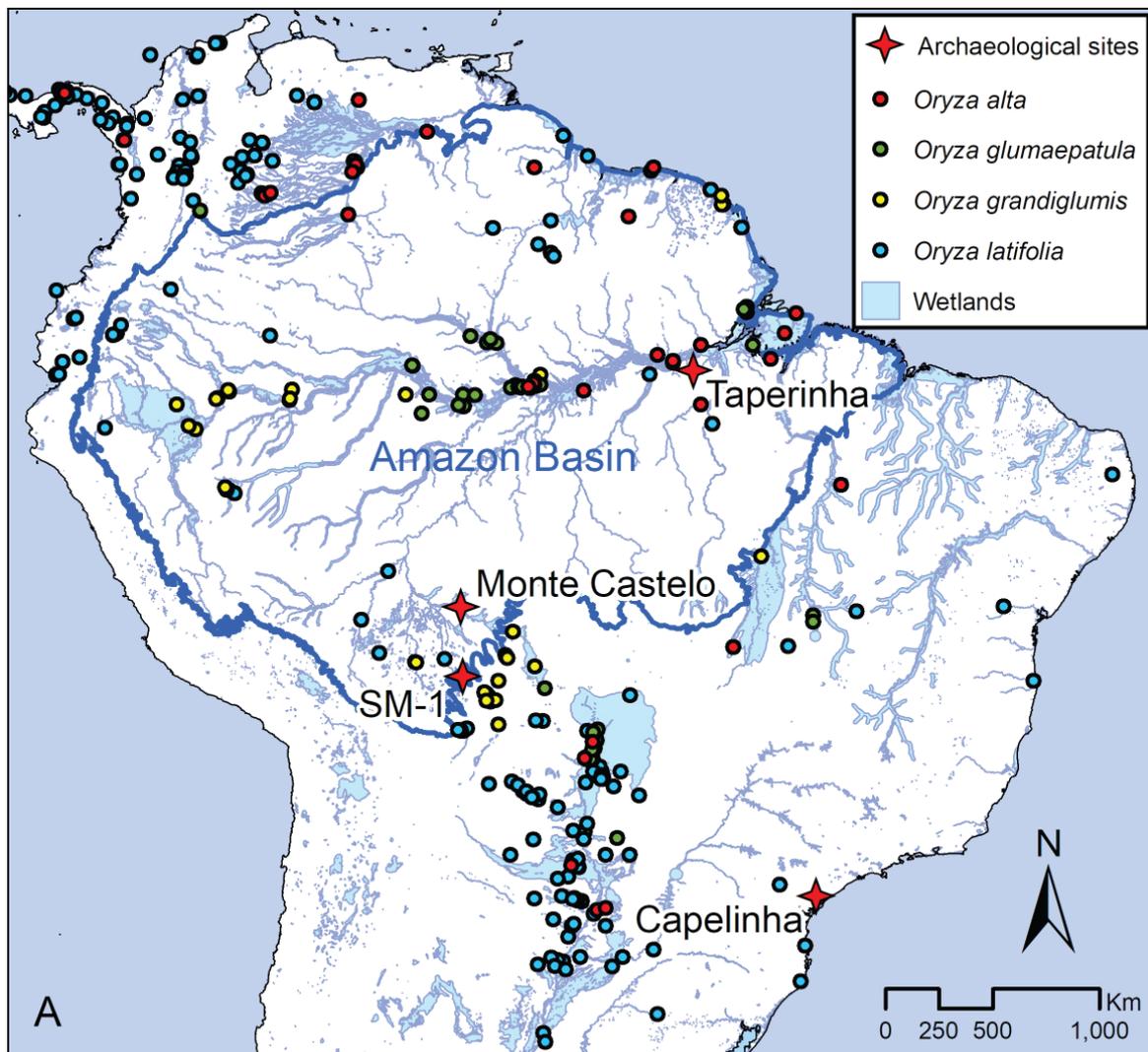


Figure 2.10. Distribution of *Oryza* species and wetlands in South America. **(A)** Species occurrences from the Global Biodiversity Information Facility. Wetland areas from the Global Lakes and Wetlands Database, World Wildlife Fund (<https://www.worldwildlife.org>) (Hilbert et al., 2017 in press).

Species of wild rice (e.g. *Zizania* sp.) have been extensively documented in North America (Ford and Brose, 1975, Yost and Blinnikov, 2011). In South America, early 16th century historical and ethnographic accounts report the consumption of wild rice species throughout lowland Amazonia (Cardim, 1583 [2009], De Azara, 1742 [2014], Fonseca, 1749 [1826], Hartt and Agassiz, 1870, Hoehne, 1937, May, 1862, Winkler, 1926). Ethnographic and historic evidence (op cit) describes the consumption of wild rice by native South American peoples before the introduction of the Asian variety by Europeans in 1745 (Sprecher von Bernegg, 1960). Various accounts, such as the reports by Walter May (1862), Ludwig Riedel (Barman 1821-1829 [1971]) and Winkler (1926)

state that natives harvested wild rice by lashing the ripe ears with wooden poles for the grains to fall into their canoes. José Gonçalves da Fonseca in 1749 states the ease in which the wild rice crops could be harvested by this method (Fonseca, 1826. p. 136). Furthermore, Schmidt (1902) in his 1900-1901 expeditions to the south-west wetlands of Brazil mentions the consumption of wild rice by the indigenous Guató group (p.113). Though little is known in regards to culinary practices, Cardim (1583 [2009] p.16) mentions the use of rice mixed with maize to bake bread. Acosta , (1590 [2002] p.362) describes its consumption in the form of a fermented brew, like wine.



Figure 2.11. *Oryza latifolia* Desv. (Picture: Kunth, 1829 p.4).

Brochado (1980) in his dissertation speculated that wild rice might have been the staple food of the mound-building Marajoara societies that lived in the seasonally flooded savannahs. Despite this untested hypothesis and the ethnohistoric and ethnobotanical accounts, until now, the consumption of wild rice and its importance in the pre-Columbian subsistence system have not been explored in lowland Amazonia.

2.2.2. *Zea mays* ssp. *mays* L.

Domesticated maize (*Zea mays* ssp. *mays*) is currently the third most cultivated food crop in the world, after rice and wheat (FAOSTAT, 2017). Despite being a major component of agricultural production, and despite being grown in most

tropical and temperate climate zones, maize is little used directly as a human food, finding instead an intensive use in animal feed and as a raw material for industrialised products (Barghini, 2004).

Maize was probably domesticated from its wild ancestor Teosinte (*Zea mays* ssp. *Parviglumis*) (Doebley , 1990, 2004) in the Central Balsas River Valley of Mexico, within the last 10,000 B.P. (Buckler and Stevens 2005; Piperno et al. 2009; Ranere et al. 2009) (Fig. 2.12). The earliest recorded date for this crop derives from archaeological studies in this region documenting the presence of maize phytoliths and starch grains at about 9,688-9465 cal. yr. B.P. (Piperno et al., 2009, Ranere et al., 2009).

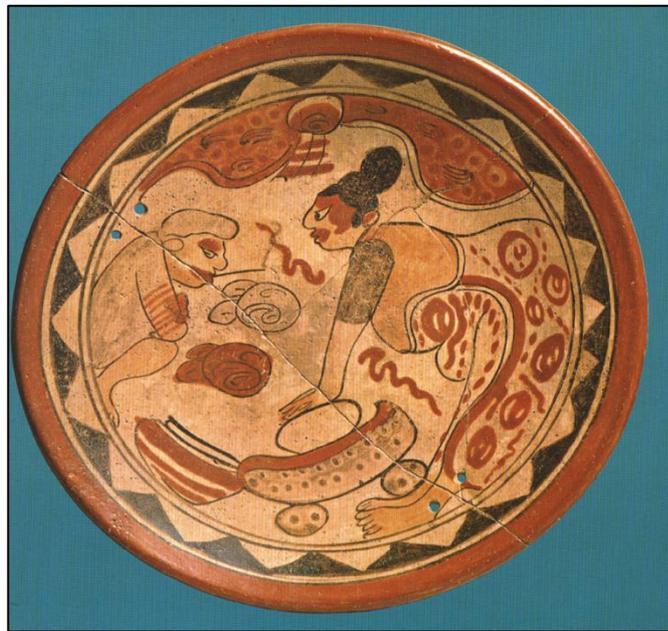


Figure 2.12. Pottery depicting the creation of humans by the Mayan goddess Xmucane by grinding kernels of maize (Laughton , 1996 p.99).

As for the diffusion of maize in South America, data suggests that it was introduced into lower Central America by 7,922-7,754 cal. yr. B.P. and probably moved into the inter-Andean valleys of Colombia between 7,321-6,597 cal. yr. B.P., from there dispersing throughout South America (Piperno, 2011). Regarding the presence of maize in shell mounds, Wesolowski (2010) recovered starch grains from dental calculus from burials found at the Itacoara (653-508 cal yr B.P.) and Enseada 1 (1,377-1,262 cal yr B.P.) sites (Wesolowski, 2007, 2010). Furthermore, Boyadjian (2012) identified maize starch grains in the Jabuticabeira II shell mound dating to circa 2,900 B.P.

(Boyadjian, 2012). To date, no phytolith of maize has reliably been identified in shell mounds.

Concerning ethnographic accounts, maize is the only plant that Christopher Columbus (1493 [1988]) cited on October 16th, 1492, on the island of Fernandina. Later, early 16th century historical and ethnographic accounts report the consumption of maize by South American natives (e.g. Cardim, 1583 [2009]; De Azara, 1781 [2012]; De Acosta, 1590 [2002]).

CHAPTER 3

ARCHAEOLOGICAL SAMPLING AND LABORATORY PROCEDURES

This chapter presents the fieldwork sampling and laboratory procedures applied to the Monte Castelo and Tucumã shell mounds. For study, a total of 54 soil samples was analysed for phytoliths. Among them, 16 from the Monte Castelo site were also subjected to specific rice metric investigations. In addition, faunal remains were collected from the Tucumã site for zooarchaeological analysis.

1. ARCHAEOLOGICAL SAMPLING

This section describes the fieldwork and soil sampling procedures for each site investigated. Most of the data collected for this thesis were extracted from soil profile samples of shell mound test pits and excavation units, except one Test Pit profile that was located outside the Tucumã shell mound. Sampling methods and excavations of Monte Castelo and Tucumã shell mound are detailed below.

1.1. Monte Castelo Shell Mound Excavation

The Monte Castelo shell mound is located at the confluence of Igarapé Preto and Branco River, near the right bank of the Guaporé River (Rondônia- Brazil). All 16 soil samples analysed from this site were collected by Eduardo Neves

and his team during the excavation season of 2014. These archaeological sediments were collected exclusively for the study of micro-botanical remains. Phytolith analyses were carried out in the sediments to tackle the question of plant management strategies in the Brazilian Amazonian freshwater shell mounds. No research that we are aware of has investigated this subject.

The excavation area corresponded to the highest point of the mound, at the same location as Miller's 1984 excavation unit – Cut 4 (Fig. 3.1). As detailed by Neves and Pugliese (2016), the excavation was conducted in the rainy season because the site could only be reached by boat. The highest levels of water occur in the rainy season when the flooded area provides a faster and reliable way to the shell mounds area.

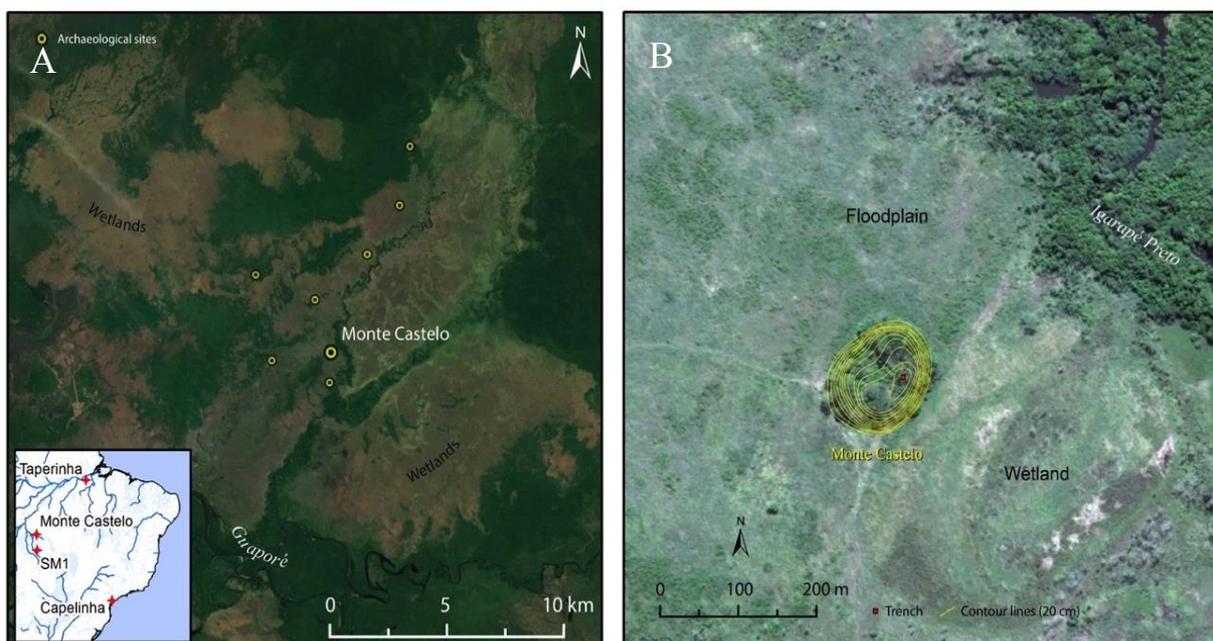


Figure 3.1. Monte Castelo site location. (A) Map showing the location of the Monte Castelo and other important early Holocene shell mound sites in South America; (B) The Monte Castelo locality, topographical map and location of the 2014 trench excavation.

The aim of the excavation was to explore the results of Miller's previous work, reopening the unit and obtaining in situ profiles. The main objectives were to register stratigraphic data and to collect initial soil samples, particularly in the contexts of early ceramic production (ca. 4,000 B.P.). A grid of 400cm by 300cm was established (Fig. 3.2) and the preserved contexts of the unit were excavated in artificial intervals of 10 cm, while the characteristics of the strata were recorded. At the end of the field season, the excavation stopped at 465cm deep (Fig. 3.3), exposing at least two different occupations (Sinimbú and

Bacabal); ten archaeological layers were identified and labelled from A to J. Unfortunately, the excavation did not reach the base of the site (ca. 800cm) due to the elevated water levels of the region during the rainy season, which meant there was a risk of collapse of the whole unit after 450cm deep.

At least one soil sample per archaeological layer was collected from non-disturbed contexts for phytolith analysis. While this is not the standard for phytolith sampling (usually collected in regular intervals Pearsall, 2010), the samples collected fit the questions addressed by this study. The soil was collected from the east profile after a new surface was exposed. The samples were then gathered from the lower layers to the upper layers. The soil was placed in plastic bags, clearly labelled, and the trowel was washed between samples. In two cases more than one sample was gathered per archaeological layer: four samples from a burial context (layer D), and four from a layer characterised by the presence of early pottery (layer J). All the material collected was registered using provenance numbers (PN) and sent to the University of São Paulo (MAE / USP). From there, phytolith samples were sent to the Department of Archaeology at the University of Exeter for laboratory procedures.

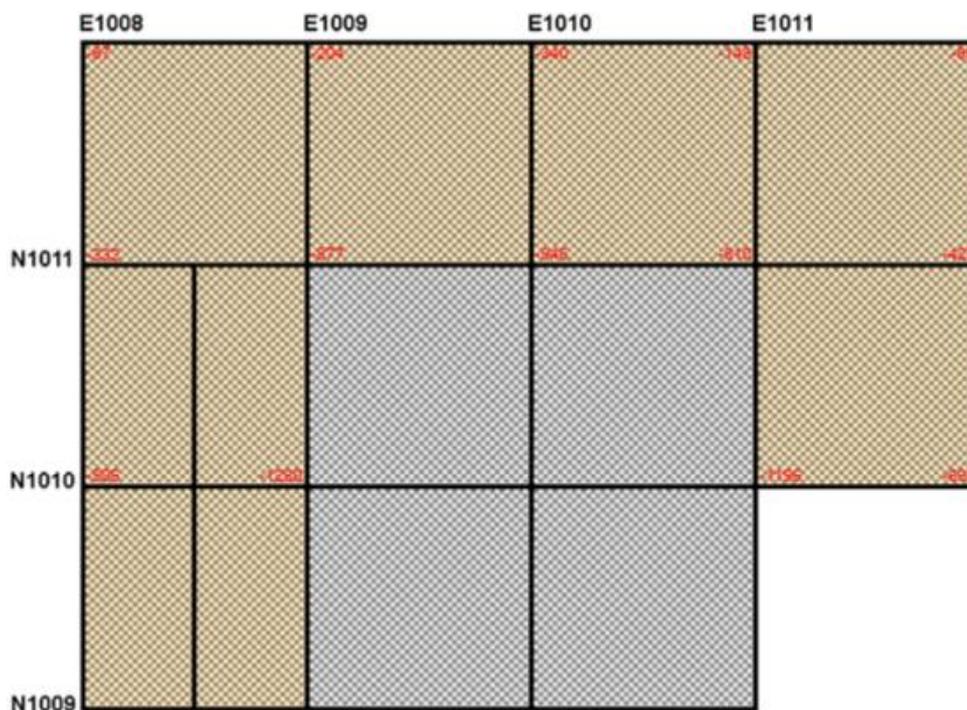


Figure 3.2. Excavation grid. The units marked in grey indicate the location of Miller's Cut-4. Brown indicated the areas excavated in February 2014. Red values indicate the original topographic dimensions of the excavations. Soil samples were collected from the East wall profile (1009 and 1010) (Neves and Pugliese, 2016).



Figure 3.3. Photograph of excavated area (picture: E. Neves).

1.2. Tucumã Shell Mound Excavation

The Tucumã shell mound is located in the Tucumã precinct, on the outskirts of the city of Melgaço (Pará-Brazil) (Fig 3.4). The sole purpose of the 2015 excavations was to collect soil and faunal remains from the site previously investigated by Denise Schaan and team in 2012. Schaan's team mapped the site in 2012 through transect coring. Stratigraphy of the cores was checked in

artificial levels of 20 cm or by natural levels according to changes in soil texture and colour. The cores revealed that the archaeological layers were distributed heterogeneously. A priori, five strata were identified, relating to at least two major occupations: a shell mound layer and a second occupation comprising of a darker soil with a large amount of ceramics and less shells.



Figure 3.4. Tucumã site location. (A) Map showing the location of the Tucumã site; (B) The Tucumã locality, topographic map and the location of 2015 excavations.

The topography of the site was mapped into a total station model Geodetic NTS 355R. First, a north/south oriented line was established by placing Station Point 1 (E1) at the geographic coordinate UTM 22M 531554L 9801080N and a second point 10m to the north located under the coordinate UTM 22M 531554L 9801090N. Second, an east/west line was drawn across E1 extending 75m to the east and 20m to the west - limited by Raimundo Anacleto Street. From these two main lines, other east/west oriented lines were defined and cored at regular intervals to map the site's limits and stratigraphy. As well as the main mapping points, several other points were taken for the creation of the topographic plan (Fig. 3.5) and sketch showing the location of the cores and excavations units (Fig. 3.6).

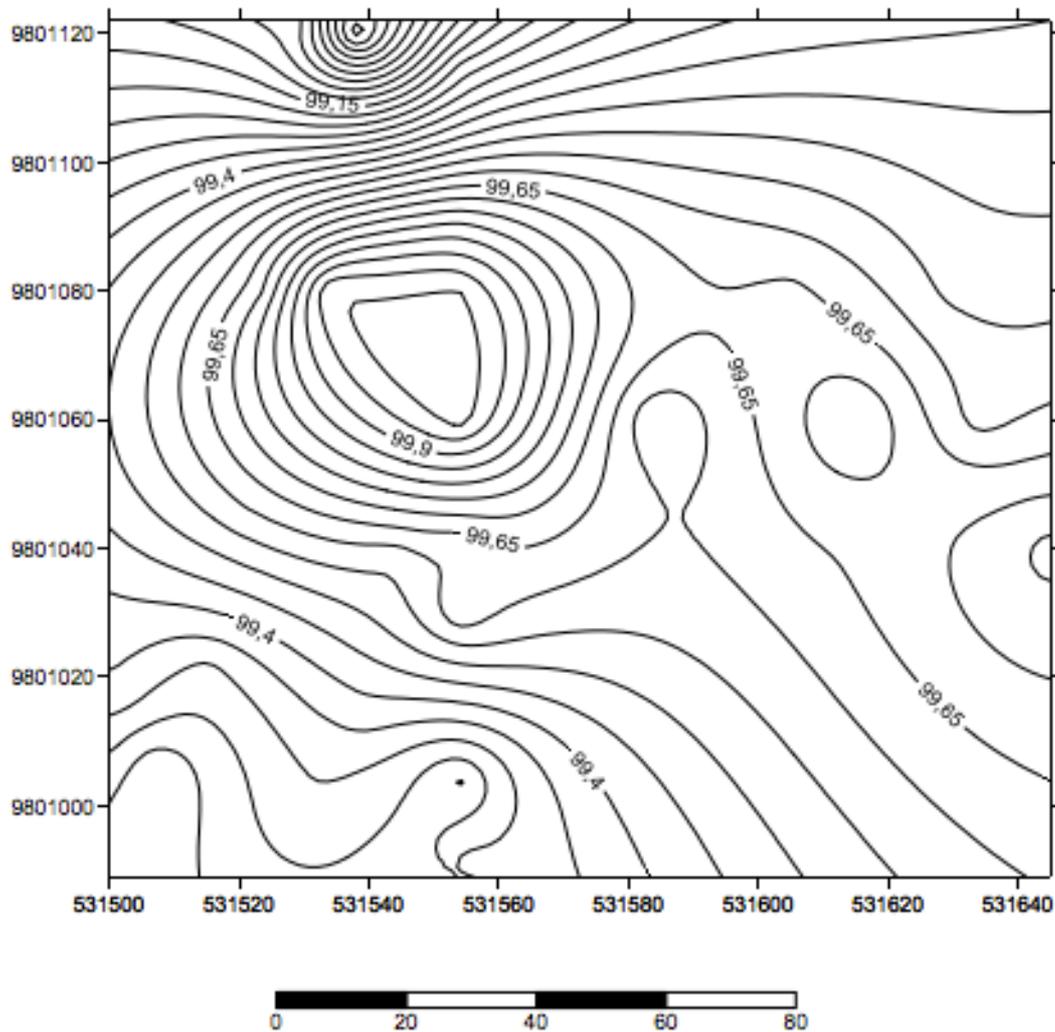


Figure 3.5. Topographic map of the Tucumã shell mound (Schaan and Silva, 2013).

From Schaan's report, we noted that the area described as Excavation 4 was one of the most well preserved in regards to the aforementioned disturbances by building activities (Schaan and Silva, 2013). Our purpose was to reopen this unit and collect soil and faunal samples. Additional soil samples were taken from four test pits in the proximity of Excavation 4. Test pits 1, 2 and 3 were opened near Schaan's excavations 2, 6 and 5, respectively. Test pit 4 was opened outside the known area of the shell mound. Units were dug with surface dimensions of 100cm x 100cm (Excavation 4), and 50cm x 100cm (Test pits) (Fig. 3.6).

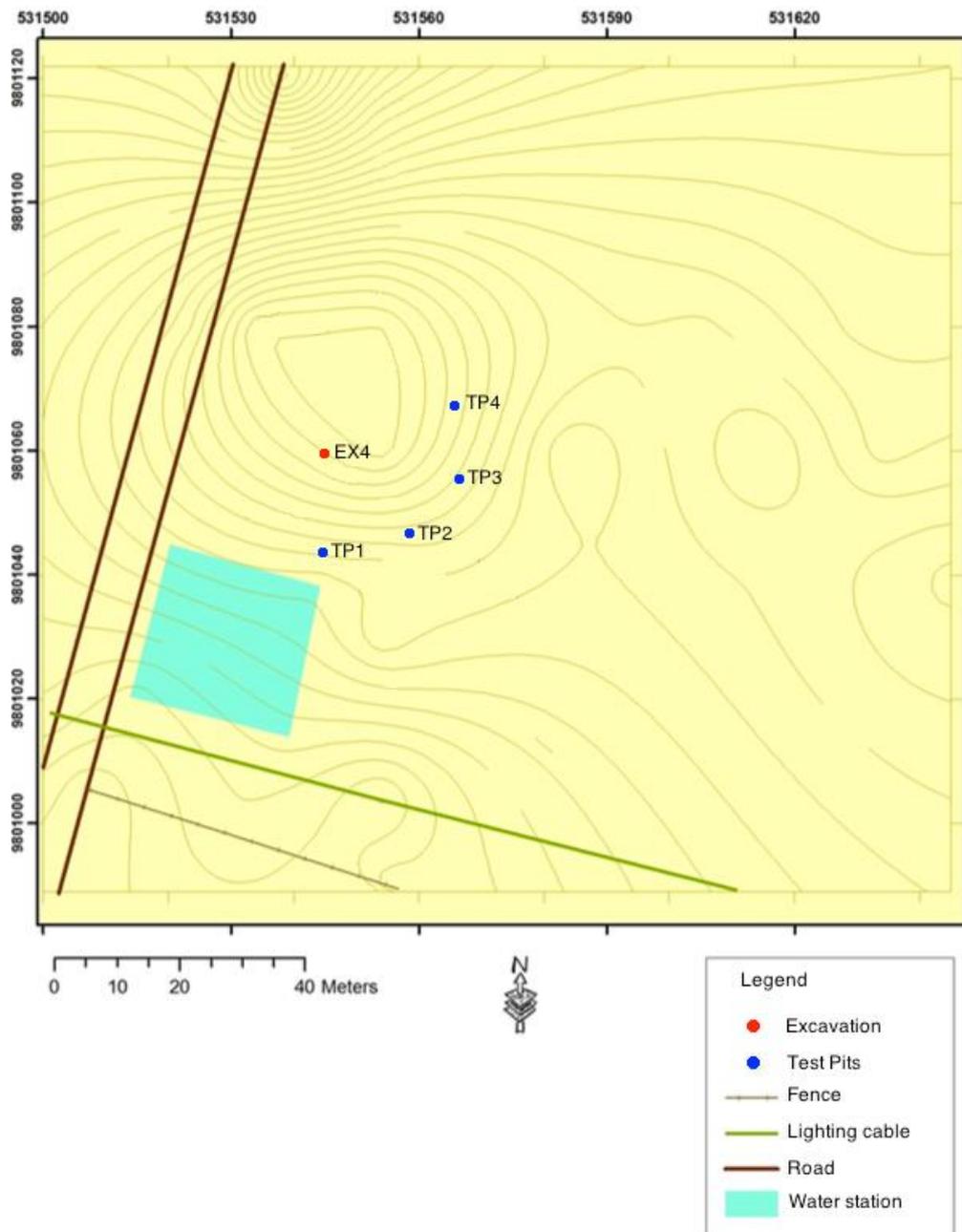


Figure 3.6. Sketch of the Tucumã mound and location of the excavated units (altered from Schaan and Silva, 2013).

The stratigraphy of the exposed soil profiles was photographed and recorded before being cleaned for sample extraction. Soil samples were taken in 10cm intervals, moving up the profile, and transferred into plastic sampling bags; the trowel was cleaned between sampling. Where there was a sign of bioturbation, care was taken to sample around it to avoid contamination (Fig. 3.7).



Figure 3.7. Profile pictures of the 2015 excavation. (A) Excavation 4; (B) Test Pit 1; (C) Test Pit 2; (D) Test Pit 3; (E) Test Pit 4.

2. LABORATORY METHODS

This section begins with a general discussion on the use of phytoliths for archaeobotanical studies. Next, we present the laboratory procedures on phytolith extraction, followed by a description of the identification method carried out for this study. Other laboratory procedures such as quantification, maize discriminant functions, squash and wild rice metric attributes are presented in subsections.

2.1. Phytolith Justification

The term “phytolith” derives from the Greek word meaning “plant stone” (Piperno, 2006b). Phytoliths are microscopic silica opal bodies produced in stems, leaves, inflorescence bracts, and seeds of many plant taxa (Piperno 2006). One of the main advantages of phytoliths for archaeobotanical studies is their durability in soils and their overall long-term resistance to environmental changes (Piperno 2006).

In some cases (e.g. Poaceae family), phytoliths are shaped actively under genetic control and can be highly diagnostic at subfamily, tribe and even genus level (Blackman, 1971, Piperno, 2006b). Generally, phytolith analysis has proved to be a reliable method for identifying various types of domesticates, particularly in regions of poor macrobotanical preservation (Piperno, 2006b, Piperno and Pearsall, 1998b, Piperno et al., 1999). Importantly, some plant species as maize (*Zea mays*) and rice (*Oryza* sp.) produce different phytoliths in separate parts of the plant, which allows the identification of activity areas relating to the processing of crops e.g. separation between fields and domestic areas (Iriarte, 2003a, Mulholland, 1987), and the documentation of the incorporation of crop residue as green mulch (Iriarte et al., 2010, McKey et al., 2010).

Phytoliths are also a reliable tool in the identification of domesticated species. As a result of domestication, a gradual increase in plant size occurs (Hancock, 2012, Pickersgill, 2007, Purugganan and Fuller, 2009, Zeder, 2006). In some cases, the increase in plant size is accompanied by an increase in phytoliths. This is the case of *Zea mays* (Piperno, 2006), *Cucurbita* sp. (Piperno, 2003) and *Musa* bananas (Vrydaghs et al., 2009), where larger fruits and seeds often yield considerably larger phytoliths. Pearsall (1995) Zhao et al. (1998) and Gu et al. (2013) have also demonstrated a clear correlation between phytolith size and seed size in Asian rice.

While phytolith analysis has successfully been used to identify known domesticates, one of its main disadvantages is the current stage of taxonomic resolution. For example, globular granulate phytoliths are produced by most arboreal eudicots, generating a multiplicity and redundancy (Rovner, 1983, Rovner, 1971) in the phytolith data. Although redundancy in eudicot phytolith assemblages still exists, various tropical eudicot families have been found to produce phytoliths diagnostic to family or genus level; these include the

Cannabaceae (*Celtis* sp.), Moraceae, Burseraceae and Annonaceae (Piperno, 2006). While at the current stage phytolith taxonomic resolution is largely based on morphological characteristics, the use of local reference collections could refine the phytolith identification. Regarding palm phytoliths, recent work carried by Morcote-Ríos et al. (2016) has managed to confirm, to some degree, that the size of phytoliths could be informative in the identification of Amazonian palms.

Another important characteristic to take into account while studying phytoliths is the fact that they are in situ deposits. They are released into the ground where the plant dies and decomposes, thus serving as a vital fossil record of the plant's presence at that location (Piperno, 2006). This in situ characteristic is advantageous for shell mound studies. Considering that all information recovered from these sites represents a direct anthropic deposition, the presence of plant remains, such as maize, does suggest a primary handling of this taxa.

Although being essentially in situ deposits, phytoliths can be redistributed through long-distance transport, such as alluvial transport and also during wind-blown fires (Fredlund and Tieszen, 1994). Because samples were taken directly from shell mound soil profiles, these mechanisms would have played only a minor part in the phytolith assemblages.

However, post-depositional processes may also affect phytoliths. These can act directly on phytolith preservation as well as in the soil profile (Piperno, 2006). For example, bioturbation and water seepage will lead to a change of phytolith material (Hart, 2003, Hart and Humphreys, 2003). Phytolith translocation due to water seepage was investigated by Fishkis et al. (2010). The investigations revealed that smaller-sized phytoliths (<12µm) might descend up to 4 cm per year in sandy or loamy soils (Fishkis et al., 2010). The degree of translocation caused by this process is still open to debate (e.g. Madella and Lancelotti, 2012), so a cautionary approach will be taken while describing the results of this study. Finally, chemical intervention on phytoliths during pedogenesis may also affect soil phytolith assemblages, leading to dissolution and subsequent silica recycling (Madella and Lancelotti, 2012). The large quantities of bivalve and gastropod carapaces in shell mounds creates an interference in the environment that neutralises the typical acidity of Brazilian soils (Gaspar et al., 2007), thus largely preserving the phytolith assemblages deposited in them.

2.1.1 Phytolith extraction

Phytoliths from all samples were extracted using the wet oxidation method described by Piperno (2006). The extraction procedure involves separating the biogenic silica fraction from the soil matrix (Piperno, 2006). A summary of the laboratory procedures is given below.

Deflocculating: 100 ml of soil is mixed with 900 ml of hot water and one spoon of sodium hexametaphosphate and put in the shaker for 24 hours to disaggregate the soil (Fig. 3.8. A).

Washing clays by gravity sedimentation: clays are removed to ensure clean microscope slides using gravity sedimentation, during which the soil solution is poured into one litre glass beakers and left to rest for one hour. The silt and sand fractions sink while the clays stay suspended in the water. The supernatant is carefully poured away. The process is repeated until the water is moderately clear (Fig. 3.8. B).

Fractionation of sediment: the remaining soil is divided into silt (fraction A < 50 μm) and sand (fraction C > 50 μm) components by wet sieving (Fig. 3.8. C). Fraction A and C are then stored separately in centrifuge tubes (Fig. 3.8. D). The reasons for fractionating the samples are to concentrate the phytoliths by their size and to allow easier viewing under the microscope (Piperno, 2006).

Removing Carbonates: for each sample, roughly 2 cm^3 of silt and sand are transferred into separately labelled test tubes ready for chemical washes (Fig. 3.8 E). Hydrochloric acid (HCl) is added to the samples to remove carbonates and some of the iron oxides. This step has been particularly slow due to the significant amount of carbonates found in shells from the shell mound samples (Fig. 3.8 F). Once reactions ceased, samples were rinsed and centrifuged at 1700 rpm for 10 minutes until the water was clear.

Removing organics: nitric acid (HNO_3) is used to remove organics. Samples in the nitric acid are heated to 100°C for at least two hours (Fig. 3.8 G). If samples are still black or red-brown, potassium chlorate is added to speed reaction. Samples were ready once they presented a clear yellow or yellow/green colour.

At this point, samples were rinsed and centrifuged at 1700 rpm for 10 minutes until the water was clear.

Heavy liquid: phytoliths are separated from the remaining sediments with the use of a zinc bromide (ZnBr_2). Water is added to zinc bromide powder until the desired density of approximately 2.30 g/cm^3 (between $2.28\text{-}2.32 \text{ g/cm}^3$) is reached (Fig. 3.8 H). The solution is then added to the samples and centrifuged for 10 min at 1700 rpm (Fig. 3.8 I).

Floating phytoliths: after centrifugation, the phytoliths, which are lighter than the heavy liquid, float to the top. They form a ring and are syphoned off (Fig 3.8. J) and transferred into fresh test tubes.

The final stage consists in drying samples and treating them with acetone. After at least 24 hours, samples are stored in accordingly labelled glass containers (Fig. 3.8 K). Entellan was used to mount the phytoliths into the microscope slides. While still fresh, entellan enables the phytoliths to be rotated leading to easier and more accurate identifications.



Figure 3.8. Phytolith extraction using the wet oxidation method. (A) Deflocculation; (B) washing clays by gravity sedimentation; (C-D) fractionation of sediment; (E-F) removing carbonates; (G) removing organics; (H) heavy liquid preparation; (I-J) centrifuging and collecting supernatant phytoliths; (K) dried and stored samples.

2.1.2. Phytolith Identification

Phytolith identifications were made using published material (e.g. Boyd et al., 1998, Chandler-Ezell et al., 2006, Dickau et al., 2013, Gu et al., 2013, Iriarte and Paz, 2009, Kondo et al., 1994, Mercader et al., 2009, Meunier and Colin, 2001, Pearsall et al., 1995, Piperno, 2006b, Piperno and Pearsall, 1998b, Runge, 1999, Twiss et al., 1969, Wallis, 2003, 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. Additionally, Cross variants 1 and 5/6, were counted, measured and subjected to discriminant function and maize prediction values per Piperno (2006). Whenever possible, naming and descriptions followed the ICPN descriptors defined by Madella et al. (2005). Phytoliths from slides were scanned at least three times at 200 to count. List of archaeological sediments analysed for phytoliths is shown in Table 3.1. Finally, the phylogenetic classification of the *Poaceae* family used in this study will follow the reports of Soreng et al. (2015) and Judziewicz et al. (2000).

This section describes the morphological characteristics and taxonomic significance of the phytoliths identified. Table 3.2 displays a summary of the morphotypes identified and Figure 3.9 shows microphotographs of the phytoliths. An outline of the different *Poaceae* subfamilies morphotypes is described below, followed by other monocots and eudicots.

The taxonomic resolution of the *Poaceae* family phytoliths has improved since the classification was initially proposed by Twiss et al. (1969). Later studies were able to validate and refine this taxonomic resolution, applying three-dimensional parameters for classifying *Panicoideae*, *Chloridoideae* and *Pooideae* grasses by the composition of lobate forms, saddles, and rondels/wavy trapezoids (Alexandr e et al., 1997, Fredlund and Tieszen, 1994, Honaine et al., 2006, Iriarte, 2003a, Lu and Liu, 2003, Piperno, 2006b, Piperno and Pearsall, 1998b). However, some overlap among phytolith morphotypes in the *Poaceae* taxa remains (Piperno, 2006).

Table 3.1. List of archaeological sediments analysed for phytolith for this study.

Sample no.	Provenience Level b.s. (cm)	Site	Unit	Age Cal.yr. B.P.
A	30-40 cm	Monte Castelo (MC)	Cut 4	
B	50-60 cm	Monte Castelo (MC)	Cut 4	
C	70-80 cm	Monte Castelo (MC)	Cut 4	
D PN75	90-100 cm	Monte Castelo (MC)	Cut 4	
D PN64	130 cm	Monte Castelo (MC)	Cut 4	
D PN1003	130-140 cm	Monte Castelo (MC)	Cut 4	4,085-3,895 (95%)
D/E	140 cm	Monte Castelo (MC)	Cut 4	
E	140-150 cm	Monte Castelo (MC)	Cut 4	
F	200-210 cm	Monte Castelo (MC)	Cut 4	
G	220-230 cm	Monte Castelo (MC)	Cut 4	
H	260-270 cm	Monte Castelo (MC)	Cut 4	
I	350-360 cm	Monte Castelo (MC)	Cut 4	
J PN 112	390-400 cm	Monte Castelo (MC)	Cut 4	
J PN137	400-410 cm	Monte Castelo (MC)	Cut 4	
J PN142	420-430 cm	Monte Castelo (MC)	Cut 4	
J PN 159	450-460 cm	Monte Castelo (MC)	Cut 4	5,310-5,210 (95%)
TUC-1	0-10 cm	Tucumã (Tuc)	Excavation 4	
TUC-2	10-20 cm	Tucumã (Tuc)	Excavation 4	
TUC-3	20-30 cm	Tucumã (Tuc)	Excavation 4	
TUC-4	30-40 cm	Tucumã (Tuc)	Excavation 4	1,629-1,569 (94%)
TUC-5	40-50 cm	Tucumã (Tuc)	Excavation 4	1,695-1,647 (92.5%)
TUC-6	50-60 cm	Tucumã (Tuc)	Excavation 4	
TUC-7	60-70 cm	Tucumã (Tuc)	Excavation 4	
TUC-8	70-80 cm	Tucumã (Tuc)	Excavation 4	4,425-4,245 (95%)
TUC-9	80-90 cm	Tucumã (Tuc)	Excavation 4	
TUC-10	0-10 cm	Tucumã (Tuc)	Test Pit 1	
TUC-11	10-20 cm	Tucumã (Tuc)	Test Pit 1	
TUC-12	20-30 cm	Tucumã (Tuc)	Test Pit 1	
TUC-13	30-40 cm	Tucumã (Tuc)	Test Pit 1	
TUC-14	40-50 cm	Tucumã (Tuc)	Test Pit 1	
TUC-15	50-60 cm	Tucumã (Tuc)	Test Pit 1	
TUC-16	60-70 cm	Tucumã (Tuc)	Test Pit 1	
TUC-17	70-80 cm	Tucumã (Tuc)	Test Pit 1	
TUC-18	80-90 cm	Tucumã (Tuc)	Test Pit 1	
TUC-19	90-100 cm	Tucumã (Tuc)	Test Pit 1	
TUC-20	100-110 cm	Tucumã (Tuc)	Test Pit 1	
TUC-21	0-10 cm	Tucumã (Tuc)	Test Pit 2	
TUC-22	10-20 cm	Tucumã (Tuc)	Test Pit 2	
TUC-23	20-30 cm	Tucumã (Tuc)	Test Pit 2	
TUC-24	30-40 cm	Tucumã (Tuc)	Test Pit 2	
TUC-25	40-50 cm	Tucumã (Tuc)	Test Pit 2	
TUC-26	50-60 cm	Tucumã (Tuc)	Test Pit 2	
TUC-27	0-10 cm	Tucumã (Tuc)	Test Pit 3	
TUC-28	10-20 cm	Tucumã (Tuc)	Test Pit 3	
TUC-29	20-30 cm	Tucumã (Tuc)	Test Pit 3	
TUC-30	30-40 cm	Tucumã (Tuc)	Test Pit 3	
TUC-31	40-50 cm	Tucumã (Tuc)	Test Pit 3	
TUC-42cm	42 cm	Tucumã (Tuc)	Test Pit 3	
TUC-32	50-60 cm	Tucumã (Tuc)	Test Pit 3	
TUC-33	0-10 cm	Tucumã (Tuc)	Test Pit 4	
TUC-34	10-20 cm	Tucumã (Tuc)	Test Pit 4	
TUC-35	20-30 cm	Tucumã (Tuc)	Test Pit 4	
TUC-36	30-40 cm	Tucumã (Tuc)	Test Pit 4	
TUC-37	40-50 cm	Tucumã (Tuc)	Test Pit 4	

Non-diagnostic Poaceae morphotypes identified in this study included cross-shaped bodies (Fig. 3.9 A-B). These, produced in the leaf of most known grasses (Piperno, 2006), are classified as lobate forms with three or more lobes. While cross-shaped phytoliths are used to differentiate wild grasses from

domesticated maize, this is only possible through cross-variant-1 discriminant functions (Iriarte, 2003; Pearsall 1978; Piperno and Pearsall, 1990). Thus, only the presence or absence of maize can be verified and it is not possible to pinpoint which one of the phytoliths is diagnostic to maize. It is still a subject for debate, but it is possible that variant-1 crosses with a width greater than 20.6µm could be diagnostic of domesticated maize (Pearsall, 1978). Nevertheless, a priori, all crosses identified in this study have been classified as Poaceae. Poaceae also produce smooth-edged bulliforms (Fig. 3.9. C-D) and silicified elongated epidermal cells (Fig. 3.9. F). Additionally, general rondel phytoliths characterised by at least one circular face (Fig. 3.9. E) occur in all Poaceae subfamilies (Piperno, 2006).

The Panicoideae subfamily consists mostly of C4 type grasses distributed across warm and humid tropics and is also found in a variety of savannah environments as well as forest understoreys (Twiss, 1992). Among the lobate morphotypes identified in this study were the bilobates (Fig. 3.9. G) ("dumbbell" types) and polylobates (Fig. 3.9. H) (elongated bodies with more than four lobes) which are diagnostic to the subfamily (Sase and Hosono, 2001, Twiss, 1992, Twiss et al., 1969). Other "dumbbell" forms include the phytoliths from the Aristidoideae subfamily, these specific bilobates are characterised by having a long narrow shaft, and flared convex lobes (Fig. 3.9. I) (Mulholland, 1987, Piperno and Pearsall, 1998b).

The Bambusoideae subfamily consists of three tribes: tropical woody bamboos (Bambuseae), temperate woody bamboos (Arundinarieae), and herbaceous bamboos (Olyreae) (Attigala et al., 2016, Kelchner and Clark, 2013). The subfamily contributes to a significant number of diagnostic phytolith morphotypes (Behling and Hooghiemstra, 2000, Iriarte, 2003a, Iriarte, 2003b, Kealhofer and Penny, 1998, Kondo et al., 1994, Piperno and Pearsall, 1998b, Sase and Hosono, 2001), of which a large variety has been identified in this study. The bamboo subfamily is known to produce "blocky" (variants 3, 8 or 10) crosses (Fig. 3.9 J) (Iriarte, 2003a) and rondels with spikes (Fig. 3.9. K-L) (Piperno and Pearsall, 1998b). The saddle-shaped phytoliths encountered were tall ridged-platforms (Fig. 3.9. M) and saddles with "collapsed sides" (Fig. 3.9. N) (Piperno and Pearsall, 1998b). Bamboos are also known to produce distinguishable bulliforms, characterised by having flared protrusions along the fan edge, which are displayed as wrinkled decoration in its side view (Fig 3.9.

O-P) (Sase and Hosono, 2001). The Chloridoideae subfamily consists of grasses adapted to hot and dry environments which produce saddle-like phytoliths exhibiting axes of equal dimensions in side view (Fig. 3.9. Q).

The Oryzeae tribe (Erhartoideae) grasses are an excellent indicator of wetland and wet prairie formations due to their distribution being limited to seasoned inundated wetland environments (Alonso Paz, 1997, Bertazzoni and Damasceno-Júnior, 2011, Burkart, 1969, Rosengurt and de Maffei, 1970). The species of this tribe are known to produce four distinct phytoliths associated with different parts of the plant: (1) cuneiform keystone bulliform cell phytoliths exhibiting fish-scale decorations on the fan edges (Fig. 3.9. R) are produced in the leaves; (2) 'scooped'-end bilobates (Fig. 3.9. S) are produced in the leaves and stems; (3) deeply serrated phytoliths (Fig. 3.9. T) and (4) double-peaked glumes (Fig. 3.9. U-V) are both derived from the epidermis of the seed (husk) and are exclusive to the species of the *Oryza* genus (Gu et al. 2013; Pearsall et al., 1995; Zhao et al., 1998).

Domesticated maize (*Zea mays*) is known to produce species-specific phytoliths on the cob of the plant (Bozarth, 1993, Mulholland, 1987, Piperno and Pearsall, 1993). The diagnostic phytoliths of *Zea mays* are classified as wavy-top (Fig. 3.9. W-Y) and ruffle-top rondels. Wavy-top rondels are characterised by possessing a flat oval or circular base; the base needs to be longer than the height of the rondel. The top must be a single complete wave that is equal to or less than the length of the rondel, without any sharp or spiny edges; the sides need to be concave (Iriarte, 2003a). The ruffle-top rondels as defined by Pearsall et al. (2003) distinguishable from the wavy-top rondels by their many undulating edges on the top.

Non-Poaceae monocots such as the members of the Cyperaceae family have been documented as producing varying phytolith shapes. Cyperaceae typically produce conical bodies (Fig. 3.9 Z) (Honaine et al., 2009, Mehra and Sharma, 1965, Ollendorf, 1992, Piperno, 1989). This family also produces polygonal phytoliths with a densely stippled surface and a large central protuberance present in the achenes (Fig. 3.9 A2) (Schuyler, 1971; Piperno, 1989).

The Marantaceae family is known to produce a large variety of globular phytoliths; some have a nodular surface decoration involving small prominences (Fig. 3.9 D2), others have an irregularly angled to folded surface decoration

(Piperno, 2006). The seeds of Marantaceae produce phytoliths with nodular projections with either a pointed (Fig. 3.9 B2) or rounded apex (Fig. 3.9 C2).



Figure 3.9. Microphotograph of phytoliths identified in this study and their taxonomic and anatomical associations: **(A-B)** Poaceae leaf cross-shaped variant 1 (MC layer C); **(C-D)** Poaceae leaf/stem bulliform (MC layer D PN75 and Tuc TUC-2 respectively); **(E)** Poaceae leaf rondel (MC layer A); **(F)** Poaceae leaf/stem elongated epidermal cell (Tuc TUC-5); **(G)** Panicoid leaf bilobate (MC layer F); **(H)** Panicoideae leaf palylobate (MC layer B); **(I)** Aristidoideae leaf thin shaft bilobate (MC layer I); **(J)** Bambusoideae leaf cross-shaped variant 3 (MC layer B); **(K)** Bambusoideae leaf rondel (MC layer D PN 64); **(L)** Bambusoideae leaf spiked rondel (Tuc TUC-8); **(M)** Bambusoideae leaf tall saddle (MC layer J PN159); **(N)** Bambusoideae leaf collapsed saddle (MC layer D PN 64); **(O-P)** Bambusoideae leaf/stem bulliform (Tuc TUC-24 and MC layer C respectively); **(Q)** Chloridoideae leaf short-saddle (MC layer C); **(R)** Oryzeae leaf/stem keystone bulliform (MC layer D PN1003); **(S)** Oryzeae leaf sooped-end bilobate (MC layer E); **(T)** *Oryza* sp. Husk serrated body (MC layer C); **(U-V)** *Oryza* sp. Husk double-peak glume (Tuc TUC-8 and MC layer E respectively); **(W-Y)** *Zea mays* cob wavy-top rondel (Tuc TUC-4, MC layer C and Tuc TUC-17 respectively). Scales = 20 μ m.



Figure 3.9. (Z) Cyperaceae leaf conical body (MC layer J PN159); (A2) Cyperaceae seed stippled polygonal body (MC layer G); (B2-C2) Marantaceae seed conical body (MC layer B and C respectively); (D2) Marantaceae leaf/stem globular (MC layer D PN1003); (E2) Heliconiaceae rhizome smooth troughs body (MC layer I); (F2) Heliconiaceae rhizome decorated troughs body (MC layer D/E); (G2) Burseraceae fruit/seed stippled polygonal body (MC layer B); (H2-I2) Asteraceae inflorescence opaque perforated platelet (MC layer A and Tuc TUC-2); (J2) *Cucurbita* sp. rind scalloped sphere (MC layer C); (K2) leaf/bark cylindric sulcate tracheid conducting element (MC layer J PN142); (L2) Arboreal leaf irregularly particle dense elongated epidermal cell (MC layer C); (M2) Arboreal leaf/bark sclereid with protusions (MC layer B); (N2) Arboreal leaf/bark faceted elongated tracheid conducting element (Tuc TUC-9); (O2) Arboreal leaf/bark sclereid (MC layer G); (P2) Arboreal all plant parts globular granulate (MC layer D/E); (Q2) Arboreal all plant parts large globular granulate (Tuc TUC-8); (R2) *Celtis* sp. Seed/fruit stippled plate (MC layer A); (S2) Annonaceae leaf spherical facetate (MC layer C); (T2-U2) Arecaceae all plant parts globular echinate (MC layer J 159 and Tuc TUC-5 respectively); (V2-W2) Arecaceae all parts of plant conical to hat-shaped body (MC layer D PN1003 and C respectively); (X2) *Trichomanes* sp. All plant parts roughly bowl-shaped phytolith (MC layer I). Scales = 20 μ m.

The phytoliths from Heliconiaceae family are characterised by the presence of deep centrally located troughs and exhibit a smooth (Fig. 3.9. E2) or decorated (Fig. 3.9. F2) surface (Piperno, 2006b, Prychid et al., 2003, Tomlinson, 1961).

The Arecaceae (palm) family is known to produce two phytolith morphotypes: (1) globular echinates, which consist of spiny projections, distributed over the surface (Fig. 3.9. T2-U2) and (2) conical to hat-shaped bodies (Fig. 3.9. W2-X2). Reports by Tomlinson (1961) on the production of these morphotypes show that certain palm species will produce either one or the other, although exceptions may occur (Piperno, 2006). More recently Morcote-Rios et al. (2016) found that conical to hat-shaped bodies, and globular echinate morphotypes may in some rare cases co-occur in *Euterpe precatória* and *E. catinga*.

Recently, researchers have been able to refine the classification of these two palm morphotypes (Bowdery, 2015, Morcote-Ríos et al., 2016, Tomlinson et al., 2011). Morcote-Rios et al. (2016) classified the globular and conical phytoliths into eight subtypes useful for identifying Amazonian palms. The classification was based on the number, degree of symmetry and length of the projections. The phytolith morphotypes were described as: (1) globular echinate elongate; (2) globular echinate with numerous acute projections at the periphery; (3) reniform echinate; (4) globular echinate with long acute projections; (5) globular echinate symmetric; (6) globular echinate with dense short projections; (7) conical with acute basal projections and (8) conical with acute basal projections. In an effort to distinguish the globular echinate morphotypes identified in this study, a section on the phytolith results is dedicated to the classification proposed by Morcote-Rios et al. (2016).

Eudicots plants consist of circa 75% of all the angiosperm (Piperno 2006). The phytoliths produced by this clade are often from hair cells, hair bases, and sclerenchyma and vascular tissue (Piperno 2006). Among the morphotypes encountered in this study are the stippled bodies (Fig. 3.9 G2) produced in the reproductive structures of the Burseraceae family. These phytoliths are characterised by a sinuous to hexagonal edges, stippled decoration and a central domed protuberance (Piperno, 1989). The Asteraceae family contains herbs or shrubs, woody vines, lianas and small trees, and in its seeds produces large opaque platelet phytoliths with perforations (Fig. 3.9 H2-I2) (Bozarth,

1992). The Annonaceae family phytoliths are distinguished by faceted phytoliths of an overall spherical (Fig. 3.9 S2) to irregular shape (Piperno, 1985, Runge, 1999). Some species of the *Celtis* genus produce stippled plate phytoliths in the fruits and seeds (Fig. 3.9 R2). Squashes (*Cucurbita* sp.) are one of the major crops that can be informed by phytoliths. The phytoliths produced in the rind of the fruit are depicted as spheres with deeply scalloped surfaces of continuous concavities (Fig. 3.9 J2) (Bozarth, 1987; Piperno 1985; Piperno et al. 2000).

The vast majority of arboreal eudicots are amongst the plant species that do not produce taxonomically significant phytoliths (Piperno 2006). These phytoliths, when present in this study, were classified as non-diagnostic arboreal. The phytoliths include globular granulate morphotypes (Fig. 3.9 P2-Q2) (Amos, 1952, Geis, 1973, Kondo et al., 1994, Scurfield et al., 1974). A common phytolith attributed to arboreal species are the silicified conducting elements. The tracheids are usually cylindrical in shape and show regular protrusions, which are infillings of border pits in the cell walls (Fig. 3.9 K2). Sclereids are silicified support structures of the xylem; these are typically elongate phytoliths with branched ends and psilate surfaces (Fig. 3.9 O2) (Piperno, 2006). Also, included as a tracheid-type, were the elongated sclereids with protrusions instead of branched ends (Piperno, 2006). Additionally, commonly produced by woody plants are the elongated multi-faceted bodies (Fig. 3.9 N2); these are irregularly shaped phytoliths with well-defined facets (Piperno and Pearsall, 1998b). Conclusively, the phytoliths described as irregularly particle dense, elongated phytoliths are arboreal epidermal cells and could be diagnostic of a limited number of trees (Piperno, 2006). Finally, ferns (*Trichomanes* sp.) produce bowl-shaped phytoliths (Fig. 3.9 X2) these are produced in all parts of the plant (Piperno, 2006; Watling and Iriarte, 2013).

Table 3.2. Phytoliths encountered in the study, their taxonomic associations, anatomical origins, occurrence after sample fractionation, and references.

Taxonomic level	Phytoliths	Origin	Occurrence when fractionated	References
Aristidoideae (Poaceae)	Long thin shaft bilobate	leaf	silt	
Bambusoideae (Poaceae)	Tall/collapsed saddle	leaf	silt	Alexandr� et al. (1997), Fredlund and Tieszen (1994), Honaine et al. (2006), Lu and Liu (2003), Pearsall (2015), Piperno and Pearsall (1998b), Sase and Hosono (2001), Twiss et al. (1969).
Chloridoideae (Poaceae)	Blocky saddle	leaf	silt	
	Cross	leaf	silt	
Panicoideae (Poaceae)	Short saddle	leaf	silt	
	Bilobate	leaf	silt	
	Crosse	leaf	silt	
	<i>Polylobate</i>	leaf	silt	
Poacea (non-diagnostic)	Rondell	leaf	silt	
	Buliform	leaf	silt/sand	
Oryzoideae (Poaceae)	Scooped bilobate	leaf	silt	Gu et al. (2013), Pearsall et al. (1995), Zhao et al. (1998).
	cuneiform bulliform	leaf	silt/sand	
<i>Oryza</i> sp. (Poaceae)	Double peak glume	seed	sand	
	Cerrated epidermal cell	seed	sand	
<i>Zea mays</i> (Poaceae)	Wavy-top rondel	cob	silt	Bozarth (1993), Iriarte (2003a), Pearsall et al. (2003), Piperno and Pearsall (1993)
<i>Cyperus/Kyllinga</i> sp. (Cyperaceae)	Stippled polygonal body	seed	silt	Honaine et al. (2009), Piperno (1989), Pursglove (1968), (Schuyler)
Cyperaceae (general)	cones	leaf	silt	Mehra and Sharma (1965), Ollendorf (1992)
Arecaceae	Globular echinates	all parts	silt	Piperno (2006b), Tomlinson (1961)
	Large Globular echinates	all parts	sand	Dickau et al. (2013), Watling and Iriarte (2013), Watling et al. (2015)
	Hat-shapes	All parts	silt	Piperno (1989), Tomlinson (1961)
Marantaceae	Globular nodular	leaf/stem	silt/sand	Piperno (2006)
	Conical bodies	rhizome	sand	Piperno (1989)
Heliconiaceae	Troughs bodies	leaf/stem	silt	Prychid et al. (2003), (Tomlinson)
<i>Cucurbita</i> sp. (Cucurbitaceae)	Scalloped spheres	Rind	sand	Bozarth (1987), Piperno (2009), Piperno et al. (2000a)
<i>Celtis</i> sp. (Cannabaceae)	Stippled plates	seed	silt	Bozarth (1993)
Asteraceae	Opaque perforated platelets	inflorescence	sand	Bozarth (1993)
Arboreal	Globular granulates	wood	silt	Geis (1973), Scurfield et al. (1974)
	Tracheids and sclereids	leaf and bark	silt/sand	Piperno (2006)
	Faceted bodies	leaf	silt	Piperno (1985)
	elongated epidermal cell	leaf and bark	silt/sand	Piperno (2006)
<i>Trichomanes</i> sp. (Pteridophytes)	bowl-shaped	all parts	silt	Piperno (2006), Watling and Iriarte (2013)

2.1.3. Quantification measurements and relative frequencies

Phytoliths were identified, counted and photographed under a Zeiss Axioscope 40 light microscope at 500X magnification. Phytoliths from A fraction (silt) slides were scanned at least three times at the standard 200 count (Pearsall, 2015, Str mberg, 2009). For the C fraction (sand), this total varied depending upon the sample.

A wide range of phytolith morphotypes such as non-diagnostic Poaceae

and non-diagnostic Arboreal were included in the count. Phytolith types that are commonly produced by a broader range of plant taxa, such as short and long polyhedral epidermal cells, hair bases and plain tracheid bodies (Piperno, 2014, Watling and Iriarte, 2013), were excluded from the count.

Most of the C fraction (sand) phytoliths from the Tucumã shell mound were limited in frequency. Therefore all of these slides were scanned fully for phytoliths under 200x magnification rather than 500x. All A and C fraction (silt and sand) samples (after the 200 phytoliths count) were fully scanned for crop phytoliths. Once the phytoliths were identified and counted, the resulting data was transformed into percentage frequencies and plotted using C2 software (Juggins, 2010).

Zea mays discriminant function

All cross-shaped phytoliths were identified and measured using Pearsall's (1978) guidelines to classify lobate morphotypes (Fig. 3.10). Piperno's (2006 p.200) three-dimensional criteria were used to distinguish the different cross-shaped variations. Whenever possible, 20 cross phytoliths were counted for each one of the archaeological samples. Phytoliths were photographed and measured under a Zeiss Axioscope 40 light microscope at 500X magnification.

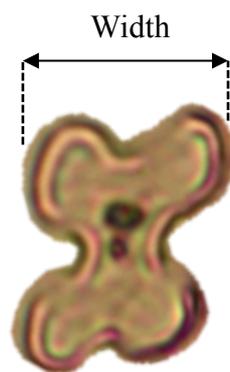


Figure 3.10. Cross variant-1 measurement parameter.

The maize prediction formula follows:

$-1.96669 + 0.1597589$ (mean width for variant-1) $- 0.0126672$ (mean width for variant-5 and 6) $+ 8.20956^{-3}$ (% of variant -1)

Wild prediction formula follows:

$+2.96669 + 0.1597589$ (mean width for variant-1) $+ 0.0126672$ (mean width for

variant-5 and 6)-8.20956⁻³(% of variant -1)

For positive prediction of maize at the site, the resulting value of the maize prediction should be greater than the wild prediction.

Of note, Hilbert's et al. (2017 in press) investigations revealed the presence of domesticated rice in the Americas. As is the case of most grasses, *Oryza* produces cross variant-1 phytoliths (Gu et al., 2014). Starting from the principle that domestication syndrome leads to larger phytoliths, larger variant-1 crosses should be expected from domesticated rice. The maize prediction discriminant functions (Piperno, 1984) did not take domesticated rice into account. This meant that it was possible that in study areas where domesticated rice is present, the use of maize discriminant functions could result in false positives. However, this should be the subject for a future investigation.

Cucurbita sp. measurement

Scalloped spheres were measured following Piperno's et al. (2002) parameters. All phytoliths identified were photographed and measured under a Zeiss Axioscope 40 light microscope at 200x magnification. Scalloped spheres were rotated and photographed in front and side view in order to estimate their length and thickness.

Oryza sp. double-peaked glume quantification and metric attributes

The double-peaked glume is a genus specific phytolith produced exclusively in the husk of *Oryza* species (Pearsal, 1995; Zhao et al., 1998; Piperno, 2006). The main aspect of this phytolith is its trapezoidal silhouette when viewed from the side, which shows its concavity and displays the "two-peaked" shape (Zhao et al., 1998).

To investigate the potential domestication of wild rice by the Monte Castelo residents a comparison of both archaeological samples and modern wild rice reference material was conducted (Hilbert et al. 2017 in press). A total of 16 archaeological sediment samples from across all ten levels uncovered during the 2014 Monte Castelo excavations, and 19 modern specimens from the four wild species of rice occurring in South America, including *O. glumaepatula*, *O. alta*, *O. grandiglumis* and *O. latifolia* (Table 3.3), were analysed for phytoliths following standard procedures (Piperno 2006).

Table 3.3. Provenance of wild rice modern reference material.

Species	Population identification	Hydrographic basin
<i>O.grandiglumis</i>	PA-1	Solimões
<i>O.grandiglumis</i>	SO-23	Solimões
<i>O.grandiglumis</i>	PU-1	Purus
<i>O.grandiglumis</i>	R.Japura	Japurá
<i>O.alta</i>	PRI-1	Ribeira
<i>O.alta</i>	RI	Ribeira
<i>O.glumaepatula</i>	SO-17	Solimões
<i>O.glumaepatula</i>	Kiv	Japurá
<i>O.glumaepatula</i>	Davavu -1992	Negro
<i>O.glumaepatula</i>	Pu-1	Purus
<i>O.latifolia</i>	Arg-11	Paraguai/Paraná
<i>O.latifolia</i>	Arg-5	Paraguai/Paraná
<i>O.latifolia</i>	Arg-7	Paraguai/Paraná
<i>O.latifolia</i>	Arg-8	Paraguai/Paraná
<i>O.latifolia</i>	E-00814355 / 1926/4	*
<i>O.latifolia</i>	E-00814354 / 1926/3	*
<i>O.latifolia</i>	E-00814353 / 1926/2	*
<i>O.latifolia</i>	E-00258728 / 1926/1	*
<i>O.latifolia</i>	E-00258733 / 1926/10	*

*Information not provided.

Following Zhao et al. (1998), five metric attributes (Fig. 3.11) were taken for each glume phytolith. (1) Top Width (TW): corresponds to the distance between the two peaks of the projecting hairs; (2) Maximum Width (MW): corresponds to the width at the point where the glume projection attaches to the base; (3-4) Height of each hair (H1, H2) measured from the tip to the base of the hair, H2 defined as the smaller measurement; (5) the Curve Depth (CD) is measured from the tip of H1 to the lowest point of the curve. Altogether 20 double-peaked glume phytoliths from each of the archaeological and modern samples were measured, totalling 700 phytoliths and 3,500 metric parameters.

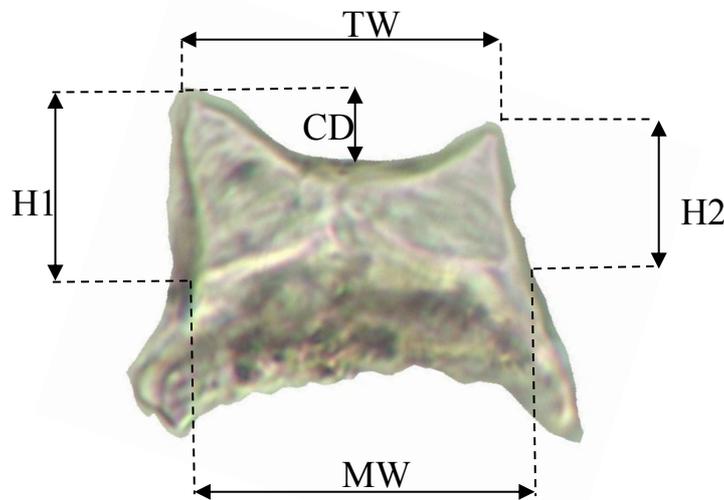


Figure 3.11. Double-peaked glume measurement parameters. (TW) top width; (MW) maximum width; (H1) maximum height; (H2) minimum height; (CD) curve depth.

Whitney S. Bronwen from the Department of Geography at the Northumbria University conducted statistical analysis on the double-peaked glume measurement and will be described in Chapter 5. Principal Component Analysis (PCA) of the five size measurements of *Oryza* phytoliths was performed on the modern wild reference (botanical) dataset to determine the key variables that define phytolith morphology. All PCA analyses were performed in R package Community Ecology package ‘vegan’ version (2.2-1) (Vegan, 2015).

2.2. Zooarchaeological Method

This section presents a summary of the recovery and laboratory procedures for the faunal remains from the Tucumã site. Of all the excavated units from the site, faunal remains were only recovered from Excavation-4. Unfortunately, at the point of writing, the zooarchaeological results for the Monte Castelo site were still under progress.

Faunal remains were recovered based on the methodology described by Bitencourt (1992) and Scheel -Ybert (2006). A 50cm area was delimited from where all the sediment was removed in 10 cm layers.

All sediments withdrawn from the shell mound were sieved in a 2 mm mesh using water (Fig.3.12). It was decided to sift the sediment with water, as it ensures better sampling, better visualisation and less damage to the remains (Scheel-Ybert, 2006).



Figure 3.12. Wet sieving of the faunal remains of the Tucumã shell mound.

After it had dried, the resulting material was packed in plastic bags with their proper identifications and shipped to the University of Exeter Archaeology department for analysis. Identification was made using published materials (e.g. Chao, 1978, Gregory, 2002, Jardim, 1988). To estimate taxonomic abundance Number of Identified Specimens (NISP) and Minimum Number of Individuals (MIN) analysis were employed. These parameters are adopted in zooarchaeology investigations (Davis and Davis, 1987, Grayson, 2014, Klein and Cruz-Uribe, 1984, Lyman, 1994, O'Connor and O'Connor, 2008, Reitz and Wing, 2008).

CHAPTER 4

EXCAVATION RESULTS

This chapter presents the excavation results and chronology for the Monte Castelo and Tucumã shell mounds. Firstly, stratigraphic descriptions and radiocarbon dates revealed for the Monte Castelo site are presented. Secondly, the stratigraphy and chronology for Tucumã shell mound will be described.

1. MONTE CASTELO SHELL MOUND EXCAVATION

This section describes the results of the Monte Castelo shell mound excavation and the radiocarbon dates.

1.1. Stratigraphic Layers and Associated Structures

The 2014 excavation of the Monte Castelo shell mound revealed a ten-layer stratigraphic sequence over two occupations: Sinimbú and Bacabal. Figure 4.1 provides information about the analysed stratigraphy of the shell mound profile. The soil colouration was determined using a Munsell colour chart. Letters will be used to identify the strata. The following descriptions are from the layers identified in the profile and will be presented from upper to lower layers:

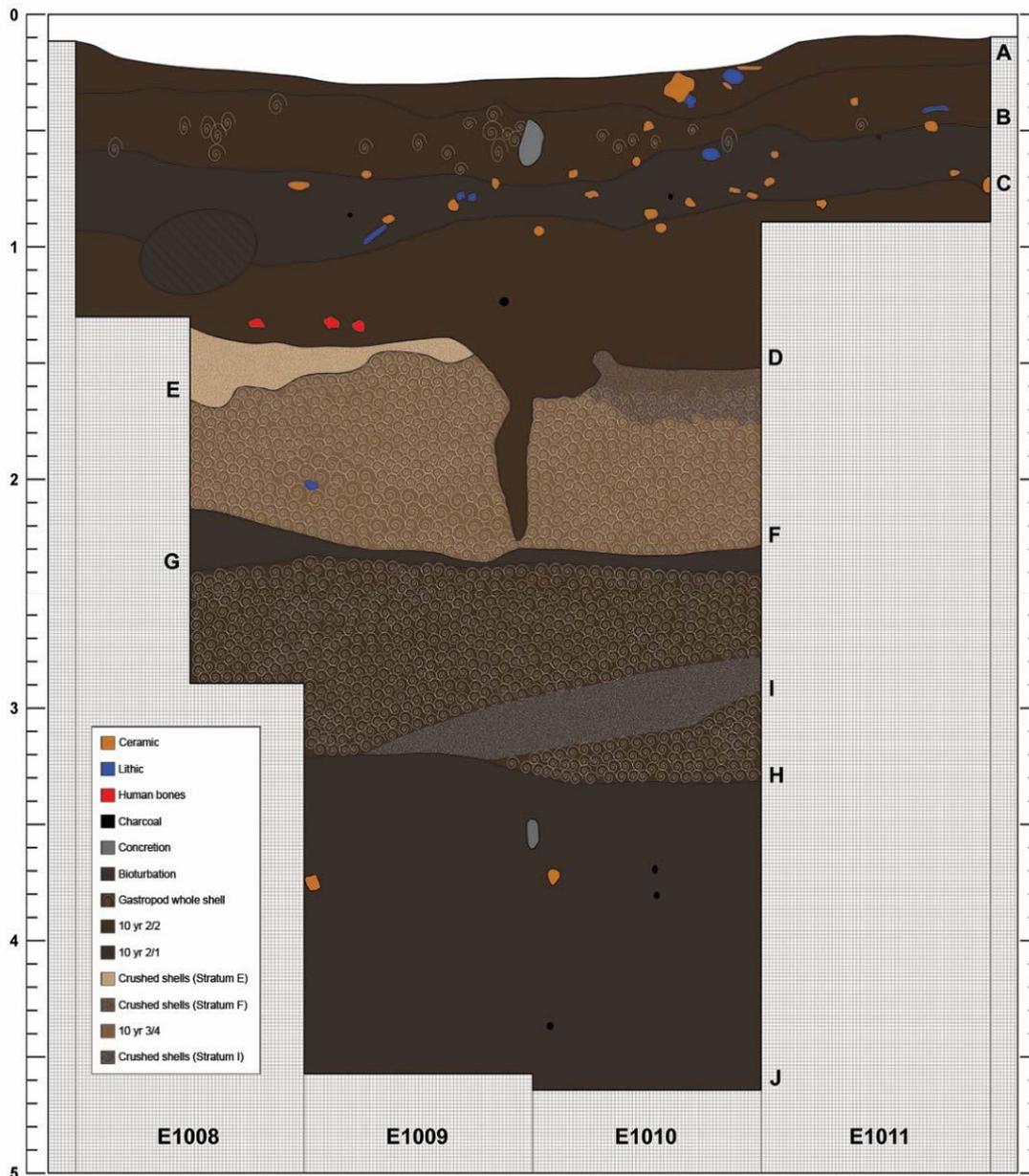


Figure 17. Illustration of the Monte Castelo shell mound stratigraphic North profile (Neves et al, 2016).

Layer A – Superficial stratum (30-40 cm b.d.): This is a 10-20 cm deep layer, composed of dark soils (10yr 2/2, very dark brown), and containing a few Bacabal phase ceramic sherds, lithics and gastropod carapaces. Based on its ceramics it can be relatively dated to around 800 B.P.

Layer B – Later shell mound construction stratum (50-60 cm b.d.): This is a 30 cm deep layer composed of dark silty clay loam soil (10yr 2/2, very dark brown), and containing about 50% of Pomacea shells. It also exhibits a high density of ceramic fragments, including zoomorphic appendages belonging to

the Bacabal Phase. It was preliminarily interpreted as a mound building construction stratum built by the later occupants of the site, represented in stratum A.

Layer C – Dark earth upper stratum (70-80 cm b.d.): This is a 30 cm deep layer composed of dark clay-silt soil (10yr 2/1, black), exhibiting a decrease in shell materials abundance when compared to the above stratum, but with a higher density of ceramic sherd corresponding to the Bababal phase. Apparent preserved areas of activity, corresponding to a possible fire pit located at the base of the layer.

Layer D – Funeral Bacabal stratum (90-100 cm b.d.): This is a 30-60 cm deep layer composed of thick clay-silty-loam soil matrix (10yr 2/2, very dark brown), and is characterised by the presence of two human burials and clear features including hearths (Fig. 4.2 A). One is a primary burial of a juvenile individual (Fig. 4.2 D – unknown age), buried with an E-W orientation with a clear grave delimitation made by accompanying gastropod shells. The other, was found near the end of this stratum where a deer skull with antlers (likely *Blastocerus dichotomus* or *Odocoileus virginianus* given its large size) (Fig. 4.2 B) was found intentionally buried over the left arm of an adult human burial surrounded by a circular shell structure (Fig. 4.2 C). The interface between layers D and E is characterised by circular features that penetrate into the lower layer, which are likely postholes.

Layer E – Burnt shell intermediate stratum (140-150 cm b.d.; PN67): This is a 15 cm deep layer composed of a thin layer of burnt and crushed shells of the *Pomacea* sp. shells. Soil matrix is composed predominately of very fragmented (<1 to 10mm) and burnt shells and ash (10yr 8/1, white, to 10yr 7/1, white grey), mixed with areas of a light brown, very fine, clay-silt soil (10yr 6/4, yellowish brown). Layer with formation linked to the Bacabal phase. Fragments of chelonian bones and a well-preserved bivalve shell were also found. Lithic remains include some flakes and a rolled pebble hammer.

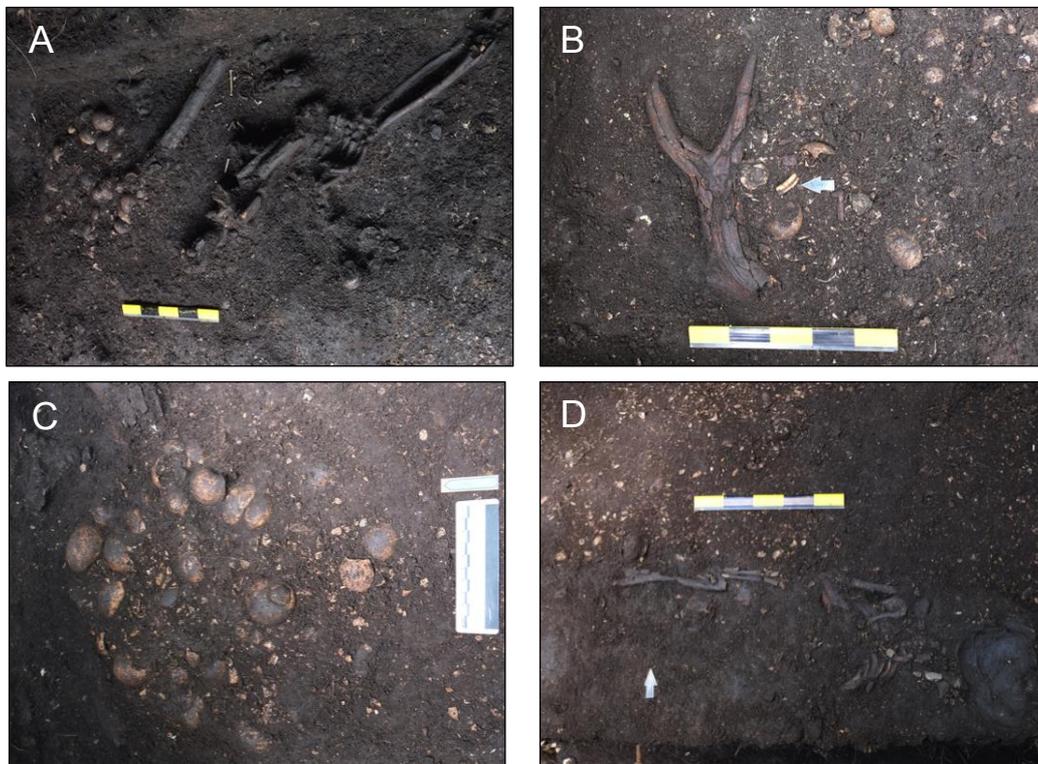


Figure 18. Photograph of the burials recovered at layer D of the Monte Castelo shell mound. (A-C) adult male burial; (A) adult burial; (B) deer cranium associated with the burial; (C) circular shell structures associated with the burial; (D) child burial (Photos: E. Neves).

Layer F – Intermediate shell mound construction stratum (200-210 cm b.d.; PN111): This is thick 150 cm deep layer composed almost entirely of entire or lightly fragmented shells of apparently unburnt *Pomacea* sp gastropods deposited in a clay-silt matrix with a coloration varying from 10yr 3/4 (dark yellowish brown) to 10yr 4/3 (brown). Interspersed with the gastropod shells, this stratum contains abundant charred faunal material, lithics and charcoal.

Layer G – Dark earth intermediate stratum (220-230 cm b.d.; PN117): This is a 40-70 cm deep layer composed of a very dark (10yr 2/1, black) clay soil matrix, showing lenses of small fragments of burnt and crushed snail shells similar to the ones in Layer E. This layer apparently marks the separation between the Bacabal and the Sinimbú phase.

Layer H – Former shell mound construction stratum (260-270 cm b.d.: PN126): This is a 30 cm deep layer, mainly composed of unburnt *Pomacea* sp. entire shells with abundant faunal remains, deposited in a dark clay matrix (10yr 2/2, very dark brown). In between the lenses of entire unburnt *Pomacea* shells,

it exhibits lenses of ground shell that appear to be superimposed occupation floors.

Layer I – Burnt shell intermediate stratum (350-360 cm b.d.): This layer has several textures and colours, showing a much more compact dark soil than stratum H and many lenses of ground shell, without visible associations of artefacts. It is not clear yet whether soil colour results from anthropic modification and enrichment or is just a representation of the adjacent dark soils of the Guaporé floodplain. It is not clear likewise whether this is a construction or occupation unit. It follows practically the same inclination as the inferior portion of layer H.

Layer J –Dark earth stratum (390-400 cm b.d. PN 112): This is a 100 cm deep layer, composed of a dark earth layer (10yr 2/1, black), with a highly compacted, clay-sand texture. It contains a high density of charcoal (at least three different types of palm pericarp were identified), several flakes and other lithic artefacts (including polished tools), as well as vertebrate and invertebrate remains that are sometimes found associated with soil concretions.

On a concise analysis of the stratigraphic layers of the Bacabal phase, the areas of activity such as the fire pits and post holes could be interpreted as habitational areas which could be compared with habitational mounds of the South and southeastern shell mounds. However, in the lower layers of the mound (Sinimbú phase), it is apparent that an edification of the mound occurred. On the other hand, through analysis of the mound's layers are being performed by Neves and his team and might bring to light the question regarding the possible functionality of the site.

1.2. Chronology

Two radiocarbon dates were retrieved from the 2014 excavations (Neves et al. 2014). Samples were chosen in order to contribute to the refinement of the overall chronology already published by Miller (2009). Table 4.1 lists all the radiocarbon dates for the Monte Castelo shell mound, showing their conventional radiocarbon ages and calibrated ages using the IntCal13 calibration (Bronk Ramsey, 2013) curve. The 2014 excavation radiocarbon

dates confirmed expectations regarding the antiquity and continuity of the settlement, notably providing high reliability for the chronology already published for Monte Castelo. The dates therefore reinforced the expected period ranges for the Sinimbú (7,431-6,979 to 5,271-4,584 cal. yr. B.P.) and Bacabal (4,813-4,087 to 910-660 cal. yr. B.P.) phases proposed by Miller (2009).

Table 4.1. Radiocarbon dates for the Monte Castelo shell mound.

Layer	Depth (cm)	Phase	Radiocarbon date B.P.	Cal.yr. B.P.	Material dated	I.D.	Reference
A	10-15	-----Bacabal-----	810±70	910-660 (95.4%)	Charcoal	B103185	Miller (2009)
A	20-30		2,475±105	2,765-2,333 (95.4%)	Shell	SI6843	Miller (2009)
A-D	10-110		2,270±105	2,699-1,999 (95.4%)	Shell	SI6844	Miller (2009)
D	110-120		3,160±70	3,560-3,212 (95.4%)	Charcoal	B66309	Miller (2009)
D	120-130		3,700±30	4,152-3,921 (95.4%)	Charcoal	*	Neves et al. (2016)
D	130-140		4,810±90	5,723-5,320 (95.4%)	Charcoal	B66310	Miller (2009)
F	160-170		3,945±110	4,813-4,087 (95.4%)	Shell	SI6845	Miller (2009)
F	210-220		3,920±85	4,580-4,090 (95%)	Shell	SI6847	Miller (2009)
G	230-240		4,455±100	5,321-4,847 (94.7%)	Shell	SI6852	Miller (2009)
H	230-240		4,395±70	5,284-4,845 (95.4%)	Charcoal	SI6848	Miller (2009)
J	430-440	-----Sinimbú-----	4,570 ± 30	5,416-5,060 (95.4%)	Charcoal	*	Neves et al. (2016)
**	600-610		6,316±105	7,432-6,980 (95.4%)	Charcoal	SI6850	Miller (2009)
**	600-610		5,065±85	5,987-5,611 (95.4%)	Charcoal	SI6849	Miller (2009)
**	610-620		5,605±95	6,637-6,215 (95.4%)	Charcoal	SI6853	Miller (2009)
**	610-620	5,165±80	6,180 -5,730 (95.4%)	Shell	SI6854	Miller (2009)	
**	620-630	-----Cupim-----	7,010±80	7,970-7,682 (95.4%)	Charcoal	B118274	Miller (2009)
**	650-670		5,970±80	7,147-6,572 (95.4%)	Charcoal	B118275	Miller (2009)
**	685-700		8,350±70	9,495-9,137 (95.4%)	Charcoal	B103187	Miller (2009)

*Information not provided. **2014 excavations did not reach depths below 460cm.

Here after all dates for the Monte Castelo shell mound mentioned in the text will be in calibrated years. Also, because the 2014 excavations did not reach levels below 460 cm, the period range used when describing the Sinimbú phase will be from 5,416-5,060 to 5,271-4,584 cal. yr. B.P. The Bacabal phase range will follow Miller (2009) (4,813-4,087 to 910-660 cal. yr. B.P.).

2. TUCUMÃ SHELL MOUND EXCAVATION

This section describes the results of Tucumã shell mound excavation units, test pits, and laboratory analysis.

2.1. Stratigraphic Layers and Associated Structures

Excavations in the Tucumã shell mound were performed based on the results of the 2013 work of Schaan and Silveira (2013). The Excavation 4 profile (Fig. 4.3) was reopened for the collection of soil samples for phytolith and zooarchaeological analysis. Additionally, 4 test pits were opened to investigate the formation of the shell mound and the possible existence of plant deposition patterns.

Excavation 4 (UTM 22M 531544L 9801061)

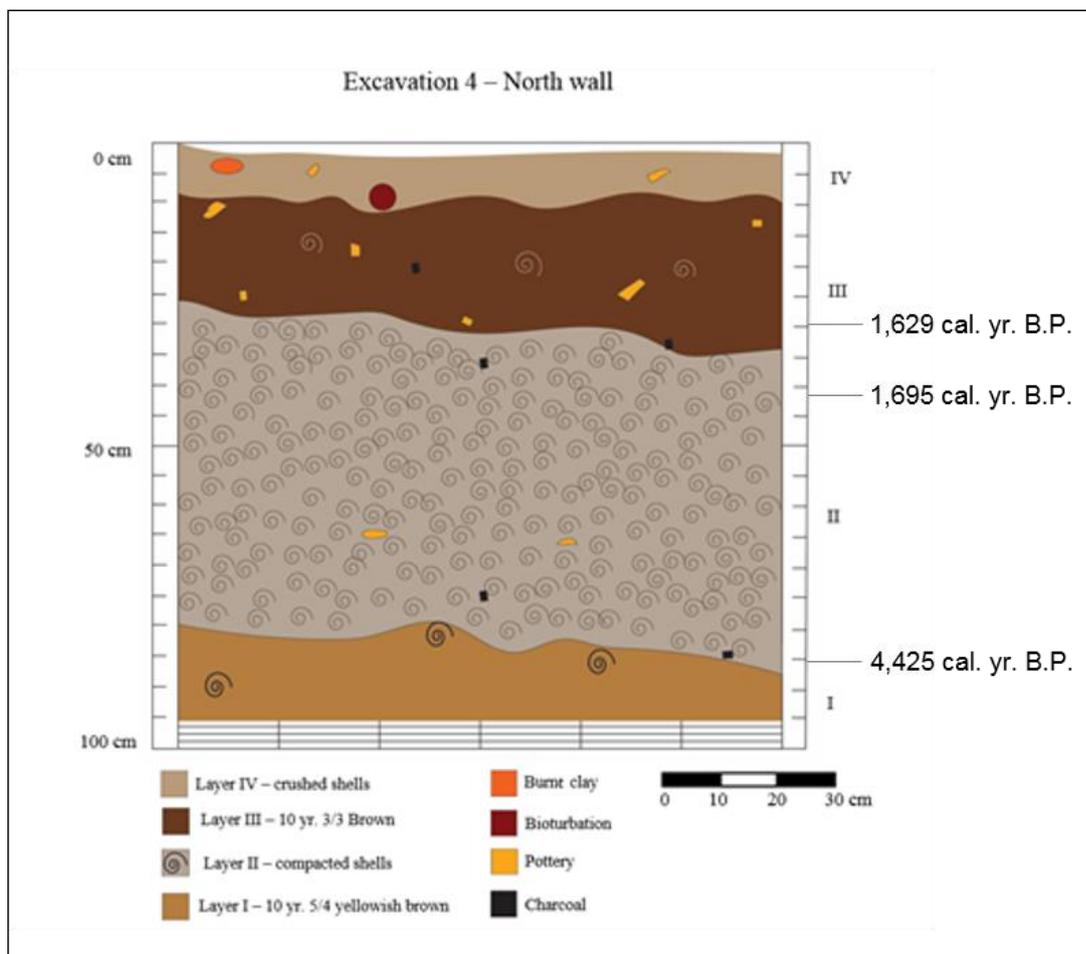


Figure 19. North profile of Excavation 4.

Layer I (ca. 84-90 cm b.s.) – Layer characterized by a compacted sandy yellowish brown soil (10yr 5/4). This is a sterile sand layer with occasional scattered shell fragments. It corresponds to the natural soil of the site, verifying Layer-II as the founding event of the shell mound.

Layer II (ca. 37-84 cm b.s.) - Thick layer (around 50 cm) formed by whole and fragmented gastropod shells, potsherds and burnt clay. The sandy soil colour varied from dark yellowish brown (10yr 3/4) on the lower levels (84-54cm) to brown (10yr 3/3) on the upper levels (54-36cm). At the lower level (82cm) a charcoal sample was collected for radiocarbon dating; Pottery fragments collected in the brown levels (53 cm and 66 cm) presented decoration characteristic of the Mina phase (as defined by Simões, 1981) (Fig. 4.4). Faunal remains consisted of large bone fragments from turtle shell pleural and neural structures (see Chapter 5 section 2.3.).

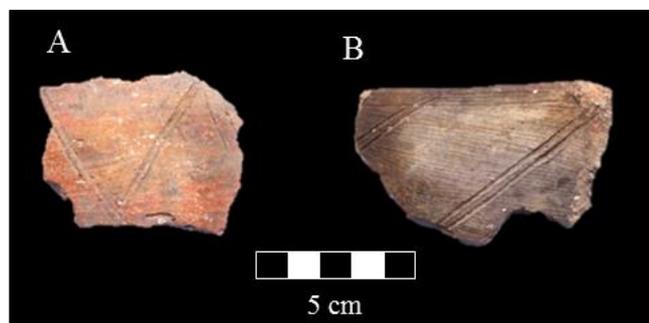


Figure 20. Probable Mina phase: (A) red slipped zoned with double criss-cross parallel incision (53 cm); (B) brushed with double parallel incision (66 cm).

Layer III (ca. 10-37 cm b.s.) – This layer consisted of a silt-clayey brown (10yr 3/3) soil marked by a sharp increase in potsherd at the expense of a decrease in gastropod shell carapaces. A charcoal sample for radiocarbon dating was collected at 31cm. Among the ceramic samples three potsherds were collected (Fig. 4.5). Faunal remains consisted of large bones and fragmented mammal and reptile vertebraes.

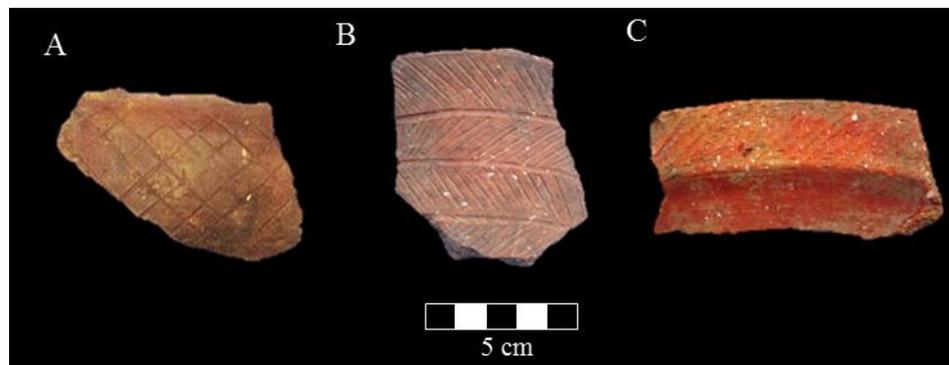
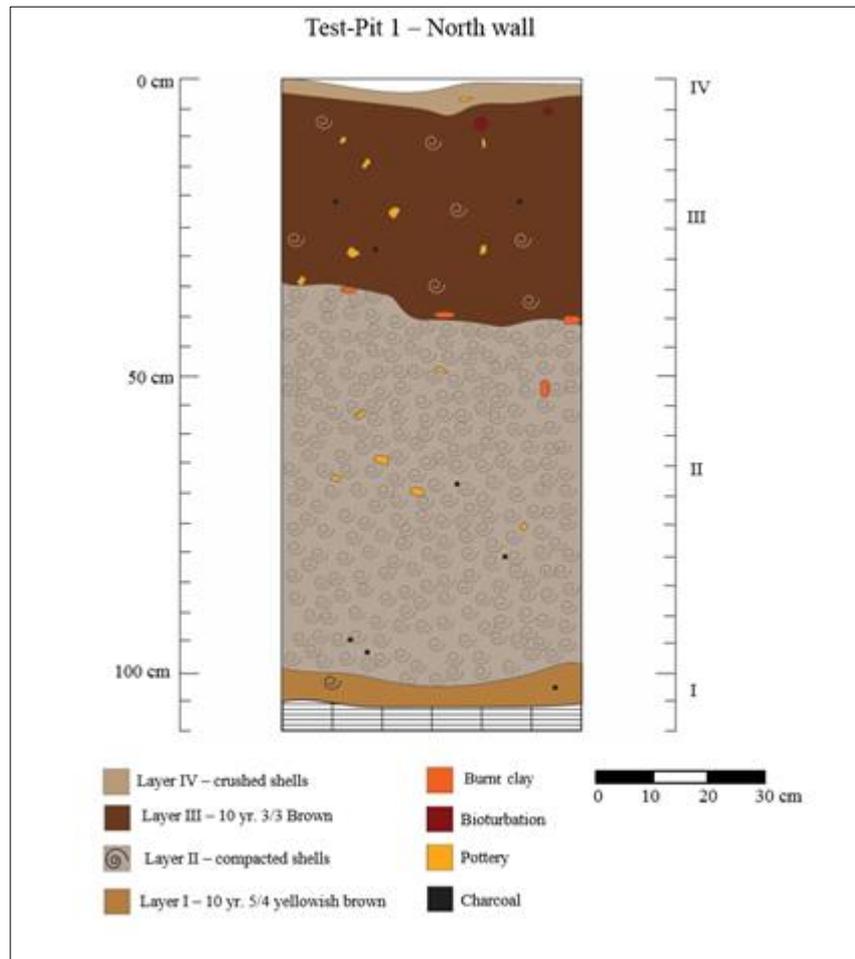


Figure 21. Potsherds recovered at layer III: **(A-B)** Sipó Incised, Ananatuba phase; **(A)** Diagonal crosshatch (34 cm); **(B)** zoned parallel lines (29 cm); **(C)** red slipped incised rim (undetermined phase, collected at 37cm).

Layer IV (ca. 0-10 cm b.s.) - Layer formed by a loose sandy brown (10yr 3/3 brown) soil. This layer is highly disturbed by the placement of a telephone tower structure over the archaeological site. Large amounts of crushed shells and small roots, and abundant small potsherds scattered close to the surface.

The excavations revealed the existence of at least three distinct cultural layers, which could indicate three different occupations over time. These layers are determined not only by the occurrence of distinct artefacts but also by the presence of carapaces of molluscs and well-preserved bones. The analysis of the stratigraphic layers indicates a long term occupation with a probable slow deposit of cultural and faunal material in multiple mounds. However, to better understand the formations of the site through studies on the entirety of the data of the site should be undertaken, in order to try to explain the nature of the site.

Test Pit 1 (UTM 22M 531556/553L 9801045)**Figure 22.** North profile of Test Pit 1.

Layer I (ca. 98-110 cm b.s. Fig. 4.6) - Corresponds to the natural soil of the site. Characterized by a compacted yellowish brown (10yr 5/4) soil. Few shell fragments scantily dispersed in the layer. No artefacts were present in this layer..

Layer II (ca. 39-98 cm b.s.) - Thick compacted layer (around 60cm) abundant in whole and fragmented gastropod shells, ceramic sherds and burnt clay in a sandy dark yellowish brown (10yr 3/4) soil. Turtle pleura and fish vertebrae composed the faunal assemblage.

Layer III (ca. 12-39 cm b.s.) - Layer formed by a silt-clayey brown (10yr 3/3) soil patched with dark brown (10yr 3/2) spots. An increase in potsherds occurs as gastropod carapaces decrease. Faunal remains consisted of mammal and reptile vertebrae.

Layer IV (ca. 0-12 cm b.s.) - Layer marked by a loose sandy brown (10yr 3/3) soil filled with large amounts of crushed shells and small roots, especially in the upper 5cm, which presented disturbances from the construction site.

Test Pit 2 (UTM 22M 531551L 9801039)

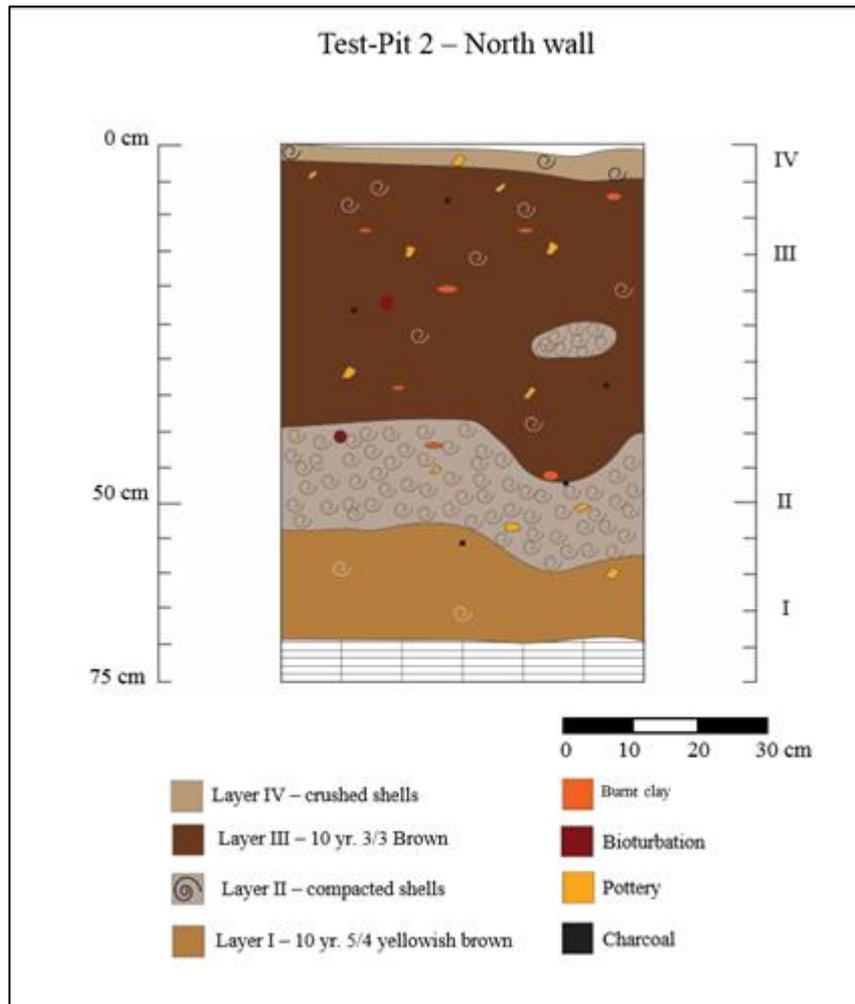


Figure 23. North profile of Test Pit 2.

Layer I (ca. 53-60 cm b.s. – Fig. 4.7) – Sterile layer corresponding to the natural soil of the site, characterized by a compacted yellowish brown (10yr 5/4) soil. Few fragmented shells dispersed in the layer and a burnt clay observed close to the transition with layer II.

Layer II (ca. 38-53 cm b.s.) – Layer abundant in whole and fragmented gastropod shells with a few lumps of burnt clay in a sandy brown (10yr 3/3) soil. Potsherds scantily distributed in the layer. A shell concentration disturbed the soil around 41cm.

Layer III (ca. 7-38 cm b.s.) – Layer comprised of a silt-clayey brown (10yr 3/3) soil with large amounts of potsherds, dispersed gastropod carapaces, burnt clay and charcoal.

Layer IV (ca. 0-7 cm b.s.) – Thin layer characterized by a loose sandy brown (10yr 3/3) soil. Abundant in crushed shells and disturbed by small roots.

Test Pit-3 (UTM 22M 531564L 9801040)

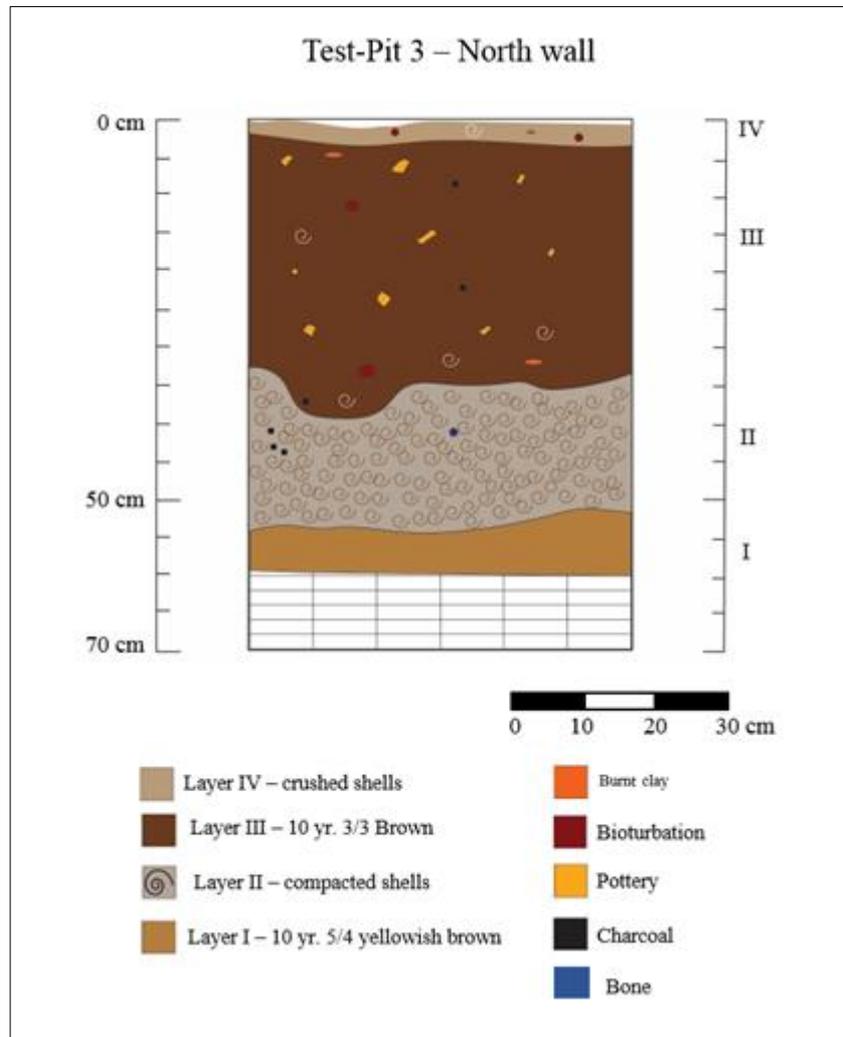


Figure 24. North profile of Test Pit 3.

Layer I (ca. 53-60 cm b.s. – Fig. 4.8) – Sterile compacted yellowish brown (10yr 5/4) soil corresponding to the natural layer of the site.

Layer II (ca. 38-53 cm b.s.) – Compacted sandy dark yellowish brown (10yr 3/4) soil filled with gastropod shells. A bone sample was collected from a sequence of alligator vertebrae associated with charcoal registered at 42cm.

Layer III (ca. 36-5 cm b.s.) – Silt-clayey brown (10yr 3/3) soil filled with an increased number of potsherds and fewer gastropod shells. Burnt clay and charcoal dispersed throughout the layer. Bioturbations spots observed. Faunal remains consisted of large turtle-shell pleural.

Layer IV (ca. 0-5 cm b.s.) – Thin layer formed by a loose sandy brown (10yr 3/3 brown) soil abundant in crushed shells and disturbed by small roots.

Test Pit-4 (UTM 22M 531560L 9801059)

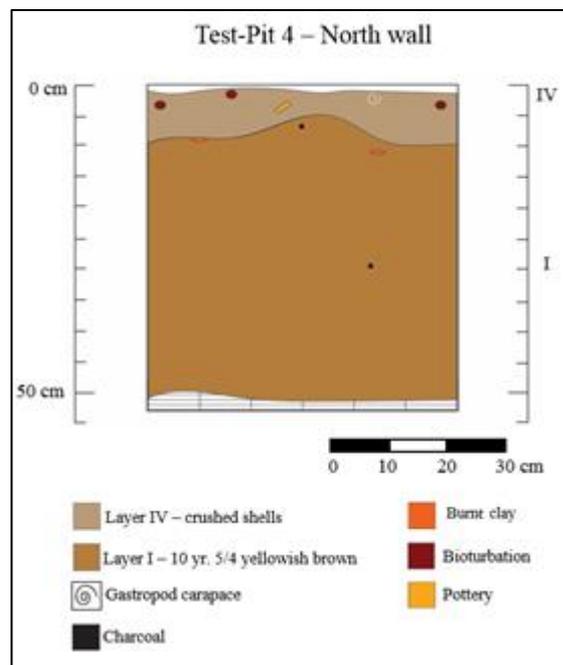


Figure 25. North profile of Test Pit 4.

Test Pit 4 (Fig. 4.9) was opened outside the archaeological site, to compare the phytolith assemblages.

Layer I (ca. 10-50 cm b.s.) - Layer characterized by a compacted yellowish brown (10yr 5/4) soil sterile in material culture. Burnt clay lumps registered in the upper levels and charcoal in the middle of the layer.

Layer II (ca. 0-10cm b.s.) – Layer characterized by a loose sandy brown (10yr 3/3) soil abundant in crushed shells and small roots.

2.2. Chronology

The 2013 excavations retrieved a total of three radiocarbon dates for the Tucumã site (Schaan and Silva, 2013). The renewed 2015 reopening of the Excavation 4 profile yielded three charcoal samples. The aim is to confirm the expectations regarding the antiquity and continuity of the settlement, notably providing high reliability for the chronology already published for Tucumã shell mound. Table 4.2 lists all the radiocarbon dates for the Tucumã shell mound, their conventional radiocarbon ages and calibrated ages using the IntCal13 calibration curve.

Table 5.2. Radiocarbon dates for the Tucumã shell mound.

Unit	Layrer	Depth (cm)	Radiocarbon date B.P.	Cal.yr. B.P.	Material dated	I.D.	Reference
Ex1	Layer III	43 cm	1,670±30	1,693-1,523 (95.4%)	Charcoal	B361797	Schaan (2013)
Ex2	Layer III	45cm	10±30	254-32 (95.4%)	Charcoal	B361796	Schaan (2013)
Ex4	Layer III	32 cm	1,720±30	1,629-1,569 (94%)	Charcoal	B433642	*
Ex4	Layer II	41 cm	1,730±30	1,695-1,647 (92.5%)	Charcoal	B433640	*
Ex4	Layer II	75 cm	2,160±30	2,307-2,228 (94.5%)	Charcoal	B361794	Schaan (2013)
Ex4	Layer II	82 cm	3,960±30	4,425-4245 (95%)	Charcoal	B433639	*

*profile samples.

Extending from the previous date of 2,307-2.228 cal. yr. B.P., the 2014 radiocarbon dates place the antiquity of the Tucumã site at 4,425-4,245 (82cm) to 1,695-1,569- cal. yr. B.P. (32cm), placing the site at the same period that the Mina phase shell mounds were occupied (Silveira and Schaan, 2005).

CHAPTER 5

PHYTOLITH RESULTS

This chapter describes the laboratory results of the Monte Castelo and Tucumã shell mound. Firstly, phytolith data (raw data in Appendix 2) are presented and compared to the archaeological contexts of each site. Secondly, phytoliths of interest (e.g. cultigens) are analysed and examined individually; conferring them sub-chapters of their own. The final section of this chapter will present the zooarchaeological analysis for the Tucumã shell mound.

1. MONTE CASTELO SHELL MOUND PHYTOLITH ANALYSIS

This section describes the results of Monte Castelo shell mound phytoliths identified. A summary of the average percentage of main taxa identified in each layer is presented in Table 5.1.

1.1. Recovered Phytoliths and Their Relative Frequencies Within Every Context

Sinimbú phase (H-J layers) (220-460cm 5,416-5,060 to 5,271-4,584cal.yr. B.P.)

Various morphotypes related to Poaceae family were recovered in the Sinimbú phase (H-J stratum). Panicoid phytoliths constituted on average 13% of the total assemblages from this phase and reached over 20% in one of the six contexts

analysed (Fig. 5.1, 390-400cm). Bambusoideae (on average 7%), Chloridoideae (on average 1%) and general Poaceae (on average 8%) related phytoliths were least frequent. Oryzae tribe scooped end bilobates constituted on average 1% of the total assemblages for this occupation. *Oryza* sp. double peaked glumes, serrated bodies and keystone bulliforms constituted on average 3%, 1% and 2% respectively. Additionally, trace amounts (<1%) from Aristidoideae were identified in this occupation. Cyperaceae wetland sedges phytoliths were the second most abundant morphotype identified constituting on average 15% of the total assemblages from this phase. Non-diagnostic Arboreal phytoliths recovered constituted on average 21% and Arecaceae morphotypes constituted on average 15% for the Sinimbú phase. Finally, Marantaceae related phytoliths constituted on average 9% in this phase.

Sinumbú-Bacabal stratum: G layer (220-230cm)

This layer clearly marks the separation between the Sinimbú (H layer) and Bacabal phase (F layer). This stratum is characterised by a sharp decrease in Panicoideae phytoliths when compared to previous layers (4%). Additionally, a gradual increase in Arboreal (33%), Marantaceae (10%) and Cyperaceae (23%) morphotypes are noticeable when compared to the former occupation (respectively 21%, 9% and 15% of the total Sinimbú phase).

Bacabal phase (30-210 cm; 4,813-4,087 to 910-660 cal. yr. B.P.)

Arboreal phytoliths were dominant in this phase. Constituting on average 27% of the total assemblages of the A to F layers, and reached over 39% in layers D/E and E. Although *Celtis* sp. phytoliths yielded less than 2% of the total Bacabal phase, they averaged 4% on layers A and B. Similarly, Asteraceae morphotypes recovered yielded less than 2% of the phase but was identified in large amount in layers A, constituting 9% of the total assemblage. Chloridoideae short saddles yielded on average 3% of the total phase.

Oryza sp. phytoliths recovered increased from an average of 6% in the Sinimbú phase to 16% on the Bacabal phase. Arecaceae phytoliths recovered yielded an average of 16%. Marantaceae phytoliths recovered continued the same as the Sinimbú phase, on average 9% of the total layers analysed. Panicoideae subfamily phytoliths recovered decreased from an average 13% on the Sinimbú phase (J-H layers) to 3% of the total Bacabal phase (F-A layers).

Bambusoideae recovered constituted on average 4% of the total phase and was largely comprised of bulliform morphotypes. Cultigens such as maize and squash was recovered in all analysed layers constituting on average 1% and 3% respectively for the Bacabal phase. Trace amounts (<1%) of Trichomanes, Heliconiaceae, Aristidoideae, Burceraceae, Annonaceae phytoliths and various forms of cystoliths were recovered in the Bacabal phase.

Table 5.1. Summary of the average percentage of main taxa identified in each layer of the Monte Castelo shell mound.

Layer	Depth	Phase	Age	Phytolith assemblage	Summary of phytolith taxa
A	10-30 cm	-----Bacabal phase-----	---4,628-625 . yr. B.P.--	Oryza-Arboreal	<i>Oryza</i> sp. husk ca. 19%; <i>Oryza</i> sp. leaf/stem ca. 4%; non-diagnostic Arboreal ca. 21%; Arecaceae ca. 18%; Asteraceae ca. 9%; Marantaceae ca. 5%. <i>Cucurbita</i> sp. ca. 4%; <i>Zea mays</i> ca. 1%.
B	30-60 cm			Arecaceae- <i>Oryza</i>	Arecaceae ca. 25%; <i>Oryza</i> sp. husk ca. 19%; <i>Oryza</i> sp. leaf/stem ca. 2%; non-diagnostic Arboreal ca. 21%; Bambusoideae ca. 5%; non-diagnostic Poaceae ca. 5%; <i>Celtis</i> sp. ca. 4%; <i>Cucurbita</i> sp. ca. 3%. <i>Zea mays</i> ca. 1%.
C	60-90 cm			<i>Oryza</i> -Arecaceae	<i>Oryza</i> sp. husk ca. 21%; <i>Oryza</i> sp. leaf/stem ca. 3%; Arecaceae ca. 18%; non-diagnostic Arboreal ca. 17%; Cyperaceae ca. 9%; non-diagnostic Poaceae ca. 7%; Marantaceae ca. 7%; <i>Cucurbita</i> sp. ca. 3%. <i>Zea mays</i> ca. 1%.
D	90-150 cm			Arboreal-Arecaceae	Non-diagnostic Arboreal ca. 23%; Arecaceae ca. 17%; <i>Oryza</i> sp. husk ca. 11%; <i>Oryza</i> sp. leaf/stem ca. 4%; Cyperaceae ca. 11%; Marantaceae ca. 9%; Bambusoideae ca. 6%; Panicoideae ca. 5%; <i>Cucurbita</i> sp. ca. 4%. <i>Zea mays</i> ca. 1%.
E	150-165 cm			Arboreal-Marantaceae	Non-diagnostic Arboreal ca. 42%; Marantaceae ca. 16%; <i>Oryza</i> sp. husk ca. 7%; <i>Oryza</i> sp. leaf/stem ca. 4%; Arecaceae ca. 6%; Bambusoideae ca. 5%; <i>Cucurbita</i> sp. ca. 1%; <i>Zea mays</i> ca. 1%.
F	165-225 cm			Arboreal-Cyperacea	Non-diagnostic Arboreal ca. 28%; Cyperaceae ca. 13%; Marantaceae ca. 12%; <i>Oryza</i> sp. husk ca. 8%; <i>Oryza</i> sp. leaf/stem ca. 2%; Arecaceae ca. 9%; Bambusoideae 7%; Panicoideae ca. 5%; <i>Cucurbita</i> sp. ca. 4%; <i>Zea mays</i> ca. 1%.
G	225-135 cm	Sinimbú-Bacabal	-----	Arboreal-Cyperaceae	Non-diagnostic Arboreal ca. 33%; Cyperaceae ca. 23%; <i>Oryza</i> sp. leaf/stem ca. 5%; <i>Oryza</i> sp. husk ca. 5%; Marantaceae ca. 10%; Arecaceae ca. 7%; Bambusoideae ca. 5%; <i>Cucurbita</i> sp. ca. 1%.
H	235-330 cm	-----Sinimbú phase-----	5,310----4,280 . yr. B.P.	Arboreal-Cyperaceae	Non-diagnostic Arboreal ca. 22%; Cyperaceae ca. 16%; Arecaceae ca. 14%; <i>Oryza</i> sp. husk ca. 6%; <i>Oryza</i> sp. leaf/stem ca. 4%; Marantaceae ca. 9%; Bambusoideae ca. 9%; non-diagnostic Poaceae ca. 9%; <i>Cucurbita</i> sp. ca. 2%; <i>Zea mays</i> ca. 1%.
I	290-320 cm			Arecaceae-Arboreal	Arecaceae ca. 23%; non-diagnostic Arboreal ca. 19%; Cyperaceae ca. 15%; Marantaceae ca. 10%; non-diagnostic Poaceae ca. 9%; Panicoideae ca. 7%; Bambusoideae ca. 7%; <i>Oriza</i> sp. husk ca. 3%; <i>Oryza</i> sp. leaf/stem ca. 2%; <i>Cucurbita</i> sp. ca. 1%; <i>Zea mays</i> ca. 1%.
J	330-460 cm			Arboreal-Panicoideae	Non-diagnostic Arboreal ca. 22%; Panicoideae ca. 16%; Cyperaceae ca. 14%; Arecaceae ca. 13%; Marantaceae ca. 8%; non-diagnostic Poaceae ca. 8%; <i>Oryza</i> sp. husk ca. 4%; <i>Oryza</i> sp. leaf/stem ca. 3%; Bambusoideae ca. 7%; <i>Cucurbita</i> sp. ca. 1%; <i>Zea mays</i> ca. 1%.

1.2. Phytolith Results and Archaeological Context

Considering the overall quantity and variability of phytoliths recovered at the A and C fractions of the Monte Castelo site, three zones are observable (Fig. 5.1).

The first zone encompassed by the J Layer (Fig. 5.1. 390-460cm) of the Sinimbú phase is characterised by a dark soil (10k 2/1), a significant amount of charcoal, charred-palm seeds, faunal remains and lithic flakes. Moreover, phytolith investigation on this zone revealed various morphotypes related to the Poaceae (on average 34%) and Cyperaceae (on average 14%) families. Whereas, Arboreal and palm phytoliths were less frequent (on average 22% and 14% respectively). Additionally, phytoliths from domesticated maize and squash are present in this context.

Although archaeological context reported large amounts of charcoal and charred-palm seeds, phytolith records revealed an abundant quantity of grasses and sedges. This pattern of abundance of grasses together with arboreal phytoliths was not observed again in all subsequently analysed layers.

The Bacabal phase exhibited two zones. The first, comprising of the layers E to D (Fig. 5.1 130cm). This zone presented two burial contexts with preserved areas of activity. The first burial recovered was that of an adult male. A series of circular shell structures near to his feet, and a well-preserved deer cranium with its horns still attached was placed near his left arm. These patterns suggest an elaborate funeral composition for this individual. The second burial was that of a child (unknown sex). Though less elaborated, this burial also presented similar circular shell structures like the ones described for the adult individual.

The phytolith analysis of this zone revealed an overall decrease in arboreal morphotypes (from 43% to 24%), increase in Arecaceae (from 7% to 17%) and Cyperaceae (from 7% to 11%) phytoliths. Plants such as Chloridoideae (on average 2.5%), Bambusoideae (on average 6%) and Marantaceae (12%) morphotypes had a secondary peak in its abundance when compared to previous layers (F-I Layer). Furthermore, trace amounts of domesticated maize and squash were present in this zone. Additionally, this zone presented the highest amount of Oryzae scooped end bilobates for the entirety of our analysis of the Monte Castelo site.

Noteworthy, *Oryza* sp. seed vs. leaf phytoliths recorded on the D/E layer (underneath the burial context), had the lowest ratio of all analysed contexts of the shell-midden. Furthermore, double-peaked glume phytoliths recovered in

this layer presented the highest parameters of curvature degree (CD) and overall peak height (H1-H2) when compared to previous strata and successive D layers. The increase of leaf over seed phytoliths suggests that no previous selection of plant parts occurred before its deposition on the shell-midden. While seed phytoliths were present in reduced quantity, double-peaked glume parameters revealed to be one of the highest for the D layer. This evidence suggests not only intentionality in the deposition of different *Oryza* plant parts on the mound but also a careful selection of particular larger seed specimens for this episode.

The second zone, from layers D (90-100cm) to A (Fig. 5.1.), is determined by a significant decrease in gastropod carapaces and overall darkening of the soil. Additionally, these layers recorded an increased amount of Bacabal pottery including zoomorphic appendixes.

The phytolith data revealed a dominance of Arecaceae (on average 24%), Arboreal (on average 20%) and *Oryza* sp. seed (on average 18%) morphotypes. The quantity of Chloridoideae (2%), Asteraceae (3%), Annonaceae (<1%) and *Celtis* sp. (3%) phytoliths recovered increased substantially in the upper zone. Furthermore, consistently recovered in this layer were phytoliths of domesticated maize (<1%) and squash (on average 4%).

Preliminary taxonomic identifications have revealed a progressive increase in the animal biodiversity from the lower (J) to the upper layers (A-D) (Neves et al., 2016 p.23). Likewise, phytolith records also reveal an increase in cultivars such as maize, squashes and wild rice from lower to upper layers. Accordingly, the data presented suggest an increase in the plant component at the upper layers of the Bacabal phase.

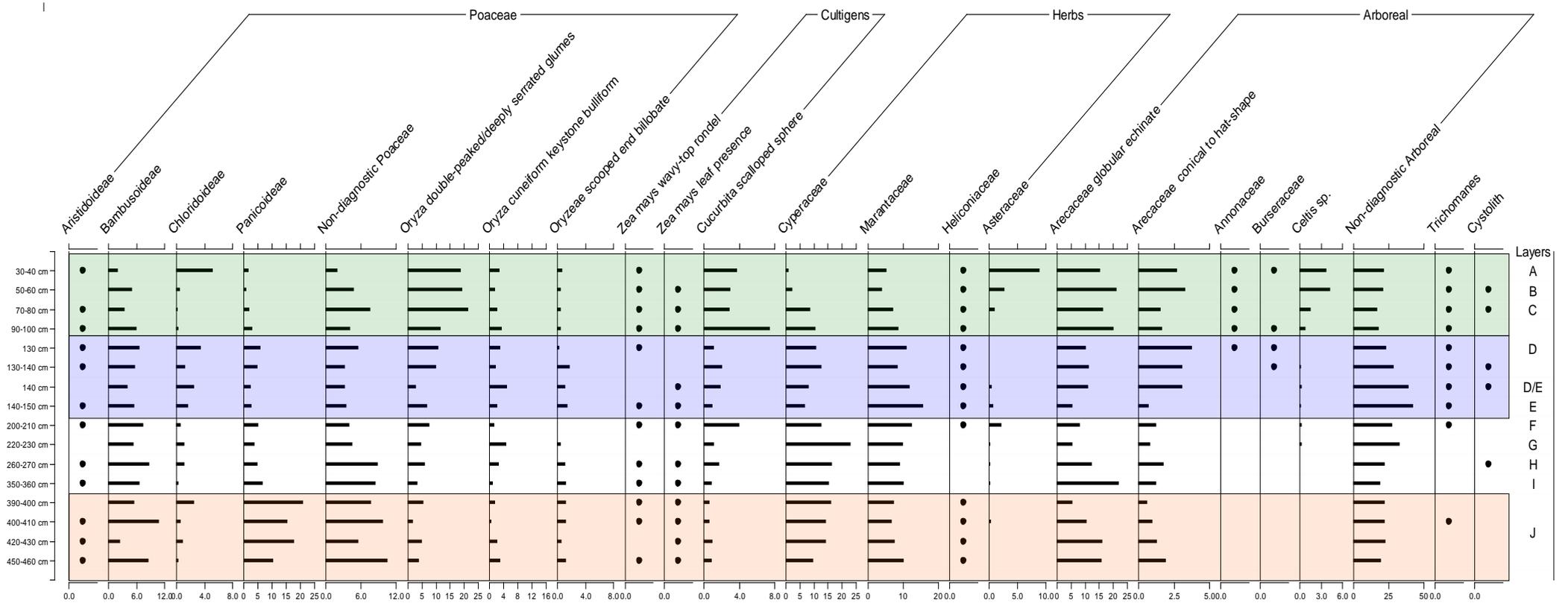


Figure 26.1. Relative frequencies of phytolith recovered on the A and C fraction. Horizontal bars represent percentages; circles correspond to presence of plant taxa lower than 1% in abundance. Orange bar represents the zone observed in the Sinimbu phase; blue and green represent the zones observed for the Bacabal phase.

1.2.1. Palm phytoliths analysis

This section will concentrate on the palm phytolith diversity recovered at the Monte Castelo shell mound. To improve the taxonomic resolution of palm species this study will follow the globular echinate classifications proposed by Morcote-Ríos et al. (2016).

Scholars have been able to differentiate two phytolith morphotypes (globular echinate and conical to hat-shape) mostly to family level (e.g. Tomlinson, 1961; Tomlinson, Horn and Fisher, 2011; Romain and De Franceschi, 2013; Watling and Iriarte 2013). Recent studies have focused on exploring the morphological variation in palm phytoliths to narrow its taxonomic level (Benvenuto et al., 2015; Patterer, 2014; Bowdery, 2015; Morcote-Ríos et al., 2016). Morcote-Ríos et al. (2016) provided a survey of phytoliths across a highly representative sample of Amazonian palm species recognising eight types, which provide diagnostic information at the levels of subfamilies, tribe, genus and species (e.g. *Geonoma* spp.).

From the eight globular echinates categories proposed by Morcote-Ríos, five are present at the Monte Castelo shell mound: (1) globular echinate with acute projections symmetrically arranged at the periphery (Fig. 5.2. A); (2) globular echinate with numerous long projections at the periphery (Fig. 5.2. B); (3) elongated globular echinate (also described by Bowdery, 2015) (Fig. 5.2. C); (4) globular echinate with dense short projections at the periphery (Fig. 5.2. D) and (5) conical two hat-shape (Fig. 5.2. E-H) (described by Tomlinson, 1961; Tomlinson et al. 2011; Piperno 2006).

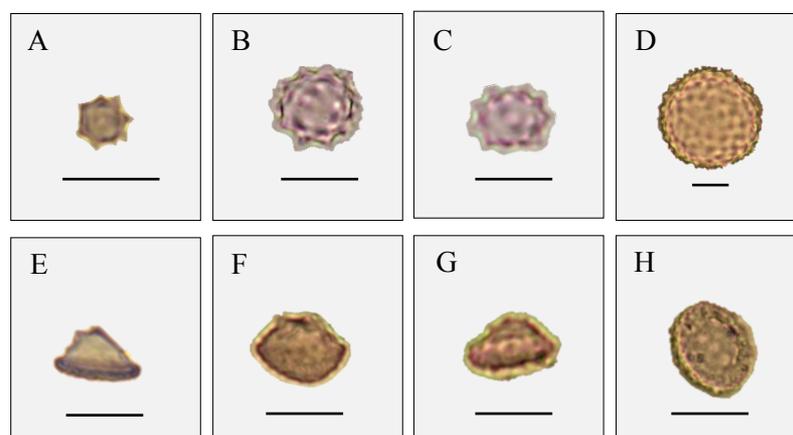


Figure 5.2. Microphotograph of palm globular echinate (Classifications follows Morcote-Ríos et al., 2016) and conical to hat-shaped phytoliths morphotypes identified at the Monte Castelo shell-midden: (A) Globular echinate symmetric; (B) Globular echinate; (C) Globular echinate elongate; (D) Globular echinate with dense short projections; (E-H) Example of Conical to hat-shaped phytolith diversity; (E-G) side view; (H) top view. Scales = 20 μm .

Sinimbú phase (H-J layers) (220-460cm 4,822-5,310 cal. yr. B.P)

At the Sinumbú phase (layers H-J) (Fig. 5.3.), globular echinate with various long projections at the periphery were the most abundant (on average 12%). Symmetric globular echinates constituted on average 5% of the recovered palm phytoliths for this phase.

Considering the quantity and variability of palm phytoliths recovered from the Sinumbú phase, one zone is noticeable. Corresponding to the J layer, this zone presents the highest amount of globular echinates with dense short projections (on average 1% of the total assemblages of this layer) when compared to other layers of the shell-midden. Also recovered in this zone were symmetric globular echinates (on average 4%), globular echinates (on average 10%) and conical to hat-shapes (1.5%).

As pointed out by Morcote-Rios (2016 p.355-356), globular echinates with short dense projections present limited taxonomic value outside the Euterpeae subtribe. Furthermore, with some exceptions (Piperno, 2006), conical to hat-shape and globular echinates do not co-occur (Tomlinson et al., 2011; Morcote-Rios et al., 2016). Additionally, the excavations of the J layer reported the presence of palm-carbonized seeds. Seeing that the phytolith data reveals the presence of globular echinate with dense short projections and conical to hat-shape morphotypes, it is likely that the shell mound inhabitants were exploring at least two distinct species of palm trees.

Sinumbú-Bacabal stratum: G layer (220-230cm)

An overall decrease in symmetric globular echinates (0.5%) and globular echinates (6%) delineates the Sinimbú-Bacabal stratum (layer G). Also, there were no globular echinate with dense short projections recovered in this layer.

Bacabal phase (30-210 cm; 625-4,628 cal. yr. B.P)

Representative to the Bacabal phase (Layers A-F) was an increase in elongate globular echinates (on average 3.6%) and general globular echinates (on average 15%). Symmetric globular echinates decreased over half its amount when compared to the Sinimbú phase (on average, from 5% to 2.3%); globular echinate with dense short projections also decreased (on average from 1% to 0.2%). Additionally, conical to hat-shaped phytoliths recovered increased over two times its amount after the Sinumbú phase (from 2% to 4.5%).

Two distinct zones are noticeable considering the quantity and variability of palm phytoliths recovered in the Bacabal phase. The first, from layers D (130cm) to E, is characterised by an absence of globular echinate with dense short projections and an increase in conical to hat-shape morphotypes (5%). The burial contexts of this zone and the overall increase in the abundance of conical to hat-shaped phytoliths might be related to funerary practices in which parts of these plants were used in those ceremonies.

The second zone, from layers A to D (90-100cm), is characterised by an overall increase in elongated globular echinates (on average 6%), globular echinates (on average 22%) and symmetric globular echinates (on average 3%). Additionally, the presence of trace amounts (<1%) of globular echinates with dense short projections occurred in two layers of this zone (A and D 90-100 cm). The archaeological context of this zone revealed a sharp decrease in the abundance of gastropod carapaces and an overall increase in the presence of Bacabal pottery.

As with the globular echinate with dense short projections, limited taxonomic distribution is given to symmetric globular echinates morphotypes; displaying taxonomic importance only in *Mauritia*, *Mauritiella*, *Euterpe*, *Oenocarpus*, *Ammandra* and *Attalea* (Morcote-Ríos et al., 2016 p.356). Thus, a shift on the exploitation of palm species could likely be the reason for the increase in elongated and symmetric globular echinates alongside the changes observed in the archaeological context. Future work on the classification of Arecaceae phytoliths could potentially clarify these preliminary patterns.

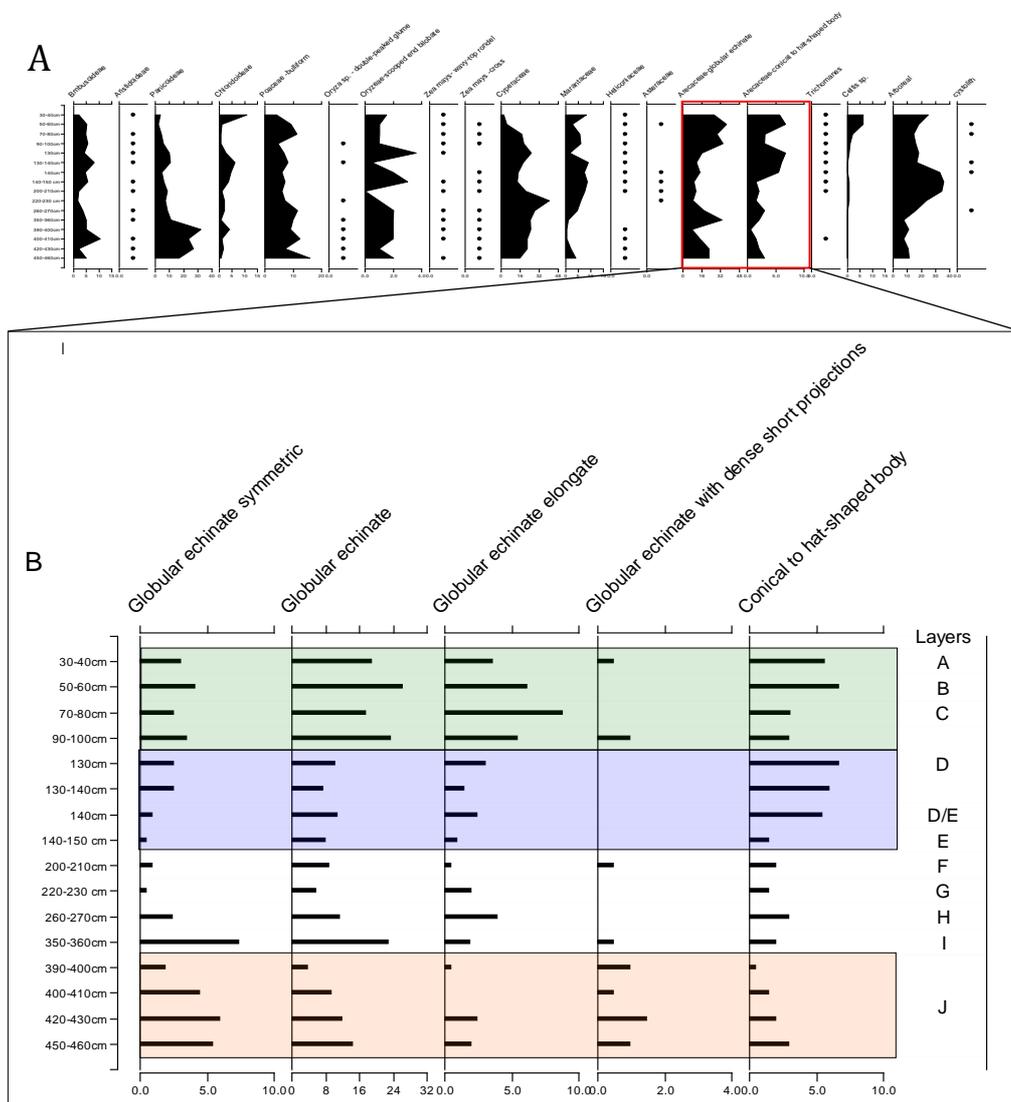


Figure 5.3. Graph showing relative frequencies of Arecaeae phytoliths recovered on the silt fraction. Horizontal bars represent percentages. **(A)** Small scale of the relative frequencies of phytoliths from silt fraction as shown on Fig 5.1., red circle represents non-separated Arecaeae phytoliths; **(B)** relative frequencies of Arecaeae phytoliths classified according to Morcote-Ríos *et al.* (2016). Orange bar represents the zone one of the Sinimbú phase; red and green bars represent zone one and two respectively of the Bacabal phase.

1.2.2. *Zea mays* phytoliths

Wavy-top rondels (Fig. 5.4. A-C) diagnostic to the cob of maize (*Zea mays*) was identified in trace amounts within 12 of the 16 analysed layers (absent in the D130-140cm, D/E, G and H Layers). Also, maize predictions and discriminant functions using cross variant 1 phytoliths was performed to further confirm its presence in the shell mound (Table 5.2). These measurements exhibited positive results for domesticated maize in 12 of the 16 analysed layers, producing negative scores for the G, D (130-140cm), D (130cm) and A stratum. Accordingly, once combined the identification of wavy-top rondels and cross

variant 1 discriminant functions, 14 of 16 units revealed the presence of domesticated maize; absent only on the G layers and D -130-140cm- context.

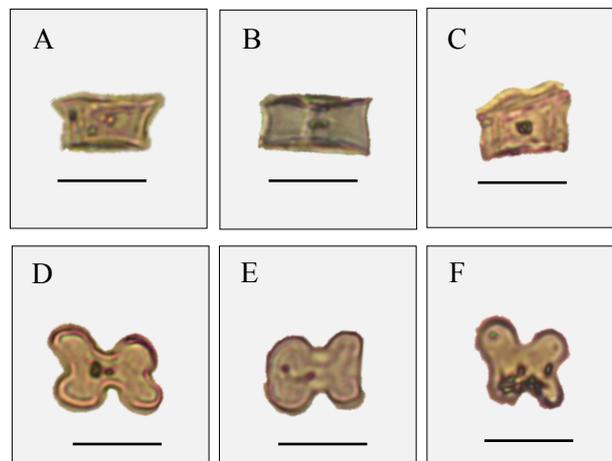


Figure 5.4. Microphotograph of maize and maize related phytoliths recovered in the Monte Castelo shell mound and their taxonomic and anatomical associations: **(A-C)** Wavy-top rondel from the cob of *Zea mays*; **(D-F)** variant 1 cross-shaped phytoliths from the leaf of members of the Poaceae family. Scales = 20 μ m.

Table 5.2. *Zea mays* wild and domesticated discriminant function values for each analysed layer. Green stripes are positive for the presence of maize leaf, red stripes are negative.

Layers	Depth	N	%X Var 1	% X Var 5/6	% Var 1	DF value	Maize Prediction	Wild Prediction	Maize leaf presence
A	30-40 cm	10	12.07	13.29	30	11.76	0.04	0.96	Negative
B	50-60 cm	8	13.24	12.34	62.5	13.31	0.51	0.49	Positive
C	70-80 cm	28	14.45	14.97	75	14.83	0.77	0.23	Positive
D PN75	90-100 cm	36	14.53	12.58	55.56	14.23	0.65	0.35	Positive
D PN64	130 cm	13	14.77	14.66	46.15	14.43	0.59	0.41	Positive
D PN1003	130-140 cm	9	12.42	13.33	51.5	13.31	0.49	0.51	Negative
D/E	140 cm	6	15.96	0	83.34	14.69	1.27	-0.27	Positive
E	140-150 cm	25	14.23	13.91	84	14.73	0.82	0.18	Positive
F	200-210 cm	19	14.29	14.39	63.16	14.38	0.65	0.35	Positive
G	220-230 cm	9	9.97	14.42	55.56	10.73	-0.10	1.10	Negative
H	260-270 cm	14	15.39	16.01	64.28	15.46	0.82	0.18	Positive
I	350-360 cm	34	13.76	14	67.65	14.01	0.61	0.39	Positive
J PN159	390-400 cm	55	14.85	15.33	80	15.29	0.87	0.13	Positive
J PN137	400-410 cm	32	14.78	15.65	78.13	15.23	0.84	0.16	Positive
J PN112	420-430 cm	15	14.89	12.85	86.67	15.21	0.96	0.04	Positive
J PN142	450-460 cm	20	13.9	14.83	70	14.26	0.64	0.36	Positive

1.2.3. *Cucurbita* sp. phytoliths

Scalloped spherical phytoliths from the rind of squash (*Cucurbita* sp.) were present in all of the analysed contexts (Fig. 5.5.). In total, 124 of these phytoliths were identified and measured (Piperno, 2009) to distinguish if they were wild or

domesticated (Table 5.3.).

Domesticated squash phytoliths have been successfully distinguished from wild species as a result of measuring their thickness and length (Bozarth, 1987; Piperno, 2009; Piperno et al., 2000). A study made by Piperno *et al.* (2000) compared scalloped sphere dimensions from wild and domesticated squash fruits. Except for *Cucurbita ecuadorensis* (upper range length of 92 μm), the analysis revealed that domesticated species exceeded 90 μm in length. Bearing in mind these parameters, from the 124 phytoliths recovered, only nine phytoliths from the shell-midden could be considered domesticated; all of them identified in the Bacabal phase on the layers B (two phytoliths), D (five phytoliths) and G (two phytoliths).

As pointed out by Watling (2014, p.263), squash species used in Piperno's (2000) study that reached lengths of 72-90 μm were essentially from species endemic to Central and North America. Furthermore, there are no native squash species in south-west lowland Amazonia. Thus, the presence of scalloped spheres in Watling's study that fitted lengths between 72-90 μm were granted a domesticated status.

When observing the measurements of the Monte Castelo shell-midden, from the remaining 115 scalloped spheres identified, 64 falls in the category presented by Watling, amassing at least one probable domesticate per layer of the midden. While most squash phytoliths identified fit into the category mentioned above, 51 scalloped spheres had lengths between 51 and 71 μm , suggesting that the manipulation of wild and domesticated squashes were occurring simultaneously throughout the shell-midden occupation.

Furthermore, a gradual increase in the recovery of these phytoliths is noticeable throughout the occupation. On the layers I and J (Sinimbú phase) scalloped spheres amassed for <1% of the total assemblages, while on A to F layers (Bacabal phase) they increased over four times their initial amount (4.5%), suggesting intensification on the consumption of this species.

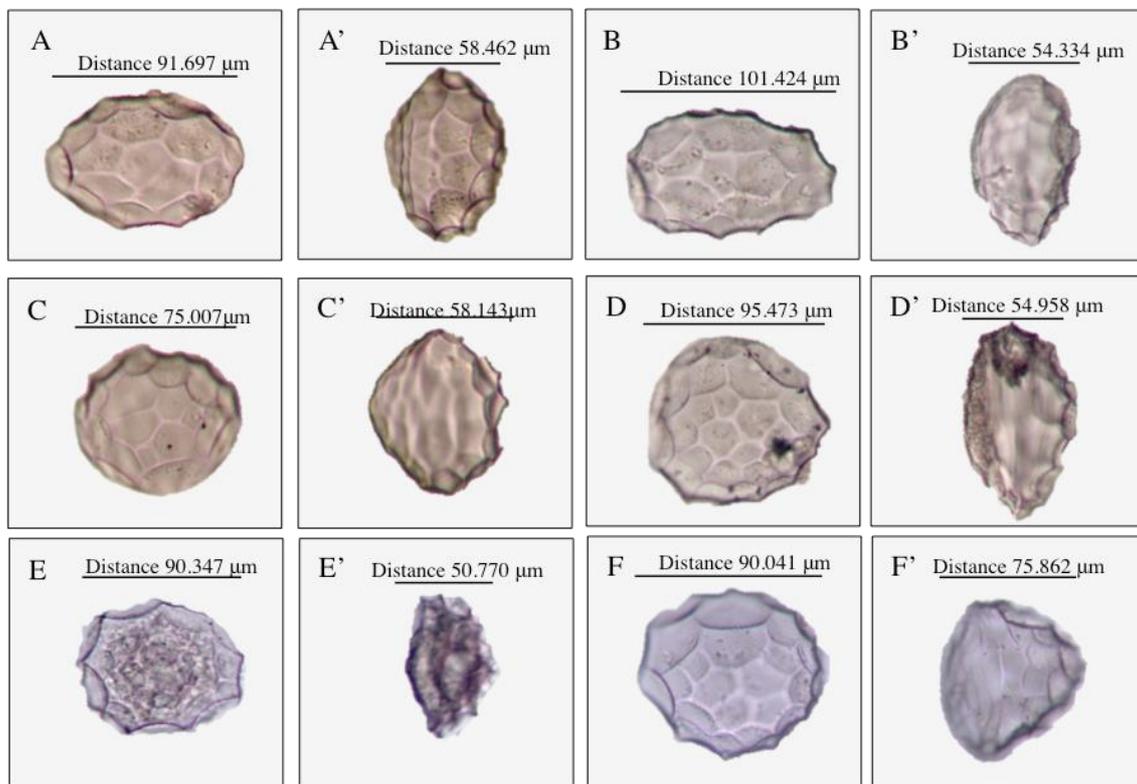


Figure 5.5. Microphotograph of scalloped spherical phytoliths from squashes with over 75 microns identified in the Monte Castelo shell mound; (A-H) length measurements; (A'-H') thickness measurements. Provenances: (A/A'-B/B') identified in the D layer (90-100cm); (C/C') identified in the A layer; (D/D') identified in the G layer; (E/E'-F/F') identified in the B layer.

Table 5.3. Length and thickness range and average size of scalloped sphere phytoliths identified in each one of the layers of the Monte Castelo shell mound.

Layer	Depth	Length range (μm)	Length average (μm)	Thickness range (μm)	Thickness average (μm)	N
A	30-40 cm	56-79	69.4	44-60	53.1	15
B	50-60 cm	58-100	76.02	30-71	52.45	12
C	70-80 cm	57-83	73.14	43-65	50	11
D PN75	90-100 cm	58-101	77.74	36-73	53.2	27
D PN64	130 cm	60-88	80	38-64	50.42	8
D PN1003	130-140 cm	71-88	83.24	46-58	55	4
D/E	140 cm	52-88	75.27	44-58	56.45	7
E	140-150 cm	54-87	74.3	31-63	48	4
F	200-210 cm	69-89	79.21	39-75	53.7	13
G	220-230 cm	70-95	81.88	41-62	53	4
H	260-270 cm	59-84	72.12	44-61	50.34	6
I	350-360 cm	66-80	71.6	55-57	56.6	3
J PN 112	390-400 cm	60-61	61	48-49	49	2
J PN137	400-410 cm	51-70	61	41-42	42	2
J PN142	420-430 cm	63-66	64.8	50-59	53.3	3
J PN 159	450-460 cm	63-85	75.7	31-47	40	3

1.2.4. *Oryza* sp. phytoliths

Oryzae tribe diagnostic phytoliths recovered include scooped end bilobates (Fig. 5.6 D) (Pearsall et al. 1995) and leaf cuneiform keystone bulliforms (Fig. 5.6 C). *Oryza* genus specific phytoliths include double peaked glume (Fig. 5.6 A) and deeply serrated epidermal cells (Fig. 5.6 B) (Pearsall et al. 1995; Gu et al., 2013). Wild rice phytolith identifications were made using published material (Gu et al., 2013, Pearsall et al., 1995, Piperno, 2006, Zhang and Wang, 1998, Zhao et al., 1998) and by direct comparison to phytolith from modern wild rice species native to the archaeological site.

Scooped end bilobate phytoliths were identified only in the A fraction. Constituting on average 1.2% for the Sinimbú phase (H-J Layers), 0.5% on the transitional stratum (Layer G) and 0.8% for the Bacabal phase (A-F Layers). *Oryza* genus specific phytoliths were recovered almost exclusively in the C fraction. A constant increase in the amount recovered of these phytoliths is observable along the two occupations of the shell-midden. Constituting on average 7% of the total assemblages for the Sinimbú occupation (H-J Layers). For the transitional stratum (Layer G), *Oryza* phytoliths composed 10%. On the Bacabal occupation, wild-rice phytoliths constituted on average 16% of the total assemblages and reached over 20% in three of the nine contexts analysed (Fig. 5.7. Layers A-C).

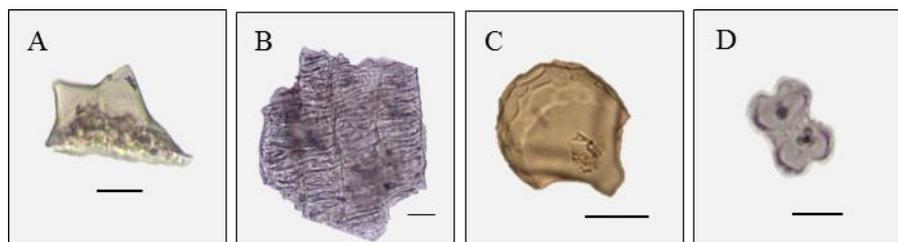


Figure 5.6. Microphotographs of selected *Oryzae* phytoliths identified in the Monte Castelo shell mound and their taxonomic and anatomical associations (A) double-peaked glume cells from the seeds of *Oryza* sp.; (B) very deeply serrated seed epidermis cell phytoliths from *Oryza* sp.; (C) cuneiform keystone bulliform cell from the leaf and stem from *Oryzae* (D) Bilobate short cell with scooped ends from the leaves from *Oryzae*. Scales = 20 μ m.

The increased recovery on wild-rice phytoliths led to a thorough examination on the ratio of glume and leaf morphotypes. Also, glume phytoliths from archaeological and modern wild rice species native to the site's area were measured and compared to test the likelihood of a domestication event.

1.2.4.1 *Oryza* sp. seed vs leaf phytoliths

Phytoliths diagnostic to the seed of *Oryza* sp. constituted on average 4.13% of the total assemblages of the Sinimbú phase (H-J Layers) amassing a ratio of 1.3x, while leaf phytoliths constituted on average 2%. For the Sinumbú-Bacabal stratum (G Layer) the average of seed versus leaf phytoliths is of 4.6% and 5.4% respectively, amassing a ratio of 0.8. On the Bacabal phase (Layers A-F) seed phytoliths constituted on average 12% of the total layers, and reached over 20% in three of the nine contexts analysed (Layers A-C). Also, leaf phytoliths constituted on average only 3.6% of the total assemblages for this occupation. Additionally, the Bacabal phase conferred the highest amount of seed versus leaf rates (4.1x), reaching over three times that of the Sinimbú occupation and Sinumbú-Bacabal stratum combined.

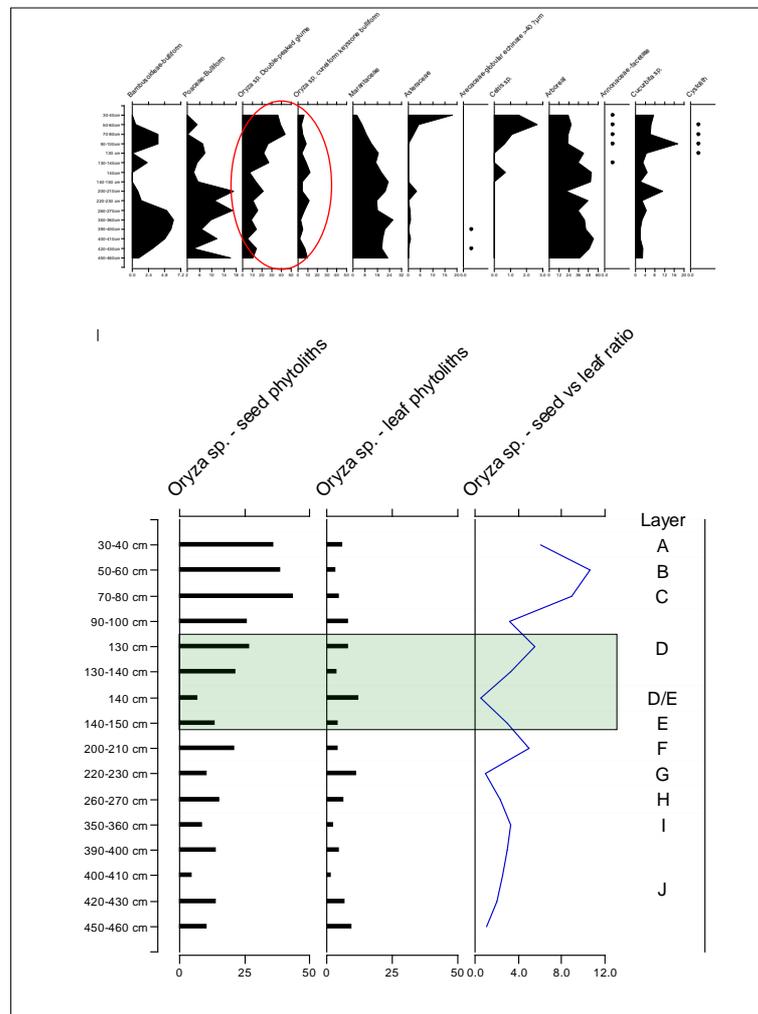


Figure 5.7. Graph showing relative frequencies of *Oryza* phytoliths and its relative ratio. Horizontal bars represent percentages of seed and leaf phytoliths. Blue line represents seed vs. leaf ratio. Green bar highlights the burial context of the shell mound.

At the burial context (Layers D 130 cm to E), glume phytoliths recovered averaged on 28% for this zone, over three times that of leaf phytoliths (on average 11%). Interestingly the soil samples analysed from the transition between layers D and E (D/E 140cm) were stratigraphically associated to underneath the burial context and presented the lowest ratio of seed versus leaf phytoliths of all the analysed layers (seed vs. leaf ratio of 0.5). In other words, the amount of leaf deposited was twice of that of seeds, suggesting that whole plants were deposited below the burial context.

1.2.4.2. *Oryza* sp. measurements parameters

The analysis of the average size parameters measured in the *Oryza* glume phytoliths (Fig. 5.8) shows a rather gradual increase of Maximum Height (H1), Minimum Height (H2) and Curvature Depth (CD) across time from the lower to the top layers of the stratigraphy (for raw and mean data see appendix 2 and 3). Curvature Depth increased over double its initial size (from 2.5 μ m to 5.4 μ m). Likewise, Maximum and Minimum Height increased respectively circa 8 μ m (from 17 μ m to 25 μ m) and 7 μ m (from 15 μ m to 22 μ m). Noteworthy, Top Width decreased in size on previous layers (A-B) receding to about its initial dimension (36 μ m). While not gradual, the increase in Maximum Width was of roughly 9 μ m (48-57 μ m) (Appendix 3 and 4).

Regarding glume morphological patterns, the surface hair on the bottom layer (J) are mostly rough in appearance. From 80 double-peaked glume phytoliths analysed, only 30% were considered as smooth. Curvature depth was mostly shallow (circa 1-2 μ m). The sizes of double-peaked glumes phytoliths are usually small in comparison to top layers (A-C). A variance greater than 3 μ m regarding the height of the peaks occurred in 32% of the double-peaked glume phytoliths. On the other hand, double-peaked glume phytoliths identified on the top layers (A-C) revealed that from 60 double-peaked glume phytoliths analysed 51% were considered smooth in appearance. The curvature depth was mostly deep, ranging from 3-7 μ m. The mean size of double-peaked glume identified was larger when compared to bottom layers. Furthermore, variations among glume cells exist but are less frequent. Double peaks with salient projections occurred in 82% of the glume analysed.

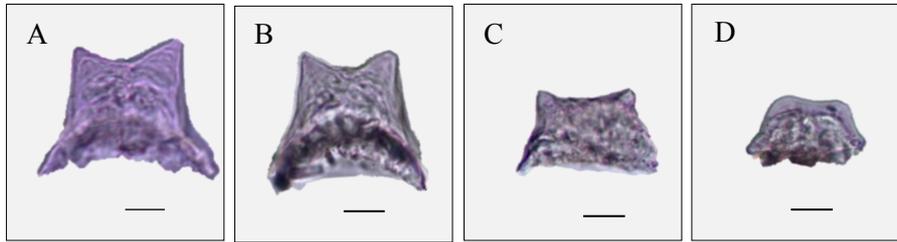


Figure 5.8. Top vs. bottom layers microphotographs of *Oryza* double-peaked glume phytoliths identified in the Monte Castelo shell-midden: **(A-B)** double-peaked glume found on layers A and B; **(C-D)** double-peaked glume found on layer J. Scales = 20 μm .

1.2.4.3. Wild Rice Species Native to the South-West Lowland Amazon

This section presents the results of the measurements of double-peaked glume phytoliths from modern wild rice species native to the shell mound region. This analysis was made having in mind a way to determine whether the changes documented on the archaeological double-peaked glumes were retained or receded on modern wild rice species (Fig. 5.9.).

The mean size of *O. glumaepatula* double-peaked glume phytoliths revealed a TW size of circa 29-36 μm , MW of 35-43 μm , H1 and H2 of 10-15 μm and 9-13 μm respectively and an average CD of 2 μm . Noticeably, the CD of *O. glumaepatula* was roughly similar to the glume curvature degree of the lower layers of the Monte Castelo shell-midden (I-J Layers) while other measurements were slightly below for the same layers. Glume morphological patterns of *O. glumaepatula* revealed that surface was mostly rough in appearance (61%). Additionally, from 80 double-peaked glume phytoliths analysed only 31% are smooth. Curvature depth was mostly shallow (ca. 2 μm). Variances between the heights of the peaks are predominantly symmetric with only 18% having fluctuations greater than 3 μm .

O. grandiglumis glume size measurements exposed an average TW of 29-33 μm , MW of 30-37 μm , H1 and H2 size of 15-16 μm and 12-14 μm respectively and a mean CD of circa 5.6 μm . Remarkably, curvature degree values were similar to the top layers (A-C Layers) of the shell-midden while all other measurements were analogous to the site's bottom occupation (I-J layer). Glume morphological patterns of *O. grandiglumis* revealed that surface was mostly rough in appearance (71%). From 80 double-peaked glume phytoliths analysed, only 29% were considered as smooth. Curvature depth was mostly deep. Variances between the heights of the peaks are mostly symmetric with

31% having fluctuations greater than $3\mu\text{m}$.

O. latifolia glume size measurements exposed an average TW of $33\text{--}46\mu\text{m}$, MW of $36\text{--}50\mu\text{m}$, H1 and H2 size of $13\text{--}18\mu\text{m}$ and $11\text{--}15\mu\text{m}$ respectively and a CD of circa $3\text{--}8\mu\text{m}$. Interestingly, the glume parameters of *O. latifolia* revealed to be the broadest amongst the analysed wild rice species. Furthermore, glume surface patterns have shown to be like the top layers of the midden. From the 180 phytoliths analysed 58% were considered rough and 42 smooth. Interestingly, while CD presented deep curvatures, the variances between heights of the peaks are mostly symmetric, with only 15% having fluctuations greater than $3\mu\text{m}$.

The average measurement of *O. alta* glume revealed a TW of $31\text{--}32\mu\text{m}$, MW of $38\text{--}41\mu\text{m}$, H1 and H2 of $15\text{--}18\mu\text{m}$ and $13\text{--}16\mu\text{m}$ respectively and CD of circa $4\mu\text{m}$. While the height of the peaks and top and maximum width are like the lower layers (J), the CD is more closely like mid-top layers (D). Regarding surface patterns, from 40 double-peaked glume phytoliths analysed 87% were rough in appearance. Furthermore, variances between the heights of the peaks are mostly symmetric with only 25% having deviation greater than $3\mu\text{m}$.

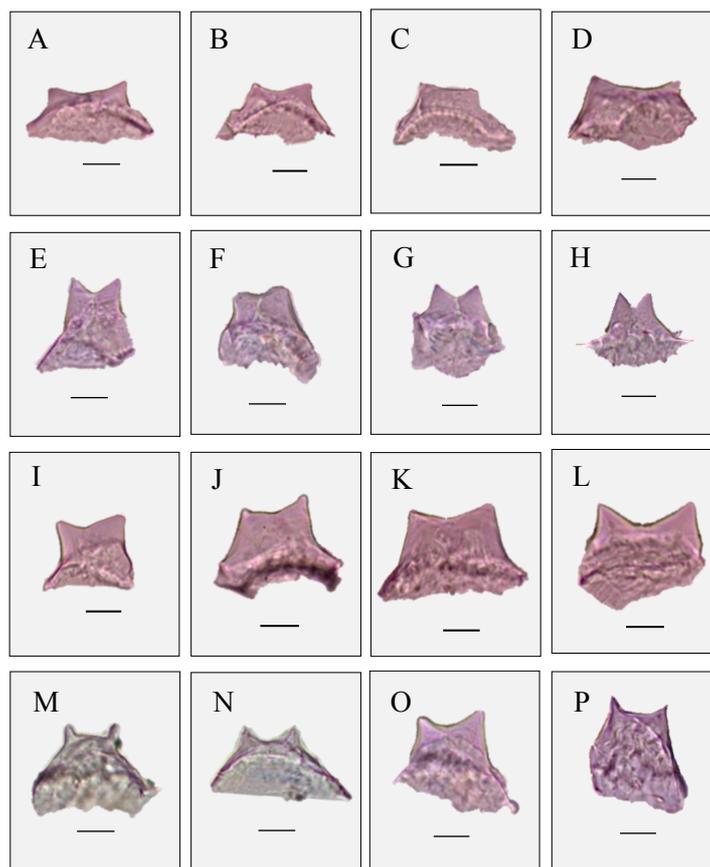


Figure 5.9. *Oryza* spp. double-peaked glume phytoliths native to southwest lowland Amazonia: (A-D) *Oryza glumaepatula*; (E-H). *Oryza grandiglumis*; (I-L) *Oryza latifolia*; (M-P) *Oryza alta*. Scales = $20\mu\text{m}$.

1.2.4.4. *Oryza* sp. Statistical Analysis and Domestication Event

To investigate the potential domestication of wild rice by the Monte Castelo inhabitants, we analysed both archaeological samples and modern wild rice reference material. This section will present a summary on the wild rice domestication investigations.

The analysis of the average size of the attributes measured on the *Oryza* glume phytoliths shows a gradual increase in Height (H1, H2) and Width (TW, MW) through time. Mean H1 values increase ca. $8\mu\text{m}$ ($17\mu\text{m}$ to $25\mu\text{m}$) and H2 increases ca. $7\mu\text{m}$ ($15\mu\text{m}$ to $22\mu\text{m}$) from Layers J to A. MW increases $9\mu\text{m}$ ($48\text{--}57\mu\text{m}$) through the stratigraphy. Mean CD values are larger in the upper occupation layers (A-H) compared to its original dimensions in Layers I- J. As the average values for the Heights and Curvature Degree presented a gradual increase through time, a 3-D scatter plot graph using Matlab was made combining the archaeological and modern wild rice measurements (Fig. 5.10). The graph revealed a clear distinction on the size of double-peaked glumes on layers A-C from the initial occupation and modern wild rice species.

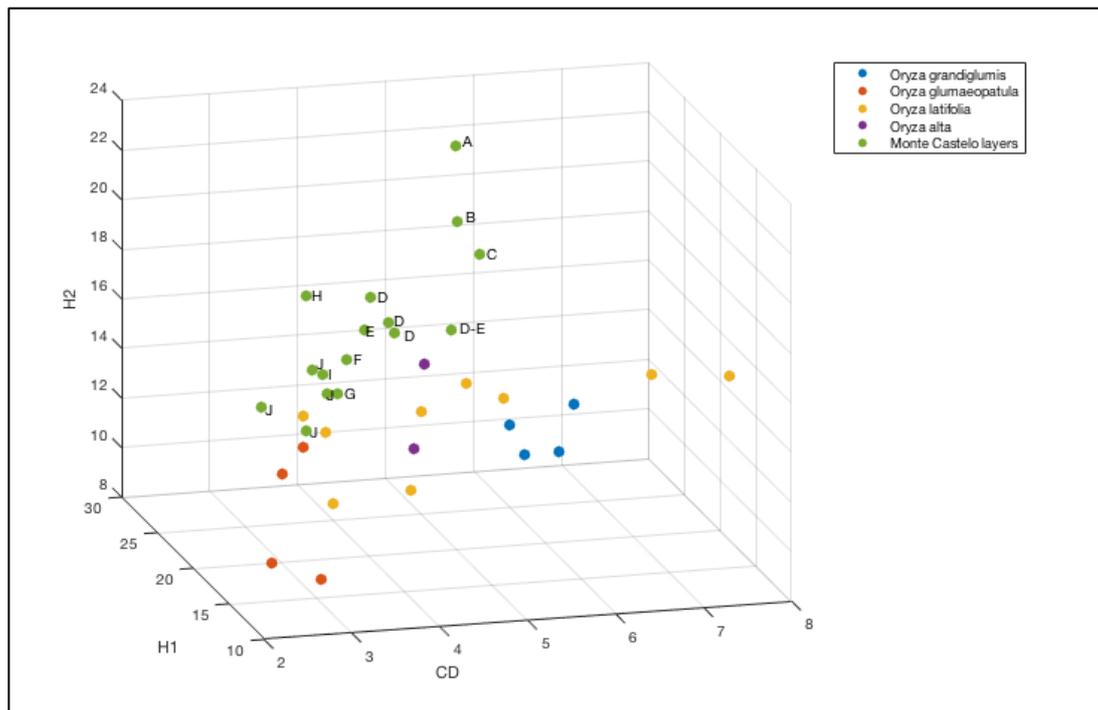


Figure 5.10. 3-D scatter plot of morphological parameters of archaeological and modern wild rice double-peaked glume phytoliths. (H1-2) Mean height of the two peaks; (CD) the depth of the curve; values are in μm .

Principal Component Analysis (PCA) and Boxplots (Fig. 5.11) of the five size measurements of *Oryza* phytoliths was performed on the modern wild rice dataset to determine the key variables that define the phytolith morphology (Fig.

5.12). Height (H1, H2) and Width (TW, MW) measurements are each shown to be highly correlated and comprise most of PCA axis 1 (60%). PCA of archaeological material (Fig. 5.13) and all specimens (archaeological and botanical) (Fig. 5.14), confirm the findings that Height and Width measurements are key defining variables. All PCA analyses were performed in R package Community Ecology package ‘vegan’ version (2.2-1).

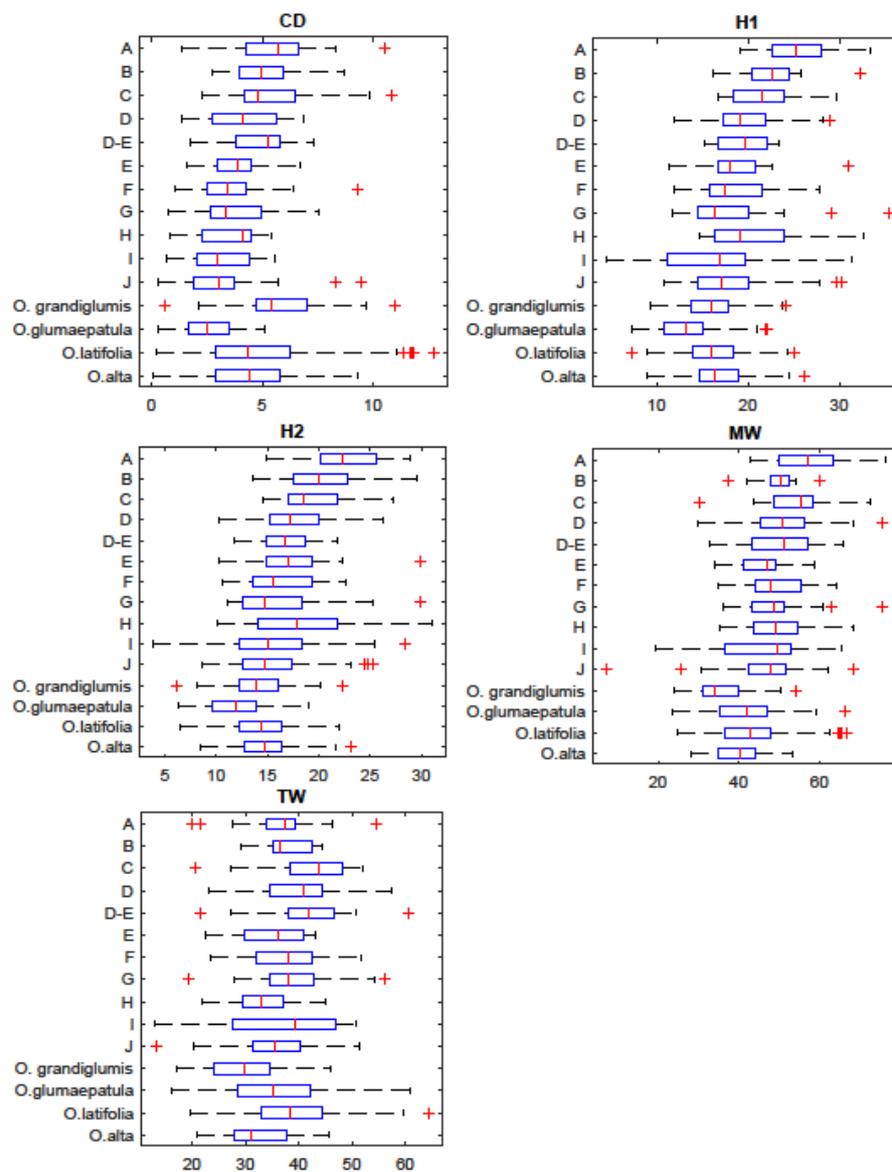


Figure 5.11. Boxplots of *Oryza* double-peaked glume metric attributes from modern reference species and the Monte Castelo stratigraphy (Hilbert et al., 2017 in press).

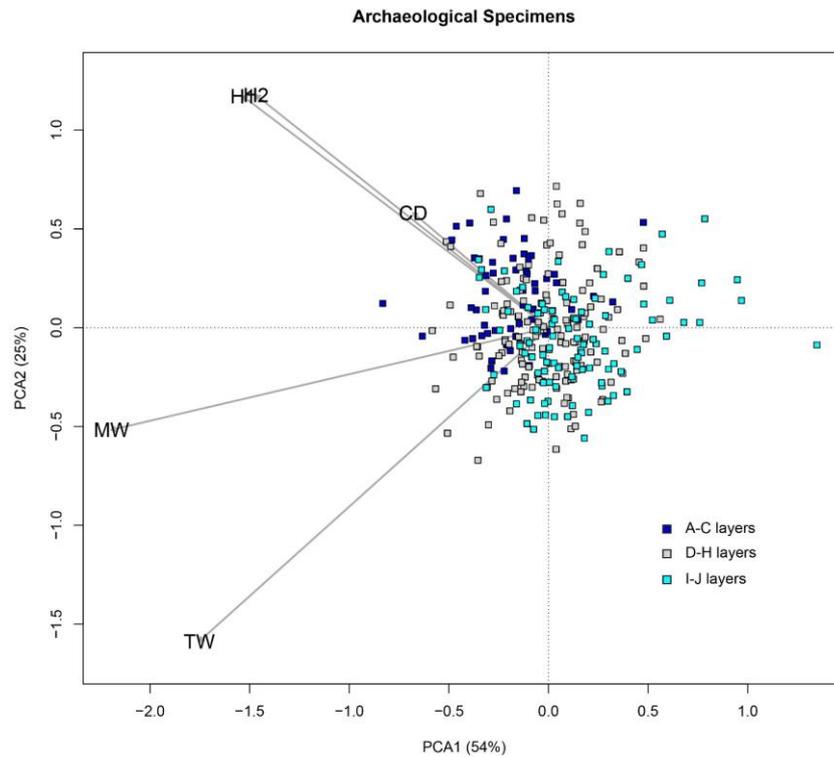


Figure 5.12. PCA of all botanical specimens showing that the two Width and Height measurements are highly correlated and correspond to PCA1, explaining 60% of the variance in the dataset. Curvature Depth (PCA 2) comprises 27% of the variance (Hilbert et al 2017 in press)

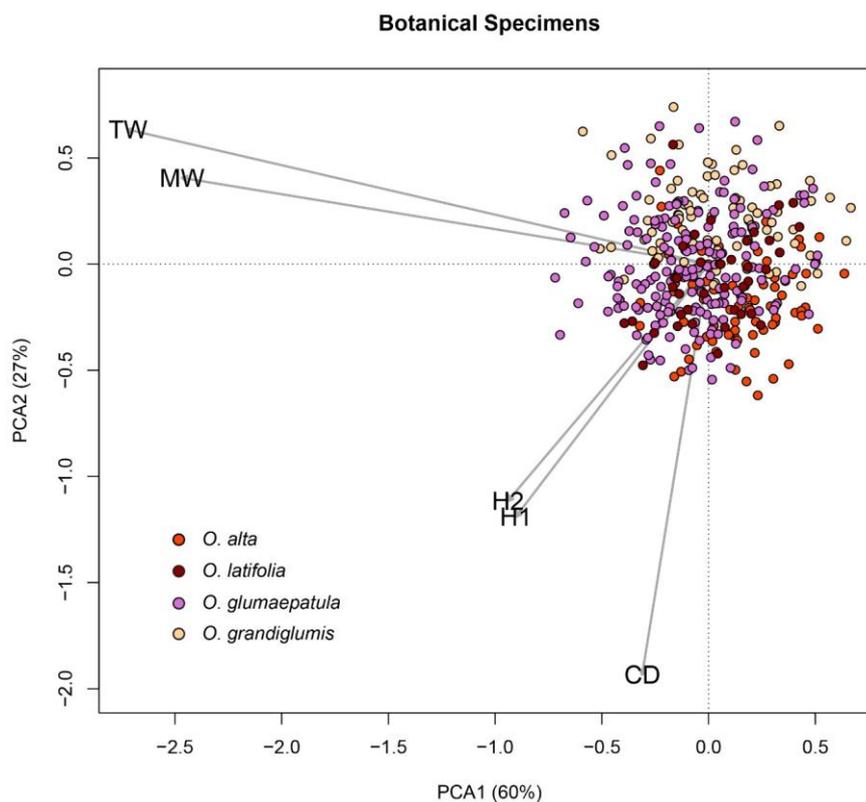


Figure 5.13. PCA of archaeological specimen. Height and width measurements explain most variance in the data and Curvature Depth has a minor contribution to Axis 1

(54%); the species score, however, is low compared to height and width (Hilbert et al 2017 in press).

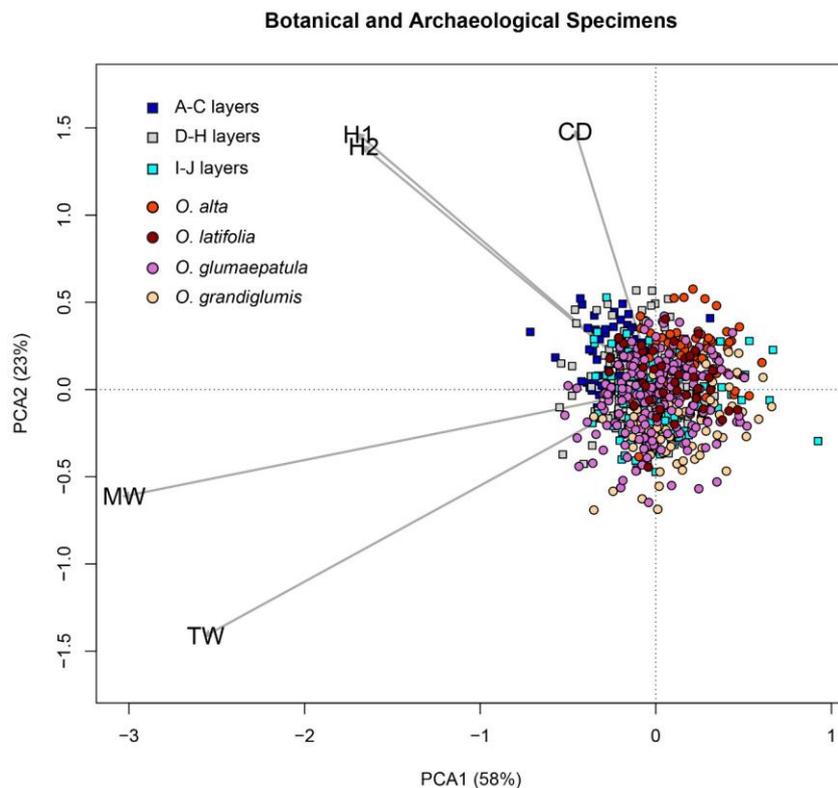


Figure 5.14. PCA for all specimens (botanical and total) confirming that Height and Width explain most variance in the dataset. PCA1 explains 58% of the variance. Again, PCA axis 2 is related to Curvature Depth (Hilbert et al 2017 in press).

One-way ANOVA with a Bonferroni corrected p-value shows phytoliths in the upper archaeological layers (A-D) are significantly larger than those in Layer J and wild reference specimens (Appendix 5).

Figure 5.15 shows mean height and width of all *Oryza* phytolith specimens, revealing an increase in phytolith size through time. The data shows a significant shift towards bigger phytoliths compared to wild specimens that began in Layers D-E (Fig. 5.15) around 4,000 BP. Furthermore, statistical analysis also revealed that phytolith size in lower archaeological layers was not significantly different in the case of *O. latifolia* and *O. alta* (Appendix 5). Principal Component Analysis (PCA) of modern and archaeological wild species shows that the variables that best-explained phytolith shape differences among specimens are the two highly correlated height and width measurements (Fig. 5.12-5.14). Conclusively, the phytolith data shows that wild rice was modified by humans leading the plant to produce larger grains which exceeded the range variation observed in the lower levels of the shell mound and also the modern populations (Hilbert et al., 2017 in press).

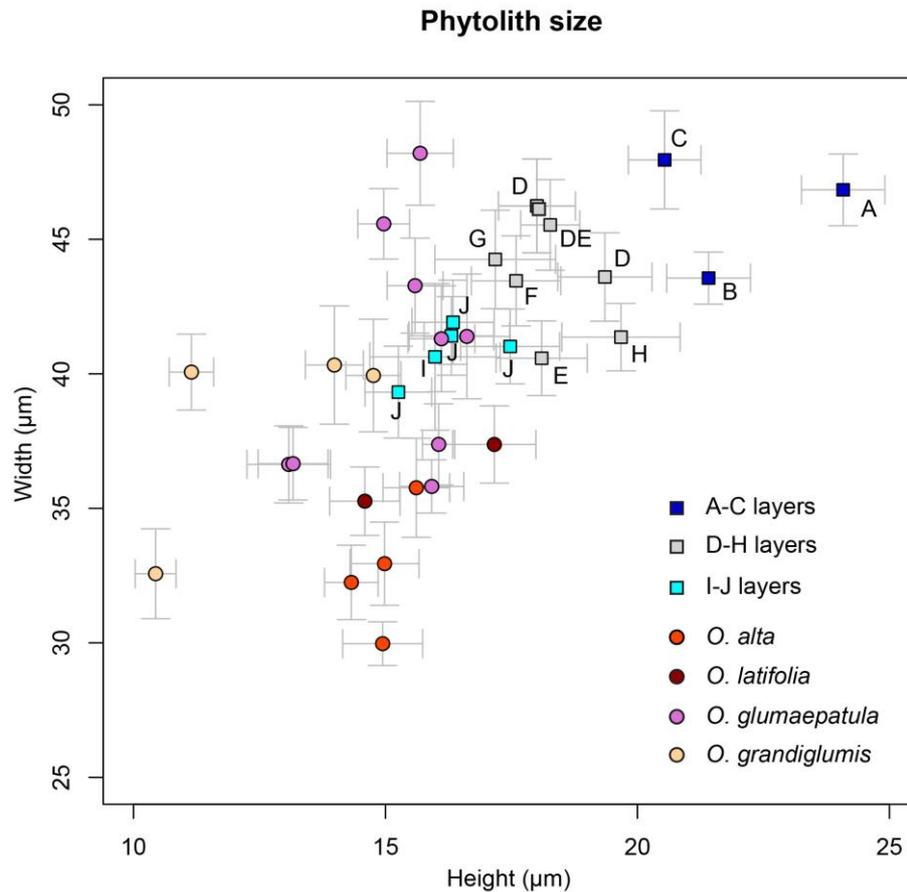


Figure 5.15. Mean height ($(H1+H2)/2$) and width ($(MW+TW)/2$) of all *Oryza* phytolith specimens showing an increase in phytolith size through time (Hilbert et al. 2017 in press).

2. TUCUMÃ SHELL MOUND PHYTOLITH ANALYSIS

This section describes the results of Tucumã shell mound phytoliths identified. A summary of the average percentage of main taxa identified in each layer is presented in Table 5.4.

2.1 Recovered Phytoliths and their Relative Frequencies within Every Context

Phytolith descriptions for the Tucumã shell mound are as follows: Excavation 4, Test Pit 1, Test Pit 2, Test Pit 3 and Test Pit 4. Average percentages of identified taxa on each unit are described from the lower to the upper layer.

Excavation 4 –Layer I (84-90cm b.s.; 4,425-4245 cal. yr. B.P.)

Layer dominated by non-diagnostic Arboreal morphotypes constituting on average 66%. The second most common morphotype recovered was from Arecaceae, constituting on average 12%, from which 3% were conical to hat-shaped bodies. Marantaceae and Asteraceae constitutes on average 5% and 2% respectively. Non-diagnostic Poaceae, Panicoideae and Bambusoideae morphotypes were less frequent, constituting on average 5%, 2% and 2% respectively. Cultigens are absent in this layer.

Excavation 4 –Layer II (37-84cm b.s.; 4,425-4245 to 1,693-1,523 cal. yr. B.P.)

Layer characterised by abundant non-diagnostic Arboreal phytoliths, constituting on average 45% of the levels analysed. Arecaceae phytoliths contributed an averaged of 16% (3% conical to hat-shaped bodies). Overall an increase in the amount of Non-diagnostic Poaceae, Panicoideae and Bambusoideae morphotypes is observable in this layer, constituting on average 10%, 3% and 3% respectively. Asteraceae and Marantaceae constitutes on average 7 and 9% respectively. Scalloped sphere phytoliths from the rind of *Cucurbita* sp. were recovered in almost all levels analysed (excluding 30-40 cm) and constitutes on average 1.5%. *Zea mays* phytoliths were identified in the lower and upper levels of this layer (30-40 cm and 70-80 cm). *Oryza* sp. double-peaked glumes were recovered in trace amounts at 70-80 cm.

Excavation 4 –Layer III (10-37cm b.s.; 1,693-1,523cal. yr. B.P.)

Layer characterised by an overall decrease in non-diagnostic Arboreal phytoliths when compared to previous layers, constituting on average 33% of the levels analysed. Arecaceae phytoliths recovered constitutes on average 15% (5% were conical hat-shaped bodies). Non-diagnostic Poaceae morphotypes exhibiton average 13% of the assemblage. Asteraceae phytoliths presented a sharp increase when compared to previous layers (Layer II 7%), constituting on average 19%. *Cucurbita* sp. scalloped spheres are present in trace amounts (<1%) in this layer.

Excavation 4 –Layer IV (0-10cm b.s.)

Phytoliths recovered in this layer reflected the current vegetation assembly for the site's area (Palm plantation interspersed by herbs and trees - see chapter

3). Non-diagnostic Arboreal morphotypes constitutes on average 34%. Arecaceae phytoliths recovered constitutes on average 19% (6% of conical to hat-shaped bodies). Asteraceae, Marantaceae and non-diagnostic Poaceae phytoliths exhibit on average 19%, 6% and 14% respectively. *Cucurbita* sp. phytoliths were present in trace amounts (<1%) in this layer.

Test Pit 1- Layer I (100-110cm b.s.)

Layer characterised by non-diagnostic Arboreal morphotypes, constituting on average 61%. Second most frequent phytoliths recovered were from Arecaceae, constituting on average 17%, (2% conical to hat-shaped bodies). Panicoideae and Bambusoideae morphotypes were less frequent, constituting on average 6%, 3% and 2% respectively. *Cucurbita* sp. scalloped sphere constitutes on average 3.5% of the analysed layer.

Test Pit 1- Layer II (40-100cm b.s.)

Layer II is characterised by abundant non-diagnostic Arboreal phytoliths, averaging on 50% for the six levels analysed. Arecaceae morphotypes constitutes on average 10% (2% conical to hat-shaped bodies). Asteraceae and Marantaceae exhibit on average 11% and 7% respectively. An increase in the abundance of non-diagnostic Poaceae, Panicoideae and Bambusoideae morphotypes is noticeable when compared to the previous layer, constituting on average 10%, 3% and 4% respectively. Scalloped spheres from the rind of *Cucurbita* sp. exhibit on average 2% and was recovered in four of the six levels of this layer (absent at 90-100cm and 40-50cm). Phytoliths from the cob of *Zea mays* are present in trace amount in one of the six levels analysed (present on 70-80 cm).

Test Pit 1- Layer III (10-40cm b.s.)

Layer characterised abundant non-diagnostic Arboreal phytoliths, constituting on average 39% of the levels analysed. Arecaceae morphotypes constitutes on average 13% (6% conical to hat-shaped bodies). Asteraceae and Marantaceae morphotypes increased in abundance when compared to previous layers, constituting on average 15% and 8% respectively. Non-diagnostic Panicoid and Bambusoideae phytoliths exhibit on average 13% and 4%, respectively.

Cucurbita sp. scalloped spheres constitutes on average 2% of the analysed levels of this layer.

Test Pit 1- Layer IV (0-10cm b.s.)

As with the Layer IV from Excavation 4, the phytolith taxa identified possibly reflects the current vegetation composition of the site. Non-diagnostic Arboreal morphotypes exhibit on average 36%. Arecaceae phytoliths constitutes on average 18% (8% conical to hat-shaped bodies). The amount of conical to hat-shaped phytoliths recovered could tentatively be attributed to the *Astrocaryum aculeatum* plantation surrounding the archaeological site. Asteraceae and Marantaceae morphotypes constitutes on average 18% and 6% respectively. Non-diagnostic Poaceae phytoliths exhibit on average 16%. *Cucurbita* sp. scalloped spheres were recovered in trace amount (<1%) in this layer.

Test Pit 2- Layer I (50-60cm b.s.)

Layer dominated by non-diagnostic Arboreal morphotypes averages 64%. Arecaceae phytoliths recovered constitutes on average 5% (1% conical to hat-shaped body). Non-diagnostic Poaceae phytoliths constitutes on average 6%. Asteraceae and Marantaceae phytoliths recovered exhibit on average 4% and 5% respectively.

Test Pit 2- Layer II (30-50cm b.s.)

Layer abundant in non-diagnostic Arboreal morphotypes, constituting on average 48% of the total assemblages for this layer. Arecaceae phytoliths recovered exhibit on average 8% (1% conical to hat-shaped bodies). Asteraceae and Marantaceae phytoliths identified constitutes on average 9% and 8% respectively. Non-diagnostic Poaceae phytoliths recovered exhibit on average 9%. *Oryza* sp. double-peaked glumes were recovered in trace amount in one of the two levels of this layer (present in 40-50 cm); keystone bulliforms were identified at all levels of this layer, constituting on average 2%. Scalloped spheres from the rind of *Cucurbita* sp. constitutes on average 3%. Wavy-top rondels from the cob of *Zea mays* were identified in trace amounts (<1%) in one of the two levels analysed (present in 30-40 cm).

Test Pit 2- Layer III (10-30cm b.s.)

Layer abundant in non-diagnostic Arboreal morphotypes, averaging on 42% of the analysed levels. Asteraceae phytoliths recovered were the second most common taxa identified, averaging on 17%. Arecaceae phytoliths recovered exhibit on average 8% (2% conical to hat-shaped bodies). Non-diagnostic Panicoideae phytoliths identified constitutes on average 10%. *Cucurbita* sp. scalloped spheres were identified on all levels of this layer and constitutes on average 1%. Oryzae keystone bulliforms and *Oryza* sp. double-peaked glumes are identified in trace amounts (<1%).

Test Pit 2- Layer IV (0-10cm b.s.)

Non-diagnostic Arboreal morphotypes exhibit on average 36%. Asteraceae phytoliths recovered were the second most abundant taxa identified, averaging on 20%. Arecaceae phytoliths identified constitutes on average 15% (4% conical to hat-shaped bodies). Non-diagnostic Poaceae identified exhibit on average 13%. *Cucurbita* sp. scalloped spheres were identified in trace amount (<1%).

Test Pit 3- Layer I (50-60cm b.s.)

Layer characterised by large quantities of non-diagnostic Arboreal morphotypes, constituting on average 63%. Arecaceae phytoliths identified exhibit on average 10% (1% conical to hat-shaped bodies). Non-diagnostic Poaceae morphotypes recovered constitutes on average 9%. Marantaceae and Asteraceae phytoliths identified exhibit on average 5% and 4% respectively. *Cucurbita* sp. scalloped spheres were recovered in trace amounts (<1%).

Test Pit 3- Layer II (30-50cm b.s.)

Layer characterised by abundant non-diagnostic Arboreal phytoliths, constituting on average 44% of the analysed levels. Second most abundant taxa identified was of Arecaceae, constituting on average 14% of the layer (2% conical to hat-shaped bodies). Non-diagnostic Poaceae morphotypes recovered exhibit on average 9%. Asteraceae and Marantaceae phytoliths identified constitutes on average 9% and 6% respectively. Scalloped spheres from the rind of *Cucurbita* sp. were identified in all levels of this layer and exhibit on

average 2%. *Zea mays* wavy-top rondel, and *Oryza* sp. double-peaked glume was recovered in trace amounts (<1%), and both in the 40-50 cm level.

Test Pit 3- Layer III (10-30cm b.s.)

Layer characterised by a decrease in Arboreal morphotypes when compared to previous layers, constituting on average 39%. Phytoliths from Asteraceae increased significantly compared to Layer II (9%), constituting on average 21% of the levels analysed. Non-diagnostic Poaceae morphotypes recovered exhibit on average 13%, showing a constant increase throughout the shell mound occupation. Arecaceae identified constitutes on average 11% of the layer (4% conical to hat-shaped bodies). Marantaceae phytoliths identified exhibit on average 7%. *Cucurbita* sp. scalloped spheres constitutes on average 2%. Oryzae leaf/stem and Heliconiaceae phytoliths were recovered in trace amounts (<1%).

Test Pit 3- Layer III (0-10cm b.s.)

Arboreal morphotypes constitutes on average 36%. Asteraceae phytoliths recovered were the second most abundant taxa identified, averaging on 22%. Arecaceae phytoliths identified exhibit on average 11% (3% conical to hat-shaped bodies). Non-diagnostic Poaceae identified constitutes on average 15%. *Cucurbita* sp. scalloped sphere were identified in trace amount (<1%) in this layer.

Test Pit 4- Layer I (10-50cm b.s.)

Layer characterised by a large amount of Arboreal phytoliths, constituting on average 51% of the analysed levels. Arboreal morphotypes identified displayed a continuous decrease (Fig. 5.16), from 76% at 40-50 cm to 34% at 10-20cm. In contrast, Asteraceae morphotypes increased through the levels of the layer (from 8% at 40-50 cm to 41% at 10-20 cm), with an overall average of 24%. Similarly, non-diagnostic Poaceae phytoliths identified exhibited a constant increase (from 2% at 40-50 cm to 13% at 10-20cm), presenting an overall average of 9%. Arecaceae phytoliths identified exhibit on average 7% (1% conical to hat-shaped bodies). *Cucurbita* sp. phytoliths were identified in trace amounts (<1%) in this layer.

Test Pit 4- Layer II (0-10cm b.s.)

Arboreal morphotypes constitutes on average 36%. Asteraceae phytoliths recovered were the second most abundant taxa identified, averaging on 28%. Arecaceae phytoliths recovered exhibit on average 13% (5% conical to hat-shaped bodies). Non-diagnostic Poaceae identified exhibit on average 12%. *Cucurbita* sp. scalloped sphere were identified in trace amounts (<1%).

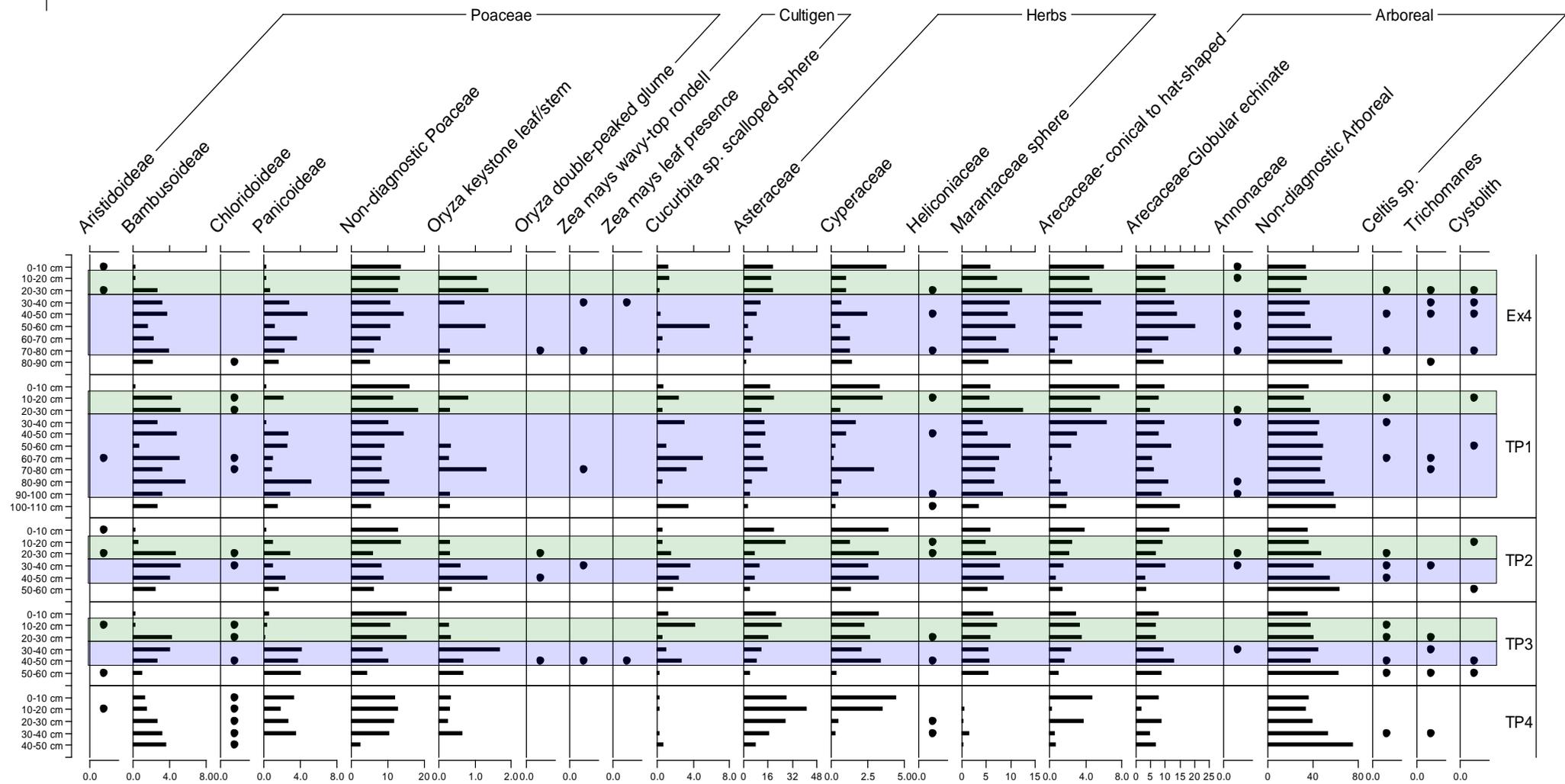


Figure 5.16. Relative frequencies of phytolith recovered in the Tucumã shell mound units. Horizontal bars represent percentages; circles correspond to presence of plant taxa lower than 1% in abundance. Green bars represent the archaeological Layer III; blue bars represent the archaeological compacted shell Layer II.

Table 5.4. summary on the average percentage of main taxa identified in each level of the Tucumã shell mound units.

Unit	Layer	Depth	Main taxa assemblage	Summary of phytolith taxa
Excavation 4	IV	0-10cm	Arboreal-Arecaceae	Non-diagnostic Arboreal ca. 34%; Arecaceae ca. 19%; Asteraceae ca. 19%; non-diagnostic Poaceae ca. 14%; Marantaceae ca. 5%; <i>Cucurbita</i> sp. ca. 1%.
Excavation 4	III	10-20cm	Arboreal-Asteraceae	Non-diagnostic Arboreal ca. 36%; Asteraceae ca. 18%; Arecaceae ca. 14%; non-diagnostic Poaceae ca. 13%; Marantaceae ca. 7%; <i>Cucurbita</i> sp. ca. 1%.
Excavation 4	III	20-30cm	Arboreal-Asteraceae	Non-diagnostic Arboreal ca. 31%; Asteraceae ca. 19%; Arecaceae ca. 13%; non-diagnostic Poaceae ca. 14%; Marantaceae ca. 12%; <i>Cucurbita</i> sp. ca. 1%.
Excavation 4	II	30-40cm	Arboreal-Arecaceae	Non-diagnostic Arboreal ca. 37%; Arecaceae ca. 19%; Asteraceae ca. 11%; non-diagnostic Poaceae ca. 11%; Marantaceae ca. 10%; <i>Zea mays</i> ca. 1%.
Excavation 4	II	40-50cm	Arboreal-Arecaceae	Non-diagnostic Arboreal ca. 33%; Arecaceae ca. 18%; non-diagnostic Poaceae ca. 14%; Marantaceae ca. 9%; Asteraceae ca. 9%; <i>Cucurbita</i> sp. ca. 1%.
Excavation 4	II	50-60cm	Arboreal-Arecaceae	Non-diagnostic Arboreal ca. 38%; Arecaceae ca. 24%; Marantaceae ca. 11%; non-diagnostic Poaceae ca. 11%; <i>Cucurbita</i> sp. ca. 6%.
Excavation 4	II	60-70cm	Arboreal-Arecaceae	Non-diagnostic Arboreal ca. 57%; Arecaceae ca. 12%; non-diagnostic Poaceae ca. 8%; Marantaceae ca. 7%; Asteraceae ca. 6%; <i>Cucurbita</i> sp. ca. 1%.
Excavation 4	II	70-80cm	Arboreal-Marantaceae	Non-diagnostic Arboreal ca. 57%; Marantaceae ca. 10%; Arecaceae ca. 6%; non-diagnostic Poaceae ca. 6%; Asteraceae ca. 5%; <i>Cucurbita</i> sp. ca. 1%. <i>Zea mays</i> ca. 1%; <i>Oryza</i> sp. husk ca. 1%
Excavation 4	I	80-90cm	Arboreal	Non-diagnostic Arboreal ca. 66%; Arecaceae ca. 12%; Marantaceae ca. 5%; non-diagnostic Poaceae ca. 5%.
Test Pit 1	IV	0-10cm	Arboreal-Arecaceae	Non-diagnostic Arboreal ca. 36%; Arecaceae ca. 18%; Asteraceae ca. 17% non-diagnostic Poaceae ca. 16%; Marantaceae ca. 5%; <i>Cucurbita</i> sp. ca. 1%.
Test Pit 1	III	10-20cm	Arboreal-Asteraceae	Non-diagnostic Arboreal ca. 34%; Asteraceae ca. 20%; Arecaceae ca. 13%; non-diagnostic Poaceae ca. 12%; Marantaceae ca. 6%; <i>Cucurbita</i> sp. ca. 2%.
Test Pit 1	III	20-30cm	Arboreal-Poaceae	Non-diagnostic Arboreal ca. 41%; non-diagnostic Poaceae ca. 18%; Marantaceae ca. 12%; Asteraceae ca. 12%; Bambusoideae ca. 5%; <i>Cucurbita</i> sp. ca. 1%.
Test Pit 1	III	30-40cm	Arboreal-Arecaceae	Non-diagnostic Arboreal ca. 46%; Arecaceae ca. 16%; Asteraceae ca. 14%; non-diagnostic Poaceae ca. 10%; <i>Cucurbita</i> sp. ca. 3%.
Test Pit 1	II	40-50cm	Arboreal-Asteraceae	Non-diagnostic Arboreal ca. 45%; Asteraceae ca. 14%; non-diagnostic Poaceae ca. 14%; Marantaceae ca. 5%; bambusoideae ca. 5%.
Test Pit 1	II	50-60cm	Arboreal-Arecaceae	Non-diagnostic Arboreal ca. 49%; Arecaceae ca. 15%; Asteraceae ca. 11%; Marantaceae ca. 10%; non-diagnostic Poaceae ca. 9%; <i>Cucurbita</i> sp. 1%.
Test Pit 1	II	60-70cm	Arboreal-Asteraceae	Non-diagnostic Arboreal ca. 49%; Asteraceae ca. 13%; non-diagnostic Poaceae ca. 8%; Marantaceae ca. 8%; Arecaceae ca. 6%; <i>Cucurbita</i> sp. ca. 5%; Bambusoideae ca. 5%;
Test Pit 1	II	70-80cm	Arboreal-Asteraceae	Non-diagnostic Arboreal ca. 47%; Asteraceae ca. 16%; non-diagnostic Poaceae ca. 8%; Marantaceae ca. 7%; Arecaceae ca. 6%; <i>Cucurbita</i> sp. 3%; <i>Zea mays</i> ca. 1%.
Test Pit 1	II	80-90cm	Arboreal-Arecaceae	Non-diagnostic Arboreal ca. 51%; Arecaceae ca. 13%; non-diagnostic Poaceae ca. 11%; Marantaceae ca. 7%; Asteraceae ca. 6%; Bambusoideae ca. 6%; <i>Cucurbita</i> sp. ca. 1%.
Test Pit 1	II	90-100cm	Arboreal-Arecaceae	Non-diagnostic Arboreal ca. 59%; Arecaceae ca. 11%; non-diagnostic Poaceae ca. 9%; Marantaceae ca. 9%.
Test Pit 1	I	100-110cm	Arboreal	Non-diagnostic Arboreal ca. 61%; Arecaceae ca. 16%; non-diagnostic Poaceae ca. 6%; <i>Cucurbita</i> sp. ca. 4%.
Test Pit 2	IV	0-10cm	Arboreal-Asteraceae	Non-diagnostic Arboreal ca. 36%; Asteraceae ca. 20%; Arecaceae ca. 15%; non-diagnostic Poaceae ca. 13%; Marantaceae ca. 6%; <i>Cucurbita</i> sp. ca. 1%.
Test Pit 2	III	10-20cm	Arboreal-Asteraceae	Non-diagnostic Arboreal ca. 38%; Asteraceae ca. 28%; non-diagnostic Poaceae 14%; Arecaceae ca. 11%;

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Test Pit 2	III	20-30cm	Arboreal-Arecaceae	Marantaceae ca. 5%; <i>Cucurbita</i> sp. ca. 1%
Test Pit 2	II	30-40cm	Arboreal-Arecaceae	Non-diagnostic Arboreal ca. 48%; Arecaceae ca. 8%; Asteraceae ca. 7%; Marantaceae ca. 7%; non-diagnostic Poaceae ca. 6%; <i>Cucurbita</i> sp. ca. 2%.
Test Pit 2	II	40-50cm	Arboreal-Poaceae	Non-diagnostic Arboreal ca. 41%; Arecaceae ca. 12%; Asteraceae ca. 11%; non-diagnostic Poaceae ca. 8%; Marantaceae ca. 7%; <i>Cucurbita</i> sp. ca. 4%; <i>Zea mays</i> ca. 1%.
Test Pit 2	I	50-60cm	Arboreal	Non-diagnostic Arboreal ca. 55%; non-diagnostic Poaceae ca. 9%; Marantaceae ca. 9%; Asteraceae ca. 8%; Arecaceae ca. 4%; <i>Cucurbita</i> sp. ca. 2%; <i>Oryza</i> sp. husk 1%.
Test Pit 3	IV	0-10cm	Arboreal-Asteraceae	Non-diagnostic Arboreal ca. 64%; non-diagnostic Poaceae ca. 6%; Arecaceae ca. 5%; Marantaceae ca. 5%; <i>Cucurbita</i> sp. ca. 2%.
Test Pit 3	III	10-20cm	Arboreal-Asteraceae	Non-diagnostic Arboreal ca. 36%; Asteraceae ca. 22%; non-diagnostic Poaceae ca. 15%; Arecaceae ca. 11%; Marantaceae ca. 8%; <i>Cucurbita</i> sp. ca. 1%.
Test Pit 3	III	20-30cm	Arboreal-Asteraceae	Non-diagnostic Arboreal ca. 39%; Asteraceae ca. 25%; Arecaceae ca. 10%; non-diagnostic Poaceae ca. 10%; Marantaceae ca. 7%; <i>Cucurbita</i> sp. ca. 4%.
Test Pit 3	II	30-40cm	Arboreal-Arecaceae	Non-diagnostic Arboreal ca. 41%; Asteraceae ca. 17%; non-diagnostic Poaceae ca. 15%; Arecaceae ca. 11%; Marantaceae ca. 6%; <i>Cucurbita</i> sp. ca. 1%.
Test Pit 3	II	40-50cm	Arboreal-Arecaceae	Non-diagnostic Arboreal ca. 45%; Arecaceae ca. 12%; Asteraceae ca. 12%; non-diagnostic Poaceae ca. 9%; Marantaceae ca. 5%; <i>Cucurbita</i> sp. ca. 1%.
Test Pit 3	I	50-60cm	Arboreal	Non-diagnostic Arboreal ca. 38%; Arecaceae ca. 15%; non-diagnostic Poaceae ca. 10%; Asteraceae ca. 9%; Marantaceae ca. 6%; <i>Cucurbita</i> sp. ca. 3%; <i>Zea mays</i> ca. 1%; <i>Oryza</i> sp. husk ca. 1%.
Test Pit 4	IV	0-10cm	Arboreal-Asteraceae	Non-diagnostic Arboreal ca. 63%; Arecaceae ca. 10%; Marantaceae ca. 5%; Asteraceae ca. 4%; <i>Cucurbita</i> sp. ca. 1%.
Test Pit 4	I	10-20cm	Asteraceae-Arboreal	Non-diagnostic Arboreal ca. 36%; Asteraceae ca. 28%; Arecaceae ca. 13%; non-diagnostic Poaceae ca. 12%; Cyperaceae ca. 4%; <i>Cucurbita</i> ca. 1%.
Test Pit 4	I	20-30cm	Arboreal-Asteraceae	Asteraceae ca. 41%; Non-diagnostic Arboreal ca. 34%; non-diagnostic Poaceae ca. 13%; Arecaceae ca. 2%; <i>Cucurbita</i> sp. ca. 1%.
Test Pit 4	I	30-40cm	Arboreal-Asteraceae	Non-diagnostic Arboreal ca. 40%; Asteraceae ca. 28%; Arecaceae ca. 13%; non-diagnostic Poaceae ca. 12%; Bambusoideae ca. 3%.
Test Pit 4	I	40-50cm	Arboreal	Non-diagnostic Arboreal ca. 53%; Asteraceae ca. 17%; non-diagnostic Poaceae ca. 10%; Arecaceae ca. 6%; <i>Cucurbita</i> sp. ca. 1%.
Test Pit 4	I	40-50cm	Arboreal	Non-diagnostic Arboreal ca. 76%; Asteraceae ca. 8%; Arecaceae ca. 8%; non-diagnostic Poaceae ca. 3%; <i>Cucurbita</i> sp. ca. 1%.

2.1.1. Palm phytoliths analysis

This section is dedicated to the palm phytolith diversity recovered at the Tucumã shell mound. Globular echinate analysis follows the classification proposed by Morcote-Ríos et al. (2016) (see section 1.21.). Phytoliths recovered are presented according to the identified layers of the mound. From the eight *Arecaceae* phytolith morphotypes categories suggested by Morcote-Ríos, five are present at the Tucumã shell mound (Fig. 5.17)

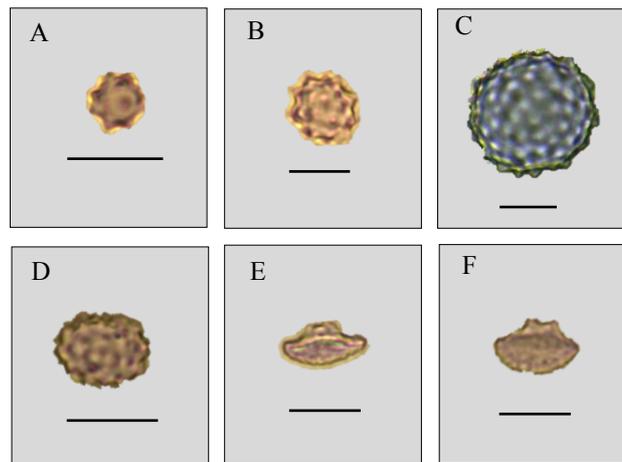


Figure 5.17. Microphotograph of palm globular echinate (Classifications follows Morcote-Ríos et al, 2016) and conical to hat-shaped body phytoliths identified at the Tucumã shell mound: **(A)** globular echinate symmetric (Ex4 LII 40-50 cm); **(B)** globular echinate (TP3 LII 30-40 cm); **(C)** globular echinate with dense short projections (Ex4 LII 30-40 cm); **(D)** globular echinate elongate (TP2 LIII 20-30cm); **(E-F)** conical to hat-shaped body (Ex4 LIII 20-30 cm). Scales = 20 μ m.

Layer I (all profiles)

In all profiles, the characteristic of this layer was the presence globular echinate with various long projections at the periphery and globular echinate with dense short projections.

Layer II (Excavation 4 Test Pit1-3)

Globular echinates with dense short projections (cf. *Euterpe* sp.) and globular echinate elongates are abundant in the layer II of all shell mound units (Fig. 5.18). Also, a gradual increase in conical to hat-shaped bodies from the lower to the upper levels is noticeable in all mound units, thus presenting a rather uniform distribution pattern of the excavated units.

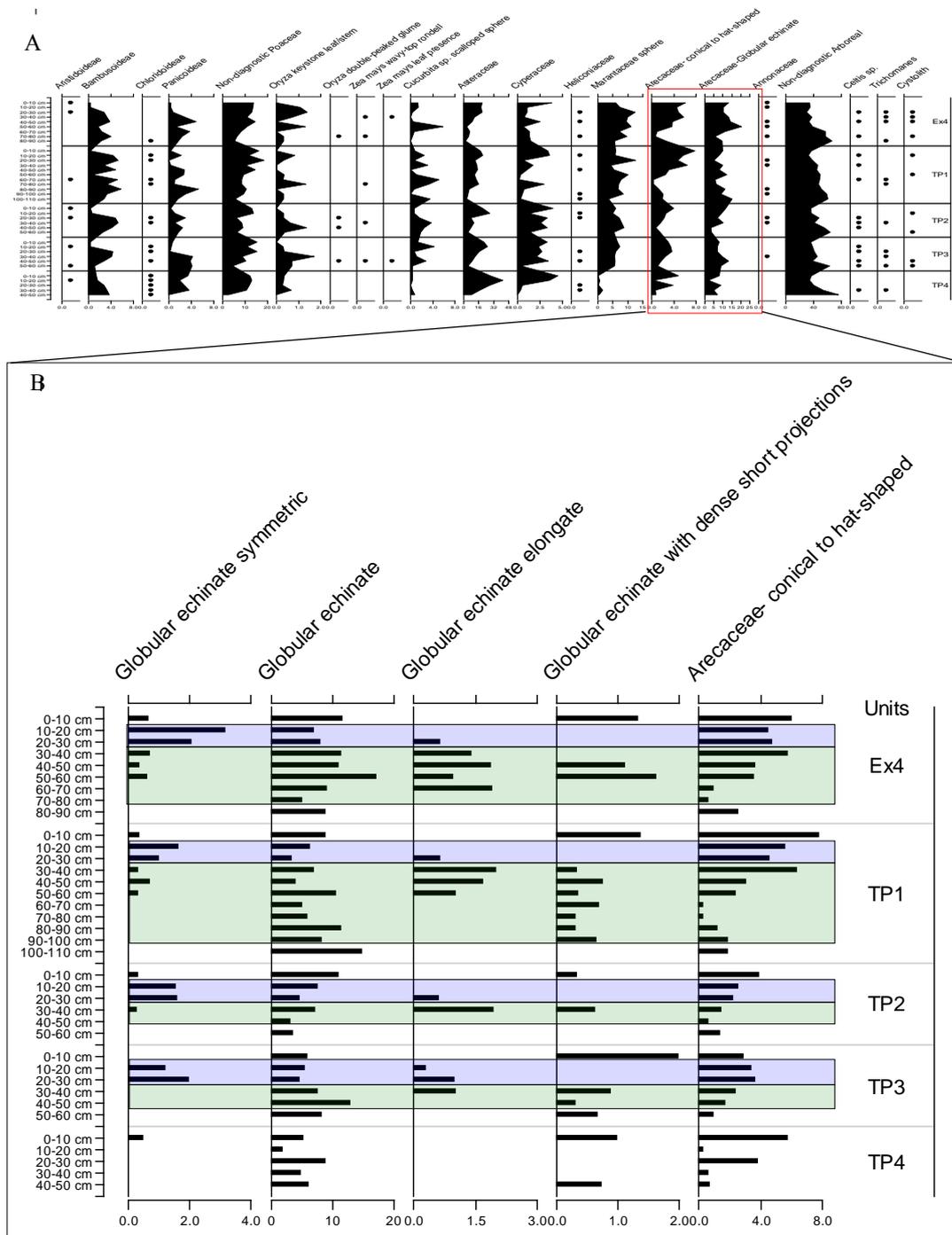


Figure 5.18. Graph showing relative frequencies of Arecaceae phytoliths recovered on the Tucumã shell mound. Horizontal bars represent percentages. **(A)** small scale of the relative frequencies of phytoliths as shown in fig 5.16, red square represents non-separated Arecaceae phytoliths; **(B)** relative frequencies of Arecaceae phytoliths classified per Morcote-Ríos *et al.* (2016). Blue bar represents the layer III; green bars represent layer II.

Layer III (Excavation 4 Test Pit 1-3)

In the layer III of all profiles, large echinates are absent and small symmetric globular echinates occur in large amounts. Of note, the change in the palm phytolith assemblage observed in all profiles is also associated to the shift

from compacted gastropod shells to silt-clayey brown soil (i.e. from layer II to III). This change could be associated to a shift in palm management in the area.

Layer IV (Excavation 4 Test Pit 1-3)

Layer characterised by an overall decrease in globular echinate symmetric and absence of globular echinate elongate. Species from the *Astrocaryum* genus are known to produce conical to hat-shaped bodies (Morcote-Ríos *et al.* 2016), thus the increase in these phytoliths could be attributed to the *Astrocaryum aculeatum* plantation surrounding the archaeological site.

The data presented shows an abundance of globular echinate symmetric and conical to hat-shaped body and an absence of globular echinate with dense short projections on Layer III. Globular echinate with dense short projections are usually associated with species of the *Euterpe* genus (Morcote-Ríos *et al.*, 2016). The absence of this phytolith in Layer III alongside the increase in the other two morphotypes could suggest that a shift in the exploitation of palm species occurred in this layer.

2.1.2. *Zea mays* phytoliths

Wavy-top rondels (Fig. 5.19. A-B) diagnostic to the cob of domesticated maize (*Zea mays*) was identified in trace amounts in all shell mound units: Excavation 4 (30-40cm and 70-80cm), Test Pit 1 (70-80cm), Test Pit 2 (30-40cm) and Test Pit 3 (40-50cm), and were identified exclusively in the Layer II of all the archaeological units.. *Zea mays* predictions and discriminant functions using Cross Variant 1 phytoliths was performed to further confirm its presence in the shell mound (Table 5.5). The calculation exhibited positive results for maize in only two units: Excavation 4 (30-40cm) and Test Pit 3 (40-50cm), and were exclusive to the Layer II. When combined, the results confirm the presence of cob and leaf morphotypes of maize in two units (Excavation 4, 30-40cm and Test Pit 3, 40-50cm).

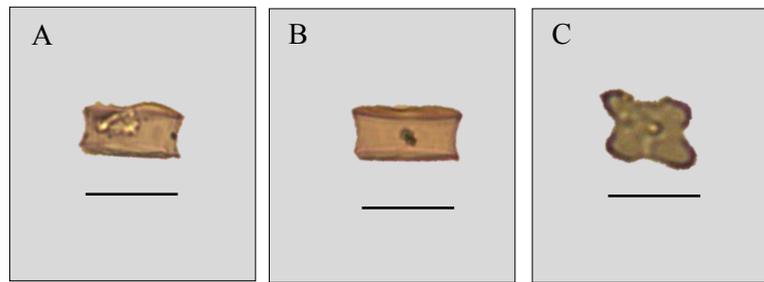


Figure 5.19. Microphotograph of maize and maize related phytoliths recovered in the Tucumã shell mound and their taxonomic and anatomical associations: **(A-B)** Wavy-top rondels from the cob of *Zea mays* (Ex4 LII 70-80cm and TP4 LII 40-50cm); **(C)** Variant 1 cross-shaped phytolith from the leaf of members of the Poaceae family (Ex4 LIII 20-30cm). Scales = 20 μ m.

Table 5.5. *Zea mays* wild and domesticated discriminant function values for each analysed levels of the Tucumã shell mound. Green stripes represent positive for the presence of maize leaves, red stripes are negative

Depth	Unit	N	%X Var 1	% X Var 5/6	% Var 1	DF value	Maize Prediction	Wild Prediction	Maize leaf presence
0-10 cm	Excavation 4	11	11.17	13.15	18.18	10.77	-0.20	1.20	Negative
10-20 cm	Excavation 4	13	12.24	13.34	13.33	11.55	-0.07	1.07	Negative
20-30 cm	Excavation 4	15	13.45	14.97	20.00	12.83	0.16	0.84	Negative
30-40 cm	Excavation 4	15	13.53	12.58	46.67	14.04	0.43	0.57	Negative
40-50 cm	Excavation 4	15	11.61	12.89	33.33	11.42	0.00	1.00	Negative
50-60 cm	Excavation 4	15	14.23	13.91	26.67	13.50	0.35	0.65	Negative
60-70 cm	Excavation 4	15	13.29	14.39	20.00	12.65	0.14	0.86	Negative
70-80 cm	Excavation 4	15	14.21	13.02	46.67	13.82	0.52	0.48	Positive
80-90 cm	Excavation 4	8	0	12.95	0.00	1.33	-2.13	3.13	Negative
0-10 cm	Test Pit 1	8	11.79	14.1	9.09	11.17	-0.19	1.19	Negative
10-20 cm	Test Pit 1	11	0	15.33	0.00	1.57	-2.16	3.16	Negative
20-30 cm	Test Pit 1	15	14.16	15.65	40.00	13.91	0.43	0.57	Negative
30-40 cm	Test Pit 1	15	14.78	14.66	33.33	14.16	0.48	0.52	Negative
40-50 cm	Test Pit 1	12	12.78	11.69	33.34	12.24	0.20	0.80	Negative
50-60 cm	Test Pit 1	15	13.81	14.83	26.67	13.25	0.27	0.73	Negative
60-70 cm	Test Pit 1	15	12.52	13.34	13.33	11.77	-0.03	1.03	Negative
70-80 cm	Test Pit 1	12	14.55	14.97	25.00	13.83	0.37	0.63	Negative
80-90 cm	Test Pit 1	15	13.24	12.58	55.56	13.18	0.45	0.55	Negative
90-100 cm	Test Pit 1	13	12.7	12.62	30.77	12.22	0.15	0.85	Negative
100-110 cm	Test Pit 1	7	11.1	13.91	28.57	11.01	-0.14	1.14	Negative
0-10 cm	Test Pit 2	13	14.29	14.39	23.07	13.52	0.32	0.68	Negative
10-20 cm	Test Pit 2	11	9.97	14.42	55.56	10.73	-0.10	1.10	Negative
20-30 cm	Test Pit 2	15	13.13	15.2	46.66	13.17	0.32	0.68	Negative
30-40 cm	Test Pit 2	15	13.76	14	33.34	13.27	0.33	0.67	Negative
40-50 cm	Test Pit 2	15	14.85	15.33	26.67	14.15	0.43	0.57	Negative
50-60 cm	Test Pit 2	10	12.89	15.65	10.00	12.24	-0.02	1.02	Negative
0-10 cm	Test Pit 3	7	12.81	14.66	46.67	12.86	0.28	0.72	Negative
10-20 cm	Test Pit 3	15	13.89	12.85	40.00	13.40	0.42	0.58	Negative
20-30 cm	Test Pit 3	14	13.9	12.87	28.57	13.17	0.33	0.67	Negative
30-40 cm	Test Pit 3	13	13.77	13.34	13.34	12.78	0.17	0.83	Negative
40-50 cm	Test Pit 3	15	14.89	13.12	53.34	14.53	0.68	0.32	Positive
50-60 cm	Test Pit 3	6	13.14	11.49	16.67	12.16	0.12	0.88	Negative
0-10 cm	Test Pit 4	5	12.63	13.91	20.00	12.06	0.04	0.96	Negative
10-20 cm	Test Pit 4	7	12.97	13.41	14.28	12.16	0.05	0.95	Negative
20-30 cm	Test Pit 4	12	9.97	13.79	33.34	10.19	-0.27	1.27	Negative
30-40 cm	Test Pit 4	10	11.78	12.7	30.00	11.47	0.00	1.00	Negative
40-50cm	Test Pit 4	8	9.75	12.4	12.50	9.42	-0.46	1.46	Negative

2.1.3. *Cucurbita* sp. phytoliths

Scalloped spherical phytoliths from the rind of squash (*Cucurbita* sp. – Fig. 5.20) was present in all units excavated, being absent only in 4 levels (Table. 5.6., Ex4 80-90cm, TP1 40-50cm-90-100cm and TP4 20-30cm). In total, 174 scalloped spheres were identified and measured (according to Piperno, 2000). Measurement analysis provided positive results for domesticated squash on three phytoliths (Ex4 60-70cm TP2 40-50cm and TP3 40-50cm) and was only present in the Layers II of all archaeological units. When following the parameters used by Watling's (2014, p.263) scalloped sphere analysis, from the 174 scalloped spheres identified, 83 fall in the category presented by her (probable domesticate for lowland Amazon are usually over 72 μm in length).

When analysing the average percentage of scalloped spheres recovered, a gradual decrease is observable from the Layers II to III. For example, in TP2 *Cucurbita* sp. phytoliths from layer II had an average of 3%, while on the upper layer it reached circa 1%. Additionally, the overall size and quantity of scalloped spheres was also greater in Layer II than in Layer III.

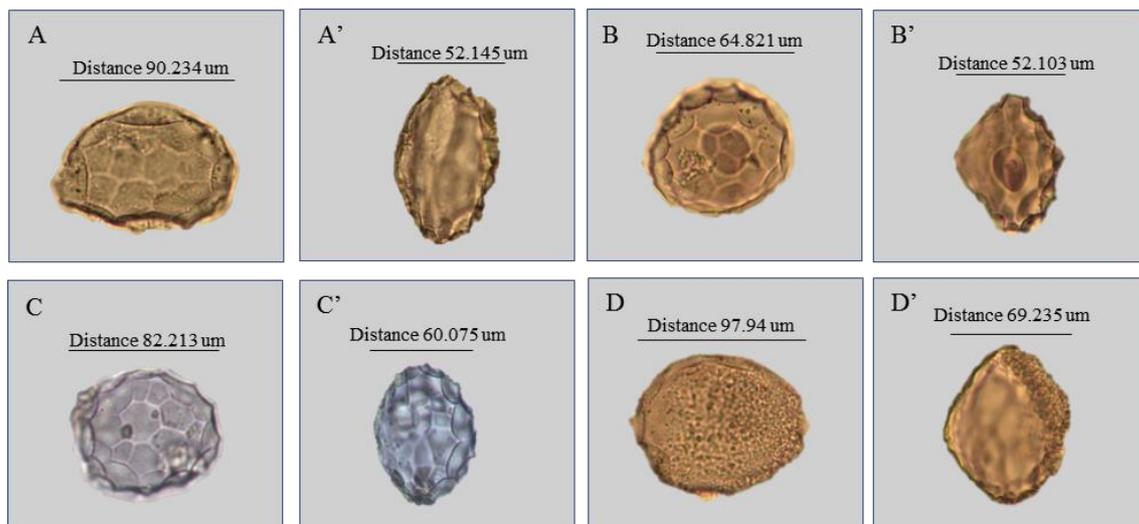


Figure 5.20. Microphotograph of scalloped spherical phytoliths from squashes identified in the Tucumã shell mound; (A-D) length measurements; (A'-D') thickness measurements; (A/A'-B/B') identified in Ex4 LII 50-60cm; (C/C') identified in TP1 LI 100-110cm; (D/D') cf. *Cucurbita maxima* identified in TP2 LI 40-50 cm.

Table 5.6. Length and thickness range, and average size of scalloped sphere phytoliths identified in each one of the Tucumã shell mound units.

Unit	Depth	Layer	Length range (µm)	Length average (µm)	Thickness range (µm)	Thickness average (µm)	N
Ex4	0-10 cm	IV	70-82	74	47-61	53	4
Ex4	10-20 cm	III	60-71	65	45-58	53	4
Ex4	20-30 cm	III	83	83	65	65	1
Ex4	30-40 cm	II	69-72	71	52-54	53	2
Ex4	40-50 cm	II		71	53	-	1
Ex4	50-60 cm	II	38-90	65	36-68	49	18
Ex4	60-70 cm	II	72-93	83	46-73	60	2
Ex4	70-80 cm	II	85	85	65	65	1
Ex4	80-90 cm	I	-	-	-	-	0
TP1	0-10 cm	IV	70-71	71	50-57	54	2
TP1	10-20 cm	III	65-88	74	42-67	55	9
TP1	20-30 cm	III	55-70	63	44-50	47	2
TP1	30-40 cm	II	59-71	67	26-56	45	9
TP1	40-50 cm	II	-	-	-	-	0
TP1	50-60 cm	II	72-79	76	55-67	60	3
TP1	60-70 cm	II	64-87	77	47-69	57	17
TP1	70-80 cm	II	53-80	69	28-63	52	10
TP1	80-90 cm	II	71-74	73	53-58	55	2
TP1	90-100 cm	II	-	-	-	-	0
TP1	100-110 cm	I	65-82	74	42-67	54	11
TP2	0-10 cm	IV	56-57	56	43-50	47	2
TP2	10-20 cm	III	69-77	73	33-60	46	2
TP2	20-30 cm	III	56-76	71	45-62	54	5
TP2	30-40 cm	II	60-85	69	48-58	54	12
TP2	40-50 cm	II	68-98	82	45-61	55	7
TP2	50-60 cm	I	67-74	69	50-69	57	5
TP3	0-10 cm	IV	64-73	68	51-58	55	4
TP3	10-20 cm	III	64-89	77	44-72	57	14
TP3	20-30 cm	III	68-75	72	54-57	56	2
TP3	30-40 cm	II	60-68	64	52-59	55	3
TP2	42cm	II	63-81	71	40-57	51	6
TP3	40-50 cm	II	67-93	81	46-77	61	8
TP3	50-60 cm	I	81	81	59	59	1
TP4	0-10 cm	II	73	73	55	55	1
TP4	10-20 cm	I	63	-	46	-	1
TP4	20-30 cm	I	-	-	-	-	0
TP4	30-40 cm	I	71	71	64	64	1
TP4	40-50 cm	I	63-72	68	48-53	51	2

2.2. Tucumã Phytolith Discussion

The phytolith analysis of the Tucumã shel mound revealed that maize was limited to Layer II (compacted gastropod shell layer). Also, despite the identification of squash phytoliths in all studied layers, measurement analysis showed that larger morphotypes (over 92 µm) were exclusive to Layer II. Additionally, a constant increase in the presence of Arecaceae conical to hat-shaped bodies is noticeable from the upper levels of Layer II towards Layer III (Fig. 5.16). This change from cultigens (maize) with the increase in palm morphotypes is concomitant to the end of layer II and start of Layer III, possibly suggesting a shift in plant exploitation.

Regarding the overall phytolith distribution, all excavated units presented a decrease in Arboreal morphotypes accompanied by an increase in Arecaceae phytoliths from the Layer I to the Layer III. Additionally, when compared to the external unit (TP4), the shell mound units (Ex4 and TP 1-3) presented abundance in Marantaceae, Oryzae and Bambusoideae morphotypes. Concerning the *Oryza* sp. morphotypes, a total of four double-peaked glumes were identified in the shell mound units (present in Ex4, TP2 and TP3). The size of these phytoliths was similar to the lower layers of the Monte Castelo shell mound (Layer J) and probably correspond to wild rice.

Noteworthy, while devoid of archaeological material, layer I yielded *Cucurbita* sp. phytoliths with length parameters over 80 μm . These larger morphotypes were identified only in the shell mound units (TP3 and TP1). Phytolith macropore channel percolation from Layer II is one possible interpretation concerning its presence in Layer I (Fishkis et. all, 2010). While macropore channels could explain the observed *Cucurbita* sp. phytoliths in the Layer I, it is plausible that squash was growing in the region before the establishment of the Tucumã occupation.

Ultimately, Layer IV in all excavated units was highly disturbed due to a nearby telephone tower construction. Consequently, no interpretation on the phytolith assembly is assigned to this layer.

2.3. Zooarchaeological Analysis

This section will present a summary of the faunal data of the Tucumã shell mound. The analysis of the Excavation 4 revealed several faunal remains belonging to four taxonomic classes: Actinopterygii, Reptilia, Mammalia and Mollusca. Additionally, when possible, bone fragments from Actinopterygii and Reptilia, and Mollusca carapaces received a more accurate taxonomic classification.

Save the presence of a few crushed shells and one gastropod carapace there were no other faunal remains in Layer I.

Layer II was mostly composed of *Pomacea* sp. carapaces (Fig 5.21 A). Regarding bone fragments, both analyses, Number of Identified Specimens (NISP) and Minimum Number of Individuals (MNI) (Fig. 5.22), revealed an overall abundance of ray-finned fish remains. Subdivided into three main

orders, Siluriformes (Fig. 5.21 D-F), Perciformes, and Characiformes, ray-finned fish remains constituted on average 70% (NISP) and 60% (MNI) of all the bone fragments analysed for Layer II. From the ray-finned fish orders identified, Siluriformes (catfish) was the most common, constituting on average 40% (NISP) and 30%(MNI); otolith from *Genidens* sp. (Fig. 5.21 D) constituted on average 6% (NISP) and 7% (MNI) for this layer. Otolith from *Cynoscion* sp. (Perciformes) (Fig. 5.21 G) gradually decreased from the lower levels (20% in 50-80cm) to the upper levels (5% in 30-50cm) of Layer II. While non-diagnostic remains from Perciformes increased from the lower levels (20% in 50-80cm) to the upper levels (5% in 30-50cm). Of note, trace amounts (<1%) of Erythrinidae bone fragments were found exclusively in Layer II. Furthermore, non-diagnostic reptile remains (Fig 5.21 I) were recovered only in this layer.

Non-diagnostic Siluriform bones were abundant in Layer III, constituting on average 30% (NISP and MNI) of the levels analysed. *Cynoscion* sp. and non-diagnostic Perciformes decreased in this layer, constituting on average 2% and 10% respectively. Cichlidae freshwater fishes increased in abundance in this layer, constituting 3% of the analysed levels. Testudinata shell plates (Fig 5.21 H) and non-diagnostic Mammalian bones constituted on average 30% and 4%. Last but not least, except crushed *Pomacea* sp. carapaces, Layer IV was mostly sterile in faunal material.

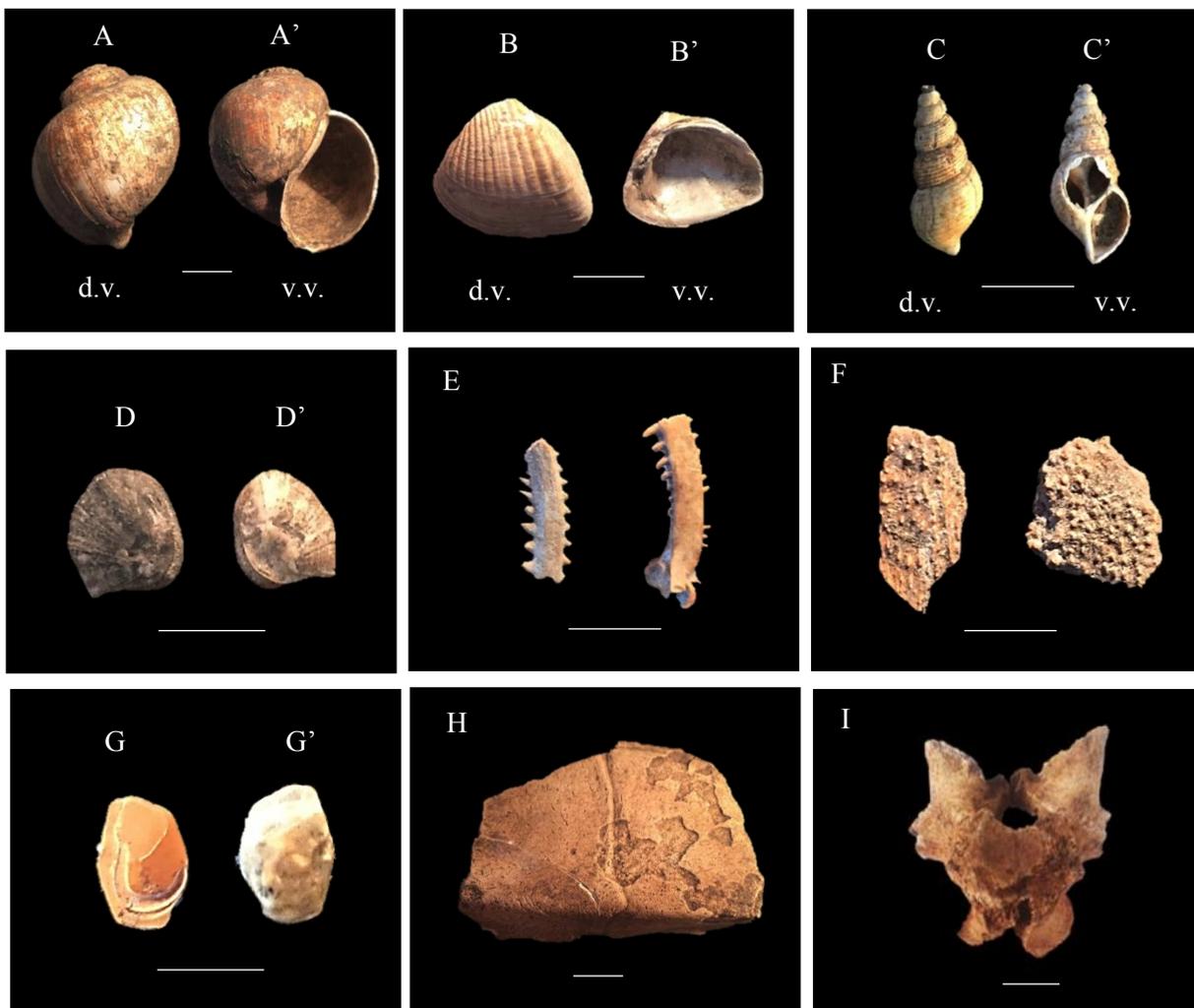


Figure 5.21. Photographs of faunal remains recovered in the Tucumã shell mound. (**A-C**) malacological remains; (**A-A'**) gastropod carapace from *Pomacea* sp. (Ex4 LII 50-60 cm); (**B-B'**) bivalve shell probably from *Castalia* sp. (Ex4 LII 30-40 cm); (**C-C'**) gastropod carapace probably from Pleuroceridae (Ex4 LII 70-80 cm); (**D-D'**) otolith of *Genidens* sp. (catfish) (Ex4 LII 50-60 cm); (**E**) dorsal spine from the Siluriform family (Ex4 LII 50-60 cm); (**F**) neurocranium from the Siluriform family (Ex4 LII 50-60 cm); (**G-G'**) otolith from *Cynoscion* sp (Ex4 LII 30-40 cm); (**H**) Testudinata shell (Ex4 LII 40-50 cm); (**I**) reptile vertebra, probably from alligator (TP3 LII 42cm). Scales = 1cm; d.v. = dorsal view; v.v. ventral view.

2.3.1. Summary on the habitat and ecological niche of the genus identified

Pomacea sp. Perry, 1810 (Gastropoda: Ampullariidae)

Pomacea sp. is a freshwater gastropod composed of circa 50 species with distribution in South America (Cazzinga, 2002). The species of this genus are mostly known for its herbivorous habits, although some species have been recognized to consume larvae and eggs of other gastropods (Estebenet, 1995).

Of note, *Pomacea* species are reported as a rice pest in Brazil (de Freitas-Machado, 1953) and more recently, in Asia (Litsinger, and Estano, 1993).

Cynoscion sp. (Perciformes: Sciaenidae)

Genus composed of approximately eight known species in Brazil. Members of the *Cynoscion* genus usually occur over sandy bottom inshore waters along beaches and estuarine areas (Haimovici, 2006).

Genidens sp. (Siluriformes: Ariidae)

The genus *Genidens* comprises of four known species (Lacépède, 1803, Cuvier, 1829, Miranda-Ribeiro, 1918, Higuchi, Reis & Araújo, 1982), all of them are known to inhabit coastal zones of South America (Marceniuk 2005; Marceniuk and Menezes 2007). Species spend most of their life at sea, migrating to estuarine areas for reproduction (Villamir, 1985).

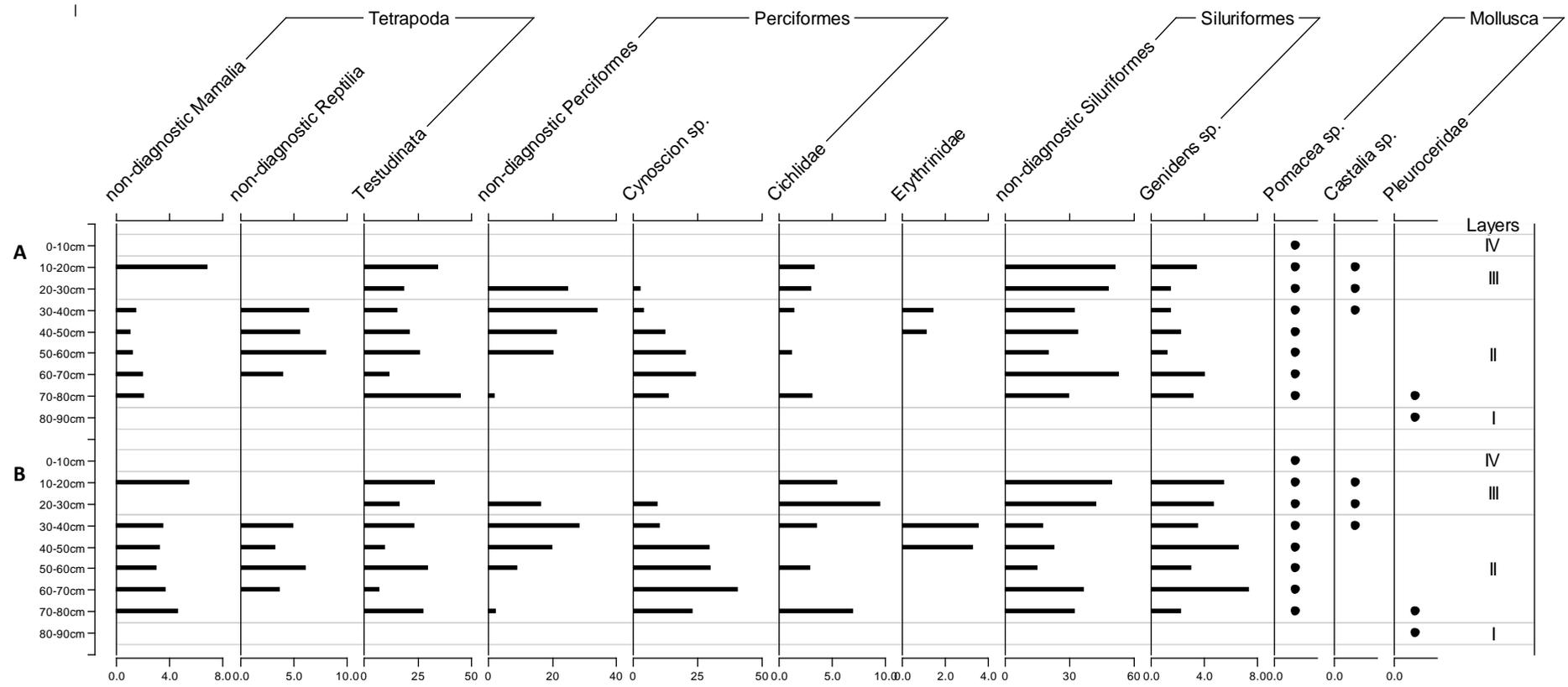


Figure 5.22. Relative frequencies of faunal remains recovered in the Excavation 4 of the Tucumã shell mound. Horizontal bars represent percentages; circles correspond to presence in the site. (A) Number of Identified Specimens (NISP) (B) Minimum Number of Individuals (MNI).

CHAPTER 6

PLANT MANAGEMENT BY THE MONTE CASTELO AND TUCUMÃ SHELL MOUND BUILDERS

The findings of this study reveal that the plant subsistence strategies of the Monte Castelo and Tucumã mound builders were based on a mixture of wild and domesticated resources. Noticeably, the presence of known cultigens such as maize (*Zea mays*) and squash (*Cucurbita* spp.), identified throughout the archaeological layers in both sites, leads us to believe that both crops were commonly grown in the region from at least 4,000 yr. B.P. onwards. Among the wild resources exploited by the shell mound builders our data also suggest the use of *Annona* sp. (soursop) and various types of palm fruits. While consistently recovered throughout both mounds, the phytoliths related to the Marantaceae family could not be associated directly to *araruta* (*Maranta arundinacea*). Still, in the case of the Tucumã mound the presence of phytoliths related to the rhizome of this family was regularly and abundantly recorded solely in the shell mound contexts.

Assuming that the mound builders were engaged in cultivating squash and maize, it is likely that other domesticates such as manioc, peanuts, chilli peppers, yam (Piperno, 2011) and araruta were also being grown and consumed. The results of this study provide novel evidence for pre-Columbian freshwater shell mound occupations. Most notably, a mixed economy, combining the gathering of wild plant resources, cultivation of domesticated species and eventually the domestication of wild rice by the Monte Castelo shell

mound builders, reveals the capability of these ancient Native American groups to recognise and manipulate plant resources.

1. THE MIXED ECONOMY OF THE MONTE CASTELO MOUND BUILDERS

The Monte Castelo site, located in Brazilian south-west lowland Amazonia, represents an important testimony to the freshwater shell mound builders' occupation in the region. The site which extends across an area of approximately 145 to 105m² and exhibiting eight metres of cultural deposits has proved to be a significant source of data regarding the continuity of human occupation in the Amazon (Miller, 1987, Miller, 1992, Neves and Pugliese, 2016). Radiocarbon dates have identified the occupation as lasting from the early Holocene to the late Holocene era (9,495-9,137 to 910-660 cal. yr. B.P., Miller, 2002), indicating a successful human adaptation to the wetland biome. Investigations on the site revealed three occupational phases: one hunter-gatherer phase called Cupim, and two shell mound builder phases, Sinimbú and Bacabal phase (Miller, 2002, Neves and Pugliese, 2016).

The Monte Castelo shell mound can be placed within a context of ancient ceramic production in the Amazon basin. This applies especially to the Bacabal phase, whose decorative elements are characteristic of some of the earliest known pottery in the New World along with Puerto Hormiga in Colombia and Valdivia in Ecuador (Neves, 2015). These characteristics could be correlated to a probable cultural exchange between the Andean ceramic technology and domesticated plant resources within the lowland Amazon during the mid-Holocene (Neves and Pugliese, 2016).

This study analysed 16 soil samples from ten layers uncovered by the 2014 excavations led by E. Neves and his team. The excavation reached 460cm below the surface to include part of the Sinimbú phase and the entirety of the Bacabal phase. The base of the excavation yielded a date of 5,416-5,060 cal. yr. B.P. Our results revealed that the Monte Castelo mound builders were already cultivating maize and squash as early as 5,416-5,060 cal. yr. B.P., which registers one of the earliest occurrences of these domesticates for the south-west Brazilian Amazon.

Further maize records for South America include findings such as in the Bolivian lowland with dates reaching 7,434-7,421 cal. yr. B.P. (Brugger et al., 2016); lowland Ecuadorian Amazon presenting dates of 6,882-6,795 cal. yr. B.P. (Bush et al., 1989, Piperno, 1990); 6,306-6,285 cal. yr. BP in Abeja, Colombia (Piperno, 2011); 5,286-5,052 cal. yr. B.P. in Los Ajos, southeastern Uruguay (Iriarte et al., 2004). For Brazil, pollen records from Lake Geral in the State of Pará revealed the presence of maize with dates of 4,234-4,149 cal yr. B.P. (Bush et al., 2000) and for the State of Acre at 1,875-1,747 cal. yr. B.P. associated with the Amazonian Geoglyphs culture (Watling et al. 2015). Accordingly, the maize findings for the Monte Castelo shell mound are, to date, the earliest known records for South American shell mound culture.

In addition to these plants, the phytolith records revealed the potential gathering of wild plant resources, such as palm fruits and wild rice. As phytolith data show that in the early Sinimbú phase the mound builders were probably engaged in incipient agriculture, the overall importance that maize and squash had in their main diet could not be determined in this study. However, to gain a fuller understanding of their importance, isotopic studies of human bones recovered from the site could reveal the scale of the consumption of maize by the mound builders.

Phytolith investigations of the Bacabal phase revealed a likely increase in the cultivation of maize and squash. Furthermore, the gathering of wild rice, which was already under human-selective pressures throughout the previous phase, resulted in a likely domestication of this species. While the changes observed in the cultivation of maize and squash was rather gradual, along with the increase in wild rice seeds, a threshold is observable from layer D upwards (Fig. 5.1 in chapter 5). This zone, which corresponds from the Layers A to D, presented the highest amount of wild and domesticated plant resources for the analysed occupation. Apart from the increase in maize, squash and rice phytoliths, the zone is characterized by the presence of wild species such as soursop and hackberry (*Celtis* sp.), and potentially at least two different palm species (cf *Euterpe* sp. and *Bactris* sp. or *Astrocaryum* sp.).

The analysis of the phytoliths recovered in the Sinimbú and Bacabal phases exhibited shifts in the management of plant resources. For example, soursop and hackberry were only present in the late Bacabal phase, while certain palm morphotypes were abundant only in the Sinimbú phase. Overall,

while the phytolith record supports an increase in the management and cultivation of domesticated species, it also shows a presumable increase in the foraging of wild species. Thus, the results indicate that the native population of the Monte Castelo shell mound were cultivating domesticated plants and managing wild plant resources at the same time.

The south-west lowland Amazon region is considered to be the cradle of domesticates such as manioc (*Manihot esculenta*) (Olsen and Schaal, 1999, Olsen and Schaal, 2001), peanuts (Kochert et al., 1996; Seijo et al., 2004; Bertioli et al. 2016) and peach palm (*Bactris gasipaes*) (Clement et al., 2010). In addition to these, the results of this research have evidenced the increased exploitation of wild rice which led to an increase in the size of the seed (Hilbert et al., 2017 in press). In conclusion, the results highlight the importance of the wetland biomes and plant domestication in the south-west lowland Amazon as a major supply of plant resources for past human populations.

1.1. Wild rice domestication by the Monte Castelo shell mound builders

Asian rice (*Oryza sativa* L.) is consumed and cultivated worldwide and serves as one of the most important grain crops in the world today (Khush 1997). Archaeological and molecular data support a domestication event in the Chinese Yangtze River at ca. 9,000 yr. B.P. (Molina et al. 2011; Normile 1997; Zhao 1998; Zhao 2010; Zhao and Piperno 2000). In addition to *O. sativa*, several rice species were and are being consumed across the world today (Ford and Brose 1975; Winkler 1926). For example, *O. glaberrima* Steud., an African variety domesticated in West Africa at ca. 2,000 yr. B.P. is also recognised as an important economic crop (Linares 2002). Nevertheless, for the Americas continent, before the introduction of any of these species by Europeans in the 18th century, wild rice was already a seasonal staple of indigenous subsistence, as is the case with *Zizania* rice species. In North America, these plants have been documented as being managed by native populations (e.g. Wet and Oelke, 1978; Ford 1979; Yost and Blinnikov 2011). However, for South America, the only evidence stems from early 16th to 19th century historical and ethnographic accounts. These reports refer extensively to the consumption of wild rice species by indigenous groups in lowland South America (Fonseca, 1826; Schmidt, 1902; Cardim, 1583 [2009]; Acosta, 1590

[2002]). Although these references point to its potential role in pre-Columbian diets, the domestication of rice has not yet been investigated in this region.

Phytoliths from the glume of *Oryza* sp. were consistently identified in the layers of the Monte Castelo shell mound. Previous studies on Asian rice have demonstrated a clear correlation between the size of the seed and the size of the husk phytoliths (Gu et al., 2013). This, and the rich ethnographic accounts on the management of wild rice in South America, led to a thorough investigation on the morphotypes identified in this study. The results of our investigations have documented for the first time the domestication of wild rice by mid-Holocene residents of the Monte Castelo shell mound, starting at ca. 4,000 yr. B.P., evidenced by the selection of increasingly larger seeds (Hilbert et al., 2017 in press). Overall, the phytolith data revealed that wild rice was modified by human selective pressures which led the plant to produce larger grains, exceeding the range of variation found in the lower levels of the Monte Castelo shell mound and in the modern populations of wild rice (Hilbert et al., 2017 in press).

While considering harvesting practices, ethnographic reports state that natives gathered wild rice through the lashing of ripe ears with wooden poles to make the grains fall into their canoes (Barman 1821-1829 [1971]; Winkler, 1926). Similar reaping practices have been reported for North American tribes (Vennum, 1988) (Fig. 6.1). Wild rice probably constituted a significant seasonal resource for the Monte Castelo mound builders, who began to manage wild rice at lake or river edges. Furthermore, wild rice was probably an especially relevant resource during the rainy season when the flooding of the wetland areas caused other resources to be dispersed and limited (Hilbert et al 2017 in press).



Figure 6.1. 19th Century North American natives harvesting wild rice (*Zizania* sp.) (Eastman, 1853).

In other regions of the Americas, wild grasses tend to decline in importance once the native population adopts maize (Austin, 2006). However, the opposite trend is apparent in the Monte Castelo record, as wild rice was domesticated and increased in importance after the residents had become involved in maize and squash cultivation (Hilbert et al. 2017 in press). With the presumed abandonment of the site and the arrival of Europeans to the American continent, the now domesticated rice, in the absence of human-induced variations and management, lost its domesticated traits which probably led to a population collapse or to a regression to its wild ancestor.

Regarding possible funerary practices, we noted that at the burial context (Layers D 130 cm to E) the rice seed phytoliths recovered were over three times that of leaf phytoliths. Notably, the soil samples analysed from beneath the burial context presented the lowest ratio of seed versus leaf phytoliths of all the investigated layers. This indicates that the amount of leaf deposited was twice that of the seeds, suggesting that whole plants were deposited below the burial context. The presence of seeds (Bianchini and Scheel-Ybert, 2012a) and faunal remains (Klokler, 2015, Okumura and Eggers, 2012) associated with burials has been documented for coastal mounds in South Brazil. As this data was interpreted as probable offerings or food consumption during funerary rituals (Bianchini and Scheel-Ybert, 2012a, Klokler, 2015, Okumura and Eggers, 2012), a similar pattern is noted for the Monte Castelo shell mound in which rice seeds were abundant in the burial contexts. In addition to this, the nearly equal amount of rice seeds and leaf phytoliths might be indicative that whole rice

plants were deposited as a base cover for the burials. However further in-depth analysis is needed to understand the burial context of the Monte Castelo shell mound to understand the rice seed and leaf pattern observed in the phytolith records.

While phytoliths alone have proven to be extremely useful in this study, it was not possible to point out which modern wild rice species (*O. glumaepatula*, *O. alta*, *O. grandiglumis* and *O. latifolia*) is/are the probable ancestors of the archaeological rice. Thus, regarding the future of Amazonian rice investigations, the use of ancient phytolith DNA could prove to be highly fruitful.

As organic matter is locked inside the phytoliths during their production, researchers have managed to extract this organic material and use it in DNA studies (e.g. Kistler, 2012). The procedure involves breaking open the phytoliths using acids and extracting the DNA (for method see e.g. Kistler, 2012). The method has proven successful in Japanese rice phytolith investigations, in which it evidenced the cultivation of different varieties of rice in the region (Tanaka et al., 2010).

This approach could elucidate the question regarding the probable ancestry of the Amazonian archaeological rice. Furthermore, it could clarify questions concerning whether varieties of rice were cultivated, and whether these were the same or different over time. Also, DNA mapping of modern rice species could show if genetic material from different regions constituted the genetic structure of the archaeological rice. However, there still needs to be a better understanding regarding phytolith formation in plant tissues and in relation to the integrity of the DNA locked within them.

1.1.1 Apple snails as a possible impact on archaeological rice cultivation

Apple snails (*Pomacea* sp.) constitute the main building material of the Monte Castelo mound. The species of this genus are mostly known for their herbivorous habits (Estebenet and Cazzaniga, 1992, Estebenet and Martín, 2002). Most noticeable is the fact that they are considered as a serious pest with regard to rice (*Oryza sativa* and *Zizania latifolia*) cultivation in South America (de Freitas-Machado, 1953). Also, more recently, the snail was unintentionally introduced to the wetlands of Japan, Philippines and Taiwan, where without any natural predator it caused major damage to rice crops (Naylor, 1996, Teo, 1999).

The investigations into the phytoliths of wild rice documented that the increase in seed size began around layer D in the Bacabal phase, at circa 4,000 yr. B.P. (Hilbert et al., 2017 in press). Additionally, from this layer upwards, a general increase in the abundance of rice double-peaked glume phytoliths is observable. Interestingly, this layer also corresponds to a major decrease in apple snails when compared to the earlier layers of the mound (Chapter 4 Fig. 4.1). Thus it can be said that the increased size and quantity of rice phytoliths occurred approximately at the same as apple snails decreased in the archaeological records of the mound.

Conceivably, as in rice cultivation today, the management of wild rice by the Monte Castelo inhabitants could have been affected by the herbivorous behaviour of the apple snails. That could have led to the mound builders controlling the snail population, leading to the decrease observed in the shell mound. However, several factors could be responsible for the decline of apple snails in the archaeological record, for example, a dietary/cultural shift, the increase in weather conditions (e.g. Whitney and Mayle, 2012) which would have elevated the water levels of the region limiting the gathering methods of the mound people or could also be related to a widespread natural decrease in the snail population. Thus, careful investigations should be carried out at the shell mound to understand the distribution of apple snails and the wild rice records. Additionally, studies on the impact of apple snails on native South American wild rice species need to be documented. Nevertheless, this evidence, if correlated, could attest to a direct human interaction on an animal population in order to control pests on managed crops.

1.2. The Role of Maize and Squash on the Monte Castelo Diet

Phytoliths from the cob of maize were identified in nine of the ten investigated archaeological layers of the Monte Castelo shell mound (absent in Layer G). Additionally, discriminant functions have revealed the presence of leaf of maize in eight of the ten archaeological layers (absent in Layer A and G). As the phytoliths from the cob are produced in small quantities by the plant organs (Piperno, 2006), we can be confident that maize was regularly grown in the region, from at least 5,416-5,060 cal. yr. B.P. onwards. The consistent presence of cob and leaf phytoliths supports this assertion, and also suggests that the

maize could have been husked in the midden area after gathering. Overall, maize identifications were more frequent in later than earlier layers. Whether this represents a temporal change in its consumption could not be determined using only phytolith analysis and would require future investigation.

Domesticated in the seasonal tropical forest of southwest Mexico (Piperno; Ranere et al. 2009) maize is a relatively demanding crop as regards nitrogen, phosphorus, potassium and water during its growing period (Watling, 2015). However, maize could have adapted to a variety of climates in South America. For example on the coast of Ecuador maize can grow in the rainy season without needing irrigation, while in the arid climate of the Andean foothills high productivity occurs only if the maize is irrigated (Salick et al., 1997). As it is considered a plant of fast growth and high yield, it favours planting strategies such as slash-and-burn and can be planted relatively intensively when combined with polycultures, for example management strategies involving maize planted with squash and beans (Barghini, 2004, Hart and Scarry, 1999, Postma and Lynch, 2012).

Given that the shell-mound builders of Monte Castelo were involved in a mixed plant economy, the wetlands region surrounding the site offers several useful characteristics for the adoption and intensification of agriculture (Diegues, 1994, Niederberger, 1979, Pohl et al., 1996, Sherratt, 1981, Siemens, 1983, Siemens, 2013). Firstly, the wetlands provide greater stability in water supply and thus, reduce risks during dry seasons (Siemens, 2013). Secondly, the seasonally exposed organic soils in the wetlands margins constitute an excellent place to practice flood-recessional horticulture (Iriarte, 2003b). During the dry season from May to October the superficial peat horizons of the wetlands of the Biological Reserve of Guaporé contain soils that are highly fertile and hold moisture (Diegues, 1994). Additionally, the dry-season yield capacity combined with the wet-season cultivation shift might have constituted a significant improvement of the subsistence system that allowed a harvest of staples in an otherwise lean season (Siemens, 1983). Therefore, the wetland regions exhibit excellent characteristics for the development of the cultivation of maize and rice in the area.

Phytoliths from the rind of the fruit of domesticated squash were identified in all investigated archaeological layers of the Monte Castelo shell mound. Due to the amount of phytolith recovered throughout the occupation, we

can be confident that this crop was also being grown in the region from at least 5,416-5,060 cal. yr. B.P. onwards. As with the maize identifications, squash phytoliths were more frequent in later than earlier contexts. Given that the shell-mound builders of Monte Castelo were engaged in a mixed agriculture, it is still unclear whether the increased frequency of maize and squash phytoliths throughout time could be related to improved management of the crop.. Instead, the latter occupation management strategies may have consisted of a more complex cultivation system, in which the mound builders incorporated several plants with the already domesticated ones. Whether our results reflect a temporal change in the consumption of these domesticated species, or are a result of sampling bias, is still unclear. Future investigations should shed light on the situation.

1.2.1. Maize and squash management strategy hypothesis

One of the models of early Mesoamerican agriculture, known as the three sister crops, consists of the management of maize, beans and squash in the same plot (Barghini, 2004, Hart and Scarry, 1999, Postma and Lynch, 2012). This approach, which combined legumes with grass plants, reduced the nutrient saturation of the soil and developed a long-term sustainable cultivation of these plants (Lewandowski, 1987, Xiao et al., 2010). The root architecture of these plants allows them to avoid direct competition for immobile resources and enables them to take up more mobile nitrate in this polyculture than would be possible in a monoculture (Postma and Lynch 2012).

While it is recognised that beans produce substantial amounts of diagnostic phytoliths (Piperno 2006), this study did not confirm the presence of beans in the shell mound. However, while this could be due to a bias in the sampling or lack of alternative investigation techniques executed in the mound (e.g. starch grains), a possible alternative component of this theoretical model is peanuts (*Arachis hypogaea*). This leguminous plant which, given genetic evidence, most probably originated through the hybridization of Andean and south-western lowland Amazon species around 9,535-9,475 cal. yr. B.P. (Kochert et al., 1996; Seijo et al., 2004; Bertioli et al. 2016), does not produce diagnostic phytoliths (Piperno, 2006). Because of the methodology used in this research, peanuts were not found in the Monte Castelo shell mound, although they are identifiable through macro remains and starch grains.

Assuming that domesticates were grown in the vicinity of the shell mound, the weather climate conditions documented in the region for the late-Holocene (e.g. Whitney and Mayle, 2012) could have reduced viable growing areas for maize and squash. This, on the other hand, would have led to a decrease in phytoliths of these species in the archaeological records. However, an overall increase in squash and maize phytoliths was observed in the later layers of the mound. Thus, it is possible that the amount of morphotypes of these crops in the later layers of the mound could be related to a productivity growth in which peanuts were part of a smaller but more yielding management strategy.

Overall, peanuts have already been documented in sustainable indigenous cultivation strategies, where they were planted together with sweet potatoes and maize to increase productivity (Magcale-Macandog and Ocampo, 2005). However, to investigate if this could be the case for the Monte Castelo shell mound would require further research, integrating multi-proxy analyses.

1.3. Wild Plant Resources

Among the wild plant resources exploited by the Monte Castelo shell mound builders, palms were notably the most common. Additionally, their phytoliths constituted a significant part of the Bacabal phase. The overall contrast between the Sinimbú and Bacabal phases palm morphotypes indicates that an increase in fruits, wood, or leaves of the plant was brought in by humans to the mound on the later phase.

From the eight globular echinates phytolith categories proposed by Morcote-Rios, five were present at the Monte Castelo shell mound. The Sinimbu phase was characterised by the presence of large globular echinates with dense short projections. As pointed out by Morcote-Rios (2016 p.355-356), globular echinates with short dense projections present limited taxonomic value outside the *Euterpeae* subtribe. Therefore, its presence on the mound could likely indicate the consumption of *açaí* fruits.

With some exceptions (Piperno, 2006), conical to hat-shaped and globular echinates do not co-occur (Tomlinson et al., 2011; Morcote-Rios et al., 2016). In addition, they are produced by the *Bactris* and *Astrocaryum* genera (Morcote-Rios et al., 2016). In the Bacabal phase, conical to hat shaped

phytoliths showed an overall increase in abundance in the layers and in the burial context. Also, a sharp increase in symmetrical echinates is observed in this phase. These have limited taxonomic distribution, displaying importance only in *Mauritia*, *Mauritiella*, *Euterpe*, *Oenocarpus*, *Ammandra* and *Attalea* taxa (Morcote-Ríos et al. 2016 p.356). Thus, with the increase in conical to hat-shaped bodies and symmetriccal globular echinates we can be confident that the shell mound inhabitants were gathering at least two distinct species of palm tree during this phase (*cf Euterpe* sp. and *Bactris* sp. or *Astrocaryum* sp.). However, to strengthen an argument of direct palm fruit consumption an analysis of pottery residue should be undertaken (Yang et al., 2012, Zarrillo et al., 2008).

Overall the most representative palm species in the state of Rondônia today are *açaí* (*Euterpe oleracea*), *buriti* (*Mauritia flexuosa*), peach palm (*Bactris gasipaes* and *B. dahlgreniana*) and tucumã (*Astrocaryum aculeatum*) (Rodrigues et al., 2007). Notably, these plants are all fruit species of economic importance today (Rodrigues et al., 2007) and are considered to be easy to manage (Anderson et al., 1995, Irvine, 1989).

Aside from palms, phytoliths belonging to soursop (*Annona* sp.) and from the seeds of hackberry (*Celtis* sp.) were also identified, with these present only in the Bacabal phase. It has already been suggested that soursop was probably domesticated to some extent (Clement, 1999). Furthermore, currently the only species of *Celtis* recorded for the state of Rondônia is *C. iguanaea* (Reflora, 2017). This species is known to produce edible fruits (Lorenzi, 1992). Thus, it is likely that the mound builders may have directly managed these trees. Consequently, as the Bacabal phase marks an abundance in the quantity of maize, squash and rice, the presence of palms, hackberry and soursop identified exclusively in this phase supports the notion that the Monte Castelo builders may also have engaged in plant management practices like agroforestry.

2. THE MIXED ECONOMY OF THE TUCUMÃ SHELL MOUND BUILDERS

The Tucumã shell mound is located in the county of Melgaço in the western part of the Marajó Archipelago in the state of Pará. The site consists of two major

layers. The first (Layer II), is mainly characterised by a 30-96cm below the surface shell mound structure (Schaan and Silva 2013) and the second (layer III) by a dark soil of approximately 10-30cm. The radiocarbon dates provided by this study placed the antiquity of the site at 4,425-4245 to 1,693-1,523 cal. yr. B.P., setting the mound at the same period as the Mina phase shell mounds (Simões, 1981).

Most of the archaeological investigations on the Marajó Archipelago were on the eastern portion (Schaan and Martins, 2010), and little is known about the pre-Columbian shell mound occupation of the western part (Schaan and Silva, 2013). This study has presented novel results regarding the possible horticulture practices of the shell mound builders of the western Marajó Archipelago. Most noticeably, the presence of squash and maize phytoliths at the beginning of the occupation indicates that these crops were grown in the region for at least 4,000 yr. B.P., showing that the mound builders were already engaged in incipient horticultural practices from the start of the occupation. Furthermore, these results are consistent with the assumption that horticulturist villages in the Marajó supposedly began between 3,833-3,721 and 3,212-3,164 cal. yr. B.P. (Schaan, 2004).

Layer II presented a broad diversity of fish and turtles. This layer is also characterized by the cultivation of maize and squash as these, together with palm fruits, could have provided an important dietary supplement as a source of carbohydrates. However, at layer III the absence of maize, decreased diversity of faunal remains and the overall increase in palm morphotypes could be indicative of a change in diet or a different approach to the management of the environment. Also, this later layer is associated with an increase in humid conditions (Hermanowski et al., 2012).

Fish will disperse into the flooded forests and savannas to feed when the waters rise in the rainy season and will move back into the deeper areas to pass the dry season (McGrath et al., 1993). In drier seasons, as the river level falls, fish will concentrate in progressively smaller bodies of water, exposing them to easier predation (McGrath, et al. 1993). However, the documented increase in wetter conditions in the late Holocene and the consequent decrease in land available could have played a part in the observed reduction in fish diversity, as these would be dispersed over a larger area. Furthermore, assuming that the mound builders were cultivating maize in the lowland regions,

the absence of its phytoliths in the archaeological record could also be associated with the weather conditions, as it could have limited the horticulture practices. On the other hand, an alternative interpretation could be that the probable Mina phase mound builders abandoned the site as the weather conditions hindered their fishing practices; the probable Ananatuba phase people later re-occupied the area and presented the change in plant and zoological records observed after layer II. Nevertheless, further investigations regarding the distribution of the pottery phases throughout the mound and careful analysis of the zooarchaeological remains should be included in future investigations to understand the patterns discussed here.

Despite the scarcity of studies on Amazonian shell mounds, this research has revealed noticeable results in that it has shown that the Tucumã mound builders were engaged in incipient horticulture methods. Furthermore, the presence of wild plant resources in the form of palms, soursop and hackberry phytoliths, identified in all archaeological layers of the mound, indicates that possible foraging practices were conducted while domesticate resources were planted. The results are undoubtedly a first attempt to understand the plant management by the shell mound occupations of the Marajó riverside areas.

2.1. The role of Squash and Maize on the Tucumã diet

Phytoliths from the cob of maize were recovered in all the excavated archaeological units of the Tucumã shell mound, but only in layer II. Additionally, discriminant functions have revealed the presence of leaf of maize in two of the four archaeological units (absent in TP-1 and TP-2) and, as with the cob phytoliths, these were identified only in layer II. As previously stated, phytoliths from the cob are produced in small quantities by the plant organs (Piperno, 2006). Therefore, its presence in a mound context is indicative that this crop was grown in the region from at least 4,425-4245 1,693-1,523 cal. yr. B.P. Additionally, as maize phytoliths were absent in all other layers except for layer II, this could indicate that the later occupation did not grow this cultigen. However, whether this represents an overall change in its consumption or a sampling bias could not be determined and would require future investigation.

Squash was the second major domesticated crop identified in the phytolith analysis of the Tucumã shell mound. Phytoliths from the rind of the

fruit were identified in all layers of all excavated units. Due to the amount of phytolith recovered throughout the occupation, we can be confident that this crop was also being grown in the region from at least 4,425-4245 cal. yr. B.P. onwards. Like the maize identifications, squash phytoliths were more abundant in layer II. Furthermore, measurements of the squash phytoliths revealed larger morphotypes in layer II. Thus, the phytolith records substantiate the argument that the shell mound occupation was probably engaged in a small-scale maize and squash cultivation model from 4,425-4245 1,693-1,523 cal. yr. B.P. It is worth noting that Layer I, while devoid of archaeological material, yielded squash phytoliths of large size. The presence of these phytoliths could be due to a sampling bias; alternatively or macropore channels (Fishkis et. all, 2010). However, given the size and amount of these phytoliths identified in the sterile layer, it is unlikely that all of them were the result of leaching. Therefore, it is possible that squash was growing in the region before the establishment of the Tucumã occupation at 4,425-4245 cal. yr. B.P. Thus, after the founding of the site, the mound builders would have managed this species, resulting in the increased quantity observed through the phytolith records.

While devoid of maize phytoliths, the occupation management strategies that followed could have consisted of a different cultivation system, in which the mound builders incorporated palm species and squash into their plant diet. However, other domesticated species could have filled the role of maize (e.g. manioc). In order to test which other cultigen was managed by the latter population of the Tucumã shell mound, a broader spectrum of archaeobotanical tools should be implemented.

2.2. Wild plant resources

Among the wild plant resources exploited by the Tucumã shell mound builders, palms were notably the most common. Phytolith records show a gradual increase in its quantity in the archaeological units, reaching its peak at Layer III. The number of palm morphotypes recovered is not unexpected, since palms have been among the most important plants used by Amazonian populations for over 10,000 years. (Morcote -Ríos and Bernal, 2001). Additionally, evidence suggests that palms constituted a significant part of Layer III of the Tucumã occupation, most notably by the presence of conical to hat-shaped bodies. As

this morphotype has little taxonomic value outside the *Bactris* and *Astrocaryum* genera (Morcote-Rios et al., 2016), it is likely that species from this genus, such as tucumã (*Astrocaryum aculeatum*) or peach-palm (*Bactris gasipaes*), were an important dietary component of the Tucumã population. Given that the Tucumã shell mound builders were already engaged in incipient agriculture the overall use of palms could also be related to construction materials, a source of fuel or medicines. It is of note that palm fruits contain more protein and carbohydrates than maize (Newman, 1990); thus, the gradual increase in palm phytoliths recovered throughout the Tucumã occupation and the resulting absence of maize in the latter layers could be due to a shift in management practices, which resulted in an increased importance of palm in dietary practices.

Other wild resources included phytoliths belonging to soursop and from the seeds of hackberry. Except for one individual phytolith of hackberry identified in the unit outside the shell mound, these morphotypes were exclusive to the archaeological units. Beside palms, these trees could also have been part of the foraging practices of the Tucumã occupants.

Interestingly, while morphotypes belonging to the stem and leaf of wild rice were present in all excavated units, seed phytoliths were restricted to the archaeological units. However, unlike the wild rice investigations of the Monte Castelo shell mound, the double-peaked glumes of the Tucumã site were present only in trace amounts and almost exclusively at the beginning of the occupation (one double-peaked glume was identified in layer III of TP-2). Additionally, measurement of these phytoliths revealed them to be more closely related to modern wild rice species than those from the upper layers of the Monte Castelo site. Nonetheless, given that wild rice has already been documented as being managed by Amazonian shell mound populations (Hilbert et al., 2017 in press), it is feasible that an initial investment in the gathering of this species was started by the Tucumã inhabitants but was promptly replaced by the cultivation of maize.

One possible economically useful herbaceous species could have been a member of the *Marantaceae* family. Species from this family are known to produce starch-rich roots (Stephens, 2006), such as in the case of arrowroot (*Maranta arundinacea*) and Iren (*Calathea allouia*). Additionally, its value ranges from dietary purposes to fibre resources (Erdman and Erdman, 1984) and potential medicinal applications (Chevallier, 1996). Regarding

archaeological studies, starch grains extracted from stone grinding tools have been effective in providing direct sources of evidence for root and tuber use (e.g. Barton et al., 1998, Fullagar et al., 2006, Perry, 2001, Piperno and Holst, 1998, Piperno et al., 2000b, Piperno et al., 2004). Furthermore, phytoliths from the rhizome of the genera *Calathea* and *Maranta* have been successfully identified in archaeological records (e.g. Chandler-Ezell et al., 2006). Also, the likely presence of *Calathea* phytoliths has been recovered from dental calculus analysis of burials from the Jabuticabeira II shell mound of southern Brazil (Boyadjian, 2012).

However, while consistently recovered throughout the Tucumã shell mound, the phytoliths related to the Marantaceae family could not, without some doubt, be positively associated with arrowroot or leren plants. Still, the presence of phytoliths related to the rhizome of this family was regularly and abundantly identified solely in the shell mound occupation. This consistency in the phytolith records could likely represent the fact that the Tucumã inhabitants were foraging or even managing a species of this family. However, a thorough investigation of the modern endemic species of Marataceae growing on the Marajó region should be undertaken to try to refine the phytolith morphotypes found in this study.

3. PHYTOLITH LIMITATIONS AND RECOMMENDATIONS FOR SHELL MOUND STUDIES

Phytoliths can provide researchers with significant information, especially in tropical regions where most macro plant remains are absent or poorly preserved (Piperno, 2006). However, in particular cases (e.g. palms and dicotyledon tree phytoliths), closely related taxa do produce similarly shaped phytolith morphotypes leading to broad taxonomic levels of identification (Ball et al., 2016). This restriction does provide limitations in investigations that require differentiations of taxa at genus/species level. Accordingly, morphometric analysis (measurements of size and shape) has grown in importance in phytolith studies (Ball et al., 2016, Vrydaghs et al., 2009). For this thesis, valuable results were given by the measurement of *Oryza* sp. seed phytoliths (Hilbert et al., 2017 in press). Still, a broad number of economically relevant

dicotyledon arboreal species are still elusive in phytolith records and could provide relevant results if thorough morphometric examinations were applied to them.

Also, as is the case for phytolith representation of domesticates, semi-domesticated and wild resources, various species are either exceedingly limited, absent or unidentifiable in the phytolith record. For example, peanuts and chilli peppers do not produce diagnostic phytoliths but were most certainly exploited in the past. An example of a rare morphotype is manioc, arguably one of the most important root crops of the Amazonian lowlands, which is known to produce diagnostic phytoliths only in its secretory bodies (Chandler-Ezell et al. 2006), making its presence on archaeological sites relatively limited. Thus, if the shell mound builders were cultivating manioc, it would require for this specific part of the plant to be deposited in the site. On the other hand, palm phytoliths are by far the most common wild resource in the phytolith records of this research, constituting a significant part of the assemblage for both sites. Though palms are amongst the most important plants used by humans in the Amazon (Morcote-Ríos and Bernal, 2001), phytolith analysis alone cannot point out which specific species are present in the archaeological record. While recent efforts on palm phytolith investigations have managed to lessen the gap in its taxonomic resolution (e.g. Morcote-Ríos et al., 2016), further research is needed to use palm phytoliths as a solid tool for designating species.

In addition to morphometric investigations, DNA analysis of the organic matter locked inside phytoliths (Kistler, 2012) could elucidate questions regarding what species are represented in the archaeological record. However, as with the morphometric analysis, a thorough investigation of the wild plants native to the study area should be undertaken to produce reliable results. In general, although phytolith studies are on their way to becoming an extraordinary tool for archaeological investigations, their use is still limited by whether or not the plant produces this type of structure. Accordingly, other archaeobotanical methods, such as the analysis of pollen and starch grains, provide counterparts to the phytolith limitations. Even though phytolith investigations do grant remarkable results, they are not free from identification and methodological biases.

For shell mound studies, where plant macro remains are scarce, a combination of microbotanical studies on soil, pottery and, if applicable, human

remains would expose a wide array of plant types. For instance, investigation into starch grains and phytoliths in pottery could reveal both dietary preferences and, together with the pottery examination, whether the plants were consumed as a solid or a liquid. Furthermore, starch grains analysis of stone grinding tools could determine the processing methods of certain plants. Additionally, if paleolakes are present in the proximity of the shell mound, pollen analysis of the lake's core could complement the phytolith results by validating that crops such as maize were planted in the region, or even confirming the presence of manioc in the area.

Additionally, the combination of anthracological and microbotanical tools might bring a better taxonomic resolution of the plant species consumed by the shell mound groups. For example, charred palm seeds have been commonly observed in southern and southeastern shell mounds (Heredia and Beltrao, 1980; Carvalho, 1984; Kneip & Pallestrini, 1987). The study of palm macroremains would most likely help to improve the taxonomic classification of these species when in conjunction to phytolith studies. Furthermore, anthracological investigations in the south and southeastern Brazilian shell mounds have revealed that the mound builders explored several environments, from grasslands to forested areas (Scheel-Ybert 2000, 2001, Scheel-Ybert et al. 2009, 2010; Bianchini et al. 2011). The study of charred remains combined to phytolith analysis might refine our understanding on what species were exploited and in which particular environment.

Clearly, a multi-proxy approach is the optimal way to produce strong, reliable results. However, choosing what methods to use on a given archaeological site should always be directly related to the specific research question, as each method would require different techniques for recovering samples in the field.

CONCLUSION

The phytolith studies implemented for this thesis have provided promising results in answering questions regarding plant management by the Monte Castelo and Tucumã shell mound builders. While plant gathering by shell mound societies has always been recognised (Scheel-Ybert et al., 2010), it has tended to be seen as a secondary activity. As recent studies from several areas indicate that in addition to an economy essentially based on fishing and the exploitation of aquatic resources, plant food had a greater importance than previously assumed (Scheel-Ybert, 2001, Scheel-Ybert, 2013). Studies in the areas of anthracology and bioanthropological analyses suggest that tubers of some species of *Dioscorea* could represent part of an incipient agriculture by the shell mound builders (Scheel-Ybert, 2003). However, investigations regarding the cultivation and the consumption of plants by these groups remain, to date, poorly understood.

The results of this thesis have revealed the presence of phytoliths from known cultigens, such as the wavy-top rondels of maize and scalloped spheres from squash, in the strata analysed, has shown that both crops were commonly grown in both regions from at least 4,000 yr. B.P. onwards. Also, in addition to these cultigens, wild resources in the form of palms, hackberry, soursop and wild rice were likely a part of the plant mixed economy management practices of these populations.

Adoption of maize by shell-mound societies in lowland Amazonia

The research conducted during this thesis provides novel results in regards to the presence of maize in Amazonian shell mounds. Initially, the phytolith records for the Monte Castelo site show that maize was grown and increased in abundance throughout time. The dates in which phytoliths were identified are as early as 5,416-5,060 cal. yr. B.P., making this finding the first of its kind for lowland Amazonian shell-mound studies. Furthermore, while excavations on the Monte Castelo site did not reach the beginning of the Sinimbú occupation, it is

likely that future analysis of this site will reveal dates similar to the ones published by Brugger et al. (2016) in the Bolivian lowlands, probably reaching about 7,434-7,421 cal. yr. B.P. Other maize recorded in shell mounds stemmed from the SE Brazil and presented radiocarbon dates of 1,377-1,262 cal. yr. B.P. (Wesolowski et al. 2007) and ca. 2,900 yr. B.P. (boyadin). Thus, to date, the Monte Castelo maize findings probably represent the earliest records for the South American shell mounds.

Next, this study also revealed that the Tucumã shell mound people were already cultivating maize since the start of the occupation. This finding is, to date, unprecedented for archaeological investigations on the Marajó Archipelago, showing that maize was planted as early as 4,425-4245 cal. yr. B.P in a region in which its early presence was only conjectured (Brochado, 1980) or inferred (Roosevelt and Housley, 1991). A detailed study of the ceramic identified on this site would most likely show which phase is related to this early maize record. Additionally, further studies on Marajó shell mounds could show the level of representation that maize might have had for these populations and if it was intensively cultivated or only an “accessory crop” (Roosevelt 1991 p.377)

Adoption of squash by shell-mound societies in lowland Amazonia

The findings of this study reveal the presence of scalloped sphere phytoliths from the rind of squash in all analysed strata from both sites. Due to the quantity and size of the phytoliths recovered the results show that domesticated squash was being grown by the Monte Castelo and Tucumã shell mound builders as early as 5,416-5,060 and 4,425-4245 cal. yr. B.P. respectively.

Domesticated squash phytoliths were already identified in cerritos from Southeastern Uruguay since 4,516-4,425 cal. yr. B.P. (Iriarte et al. 2004). For Brazilian shell mounds, Squash macroremains were retrieved from the Jabuticabeira-II shell mound in South Brazil dating at circa 3,200 yr. B.P. (Bianchini, 2008).

Similar to the maize results of this thesis, the findings of this study has provided with novel evidence regarding the presence of domesticated squash in the Marajó Archipelago at circa 4,425-4245 cal. yr. B.P. Interestingly a general decline in the phytoliths of this cultigen in the upper layers is discernible. This reduction could suggest a comparatively lower value of squash in the diet of the

mound builders as they switched to the management of other plant species. However, for this site, we believe that a multi-proxy approach would most likely clarify the documented shift in plant management.

Scalloped sphere phytoliths were also regularly identified in the Monte Castelo shell mound. The quantity and size of these phytoliths revealed that domesticated squash, alongside maize, was already part of their plant mixed economies since 5,416-5,060 cal. yr. B.P. While the presence of squash was already documented for SE Brazilian shell mounds (Bianchini, 2008), its early presence in the lowland Amazon is still unprecedented. Unlike the Tucumã mound, the amount of phytoliths recovered for the Monte Castelo mound only increased throughout time. The different plant priorities adopted by these two Amazonian freshwater shell mounds could reflect the selective histories involved in their formation processes.

The domestication of wild rice

The analysis of double-peaked glumes indicates that the shell mound builders began to systematically select larger rice seeds when they were already engaged in the cultivation of maize and squash. This practice likely led to the domestication process of wild rice (Hilbert et al., 2017 in press). Despite the fact that ethnographic and historical accounts have continuously reported the use of wild-rice by the native population, until now, the consumption of wild rice and its importance in the pre-Columbian subsistence system have not yet been explored in lowland Amazonia. The data presented in Hilbert et al. (2017 in press) provides the first evidence of its domestication for the South American continent. Furthermore, to our knowledge, these findings also present the first evidence that shell mound builder domesticated plants in the Americas, and, in addition to maize and *Zizania* sp., the third grass species to be domesticated in the whole continent.

Most notably, this event took place in a region that was also probably the cradle of domestication for manioc, peanuts and chilli peppers (Piperno, 2011) pointing to the importance of the wetland regions of South America in understanding plant domestication. In addition to phytolith research, a genetic study on Amazonian wild rice could surely expand the understanding of the glume phytolith formation. Furthermore, understanding the manipulation of rice by the Monte Castelo shell mound builders, and the role of South American wild

rice varieties in competition with apple snails, could help provide more resistant high yielding breeders. Most notably, future investigations could also highlight the potential role of plants on shell mound builders and their cultivation practices.

Overall, a multi-proxy analysis could reveal the extent of horticulture practices across the shell mound region, as well as the amount of effort required to maintain these home gardens, and the relative contribution of each domesticated resource to the everyday diet. In conclusion, the results of this thesis highlight the spatial variability of cultivated plants as well as the importance of applying phytolith measurement techniques to the study of shell mounds, as a tool to answer questions regarding plant management.

APPENDIX 1:
Earliest plant remains of South and Central America*

*table curtesy of Jose iriarte, for full references see Denham (2011).

Plant taxa	Common name	Radicarbon dates B.P.	Site	Region	Reference
Central America					
<i>L. siceraria</i>	bottle gourd	9,000 (AMS)	Guila Naquitz	Oaxaca	Smith In press
<i>C. pepo</i>	squash	8,910-8,990 (AMS)	Guila Naquitz	Oaxaca	Smith 1997a:933
<i>Dioscorea</i> sp.	yams	7,000-5,000	Aguadulce	Central Pacific Panama	Piperno <i>et al.</i> 2000
<i>Manihot esculenta</i>	manioc	7,000-5,000	Aguadulce	Central Pacific Panama	Piperno <i>et al.</i> 2000
<i>Maranta arundinacea</i>	arrowroot	7,000-5,000	Aguadulce	Central Pacific Panama	Piperno <i>et al.</i> 2000
<i>Zea mays</i>	maize	7,000-5,000	Aguadulce	Central Pacific Panama	Piperno <i>et al.</i> 2000; Dickau 2005
<i>Zea mays</i>	maize	6,200	San Andrés	Tabasco	Pope <i>et al.</i> 2001:1372
<i>Zea mays</i>	maize	4,760	Lake Martínez	Guanacaste, Costa Rica	Arford&Horn 2004
<i>Zea mays</i>	maize	5,420	Guila Naquitz	Oaxaca	Piperno&Flannery 2001
<i>C. argyrosperma</i>	squash	4,450 (AMS)	Tamaulipas	Ocampo	Smith 1997b:373
<i>C. moschata</i>	squash	2,620 (AMS)	Tamaulipas	Ocampo	Smith 2005: 373
<i>C. moschata</i>	squash	8,000-7000	Aguadulce	Central Pacific Panama	Piperno 2005
<i>Helianthus annuus</i>	sunflower	4,130 (AMS)	San Andrés	Tabasco	Lentz <i>et al.</i> 2001
<i>Gossypium</i> sp.	cotton	4,000	San Andrés	Tabasco	Pope <i>et al.</i> 2001: 1372
<i>Phaseolus vulgaris</i>	common beans	2,285	Coxcatlán	Tehuacan	Kaplan & Lynch 1999
<i>Zea mays</i>	maize	9,688	Central Balsas	Mexico	Piperno <i>et al.</i> , 2009, Ranere <i>et al.</i> , 2009)
Agricultural practices					
Slash and burn		7,000	La Yeguada	Central Pacific Panama	Piperno&Pearsall 1998
Intensive wetland agriculture		3,500	Cobweb swamp	Belize	Pohl <i>et al.</i> 1996
Colombia, Ecuador, and NW Peru					
<i>Acrocomia</i> sp.	corozo palm	10,050-9,539	San Isidro	Upper Cauca valley	Piperno&Pearsall 1998: 199-203
<i>Maranta</i> sp.	arrowroot	10,050-9,539	San Isidro	Upper Cauca valley	Piperno&Pearsall 1998: 199-203
<i>C. ecuadorensis</i>	squash	9,320-10,130 (AMS)	Vegas	Southwestern Ecuador	Piperno and Stothert 2003:1055
<i>Calathea alluioia</i>	leren	9,320 (AMS)	Vegas	Southwestern Ecuador	Piperno and Stothert 2003:1055
<i>Lagenaria siceraria</i>	bottle gourd	9,320 (AMS)	Vegas	Southwestern Ecuador	Piperno and Stothert 2003:1055
<i>Zea mays</i>	maize	7,000-6,700	Las Vegas	Southwestern Ecuador	Piperno&Pearsall 1998:187
<i>Zea mays</i>	maize	5,300	Lake Ayacuchi	Ecuadorian Amazonia	Bush <i>et al.</i> 1989
<i>Cucurbita</i> spp.	squash	9,160	Peña Roja	Upper Caqueta valley	Piperno&Pearsall 1998: 203-206
<i>Manihot esculenta</i>	manioc	7,500	Middle Cauca and Porce valleys	Colombia	Aceituno & Castillo 2005
<i>Arachis hypogaea</i>	peanut	9,535	Zaña Valley	Peru	Dillehay <i>et al.</i> , 2007
<i>Canavalia plagioperma</i>	jack beans	5,500	Real Alto	Southwestern Ecuador	Pearsall <i>et al.</i> 2004
<i>Canna edulis</i>	achira	5,500	Real Alto	Southwestern Ecuador	Pearsall <i>et al.</i> 2004
<i>Calathea alluioia</i>	leren	9,160	Peña Roja	Middle Caquetá valley	Piperno&Pearsall 1998: 203-206
<i>Lagenaria siceraria</i>	bottle gourd	9,160	Peña Roja	Middle Caquetá valley	Piperno&Pearsall 1998: 203-206

<i>Oenocarpus</i> sp.	bataua	9,160	Peña Roja	Middle Caquetá valley	Piperno&Pearsall 1998: 203-206
Agricultural practices					
Slash and burn		5,300	Ayauchi	Ecuadorian Amazonia	Bush <i>et al.</i> 1989
Irrigation canals		6,500-5,500	Zaña valley	NW Peru	Dillehay <i>et al.</i> 2005
Brazil, Bolivia, and southern South America					
<i>Dioscorea</i> sp.	yams	5,500-1,400	Sambaqui do Forte	Southern Brazil	Scheel 2001
<i>Zea mays</i>	maize	4,000	Los Ajos	SE Uruguay	Iriarte <i>et al.</i> 2004
<i>Cucurbita</i> spp.	squashes	4,000	Los Ajos	SE Uruguay	Iriarte <i>et al.</i> 2004
<i>Zea mays</i>	maize	3,350	Lake Geral	Eastern Amazonia	Bush <i>et al.</i> 2000
<i>Zea mays</i>	maize	3,000	Santana do Riacho	Central Brazil	Prous 1999
<i>Zea mays</i>	maize	6,500	llanos de mojos	Bolivia	Brugger <i>et al.</i> , 2016
<i>Zea mays</i>	maize	5,310	Monte Castelo	Rondonia	Hilbert <i>et al.</i> , 2017
<i>Cucurbita</i> spp.	squashes	5,310	Monte Castelo	Rondonia	Hilbert <i>et al.</i> , 2017
<i>Zea mays</i>	maize	4,425	Tucumã	Marajo	Hilbert, 2017
<i>Cucurbita</i> spp.	squashes	4,425	Tucumã	Marajo	Hilbert, 2017
Agricultural practices					
<i>Terra Preta</i>	<i>Terra Preta</i>	2,500-2,000	Açatuba	Central Amazon	Neves <i>et al.</i> 2003
Slash and burn	Slash and burn	5,500	Lake Geral	Eastern Amazonia	Bush <i>et al.</i> 2000
<i>Terra Preta</i>	<i>Terra Preta</i>	4,780	Porto Velho	Upper Madeira River	Miller 1992
Raised-fields	Raised-fields	2,000	Llanos de Mojos	Eastern Bolivia	Erickson 1995, Walker 2004
Coastal Peru					
<i>Phaseolus lunatus</i>	lima beans	6,920	Chilca	Chilca valley	Kaplan and Lynch 1999
<i>C. ficifolia</i>	squash	5,000	Paloma	Chilca valley	(Piperno 2005)
<i>C. moschata</i>	squash	4,500	Ventanilla	Chillon valley	Piperno 2005
<i>Ipomea batatas</i>	sweet potato	4,250	Huaynuma	Casma valley	Ugent <i>et al.</i> 1984
<i>Canna edulis</i>	achira	4,250	Huaynuma	Casma valley	Ugent <i>et al.</i> 1984
<i>Solanum tuberosum</i>	potato	4,250	Huaynuma	Casma valley	Ugent <i>et al.</i> 1984
<i>C. maxima</i>	squash	4,250	Huaynuma	Casma valley	Ugent <i>et al.</i> 1984
<i>Zea mays</i>	corn	4,100	Los Gavilanes	Huarmey valley	Bonavia 1982
<i>Ullucus tuberosus</i>	ulluco	4,000-3,350	Late Preceramic sites	Ancón-Chillón valley	Martins-Farias 1976
<i>Manihot esculenta</i>	manioc	3,800		Casma valley	Ugent <i>et al.</i> 1981
<i>Pachyrrhizus</i> sp.	yam beans	3,750	Los Gavilanes	Huarmey valley	Grobman and Bonavia 1978

**APPENDIX 2:
PHYTOLITH RAW DATA**

APPENDIX 2:

Morphotype	Taxa	MC	MC	MC	MC	MC	MC	MC	MC	MC	MC	MC
		30-40cm Layer A	50-60cm Layer B	70-80cm Layer C	90-100cm Layer D	130cm Layer D	130-140cm Layer D	140cm Layer D/E	140-150cm Layer E	200-210cm Layer F	220-230cm Layer G	260-270cm Layer H
Cross variant 1, 5/6	N.D.Poaceae	4 1.01%	4 1.07%	7 1.90%	4 1.12%	4 1.21%	3 0.81%	9 2.60%	5 1.26%	3 0.95%	4 1.17%	5 1.49%
Bulliform	N.D.Poaceae	3 0.76%	9 2.40%	8 2.17%	9 2.52%	14 4.24%	4 1.08%	3 0.87%	8 2.02%	8 2.53%	10 2.92%	17 5.06%
Rondel	N.D.Poaceae	1 0.25%	6 1.60%	13 3.52%	2 0.56%	1 0.30%	5 1.35%	0 0.00%	1 0.25%	2 0.63%	1 0.29%	8 2.38%
Billobate	Panicoideae	5 1.26%	4 1.07%	7 1.90%	9 2.52%	21 6.36%	18 4.86%	9 2.60%	12 3.03%	17 5.38%	14 4.09%	17 5.06%
Polylobate	Panicoideae	2 0.51%	0 0.00%	1 0.27%	2 0.56%	0 0.00%	1 0.27%	0 0.00%	0 0.00%	0 0.00%	0 0.00%	0 0.00%
Long thin-shaft billobate	Aristidoideae	3 0.76%	0 0.00%	2 0.54%	1 0.28%	2 0.61%	1 0.27%	0 0.00%	2 0.51%	3 0.95%	0 0.00%	3 0.89%
Cross variant 3	Bambusoideae	3 0.76%	2 0.53%	1 0.27%	1 0.28%	2 0.61%	3 0.81%	4 1.16%	2 0.51%	4 1.27%	5 1.46%	3 0.89%
Spiney rondell	Bambusoideae	1 0.25%	7 1.87%	8 2.17%	18 5.04%	11 3.33%	9 2.43%	9 2.60%	15 3.79%	6 1.90%	7 2.05%	15 4.46%
Tall saddle	Bambusoideae	2 0.51%	8 2.13%	1 0.27%	1 0.28%	5 1.52%	4 1.08%	2 0.58%	2 0.51%	5 1.58%	7 2.05%	5 1.49%
Collapsed saddle	Bambusoideae	2 0.51%	1 0.27%	3 0.81%	1 0.28%	2 0.61%	3 0.81%	0 0.00%	2 0.51%	5 1.58%	0 0.00%	5 1.49%
Flared bulliform	Bambusoideae	1 0.25%	1 0.27%	1 0.27%	1 0.28%	0 0.00%	2 0.54%	0 0.00%	1 0.25%	4 1.27%	0 0.00%	2 0.60%
Short saddle	Chloridoideae	21 5.30%	2 0.53%	1 0.27%	1 0.28%	12 3.64%	5 1.35%	9 2.60%	7 1.77%	2 0.63%	4 1.17%	2 0.60%
Keystone bulliform	Oryzeae	12 3.03%	7 1.87%	9 2.44%	13 3.64%	11 3.33%	7 1.89%	18 5.20%	9 2.27%	5 1.58%	17 4.97%	9 2.68%
Scooped billobate	Oryzeae	3 0.76%	2 0.53%	2 0.54%	2 0.56%	1 0.30%	7 1.89%	4 1.16%	6 1.52%	0 0.00%	2 0.58%	4 1.19%
Serrated Bodie	Oryza sp.	9 2.27%	4 1.07%	9 2.44%	5 1.40%	5 1.52%	4 1.08%	3 0.87%	5 1.26%	2 0.63%	2 0.58%	6 1.79%
Double-peaked glume	Oryza sp.	64 16.16%	70 18.67%	71 19.24%	36 10.08%	31 9.39%	35 9.46%	7 2.02%	22 5.56%	23 7.28%	14 4.09%	15 4.46%
Wavy-top rondel	Zea mays	2 0.51%	1 0.27%	3 0.81%	2 0.56%	1 0.30%	0 0.00%	0 0.00%	1 0.25%	1 0.32%	0 0.00%	2 0.60%
Total grasses	-	138 34.85%	128 34.13%	147 39.84%	108 30.25%	123 37.27%	111 30.00%	77 22.25%	100 25.25%	90 28.48%	87 25.44%	118 35.12%

APPENDIX 2:

Morphotype	Taxa	MC 30-40cm Layer A	MC 50-60cm Layer B	MC 70-80cm Layer C	MC 90-100cm Layer D	MC 130cm Layer D	MC 130-140cm Layer D	MC 140cm Layer D/E	MC 140-150cm Layer E	MC 200-210cm Layer F	MC 220-230cm Layer G	MC 260-270cm Layer H
Leaf conical body	Cyperaceae	0 0.00%	1 0.27%	4 1.08%	7 1.96%	2 0.61%	1 0.27%	0 0.00%	0 0.00%	2 0.63%	2 0.58%	0 0.00%
Polygonal body	Cyperaceae	4 1.01%	8 2.13%	29 7.86%	31 8.68%	34 10.30%	47 12.70%	28 8.09%	27 6.82%	39 12.34%	79 23.10%	56 16.67%
Nodular globular	Marantaceae	16 4.04%	11 2.93%	22 5.96%	29 8.12%	33 10.00%	29 7.84%	38 10.98%	58 14.65%	38 12.03%	35 10.23%	27 8.04%
Seed conical body	Marantaceae	4 1.01%	5 1.33%	5 1.36%	2 0.56%	4 1.21%	3 0.81%	3 0.87%	5 1.26%	2 0.63%	0 0.00%	4 1.19%
Troughs body	Heliconiaceae	3 0.76%	2 0.53%	3 0.81%	3 0.84%	1 0.30%	3 0.81%	1 0.29%	2 0.51%	3 0.95%	0 0.00%	0 0.00%
Opaque perforated body	Asteraceae	36 9.09%	10 2.67%	4 1.08%	0 0.00%	0 0.00%	0 0.00%	2 0.58%	3 0.76%	7 2.22%	2 0.58%	1 0.30%
Total Herbs	-	63 15.91%	37 9.87%	67 18.16%	72 20.17%	74 22.42%	83 22.43%	72 20.81%	95 23.99%	91 28.80%	118 34.50%	88 26.19%
Stippled polygonal body	Burceraceae	2 0.51%	0 0.00%	0 0.00%	1 0.28%	1 0.30%	1 0.27%	0 0.00%	0 0.00%	0 0.00%	0 0.00%	8 0.00%
Globular echinate	Arecaceae	61 15.40%	82 21.87%	62 16.80%	72 20.17%	34 10.30%	43 11.62%	39 11.27%	22 5.56%	26 8.23%	20 5.85%	42 12.50%
Conical to hat- shape	Arecaceae	11 2.78%	13 3.47%	6 1.63%	6 1.68%	13 3.94%	12 3.24%	11 3.18%	3 0.76%	4 1.27%	3 0.88%	6 1.79%
Globular facetete	Annonaceae	2 3.79%	2 0.53%	3 0.81%	2 0.56%	2 0.61%	0 0.00%	0 0.00%	0 0.00%	0 0.00%	0 0.00%	0 0.00%
Stippled plate	<i>Celtis</i> sp.	15 3.79%	17 4.53%	6 1.63%	3 0.84%	0 0.00%	2 0.54%	1 0.29%	1 0.25%	2 0.63%	3 0.88%	0 0.00%
Tracheid/Sclereid	N.D. Arboreal	29 7.32%	10 2.67%	24 6.50%	14 3.92%	31 9.39%	18 4.86%	39 11.27%	69 17.42%	20 6.33%	16 4.68%	34 10.12%
Globular granulate	N.D. Arboreal	57 14.39%	71 18.93%	41 11.11%	51 14.29%	46 13.94%	89 24.05%	97 28.03%	100 25.25%	68 21.52%	91 26.61%	42 12.50%
Total Arboreal	-	177 44.70%	195 52.00%	142 38.48%	149 41.74%	127 38.48%	165 44.59%	187 54.05%	195 49.24%	120 37.97%	133 38.89%	124 36.90%
Scalloped sphere	<i>Cucurbita</i> sp.	15 3.79%	12 3.20%	11 2.98%	27 7.56%	4 1.21%	8 2.16%	9 2.60%	4 1.01%	13 4.11%	4 1.17%	6 1.79%
Bowl-shaped body	<i>Trichomanes</i> sp.	3 0.76%	3 0.80%	2 0.54%	1 0.28%	2 0.61%	3 0.81%	1 0.29%	2 0.51%	2 0.63%	0 0.00%	0 0.00%

APPENDIX 2:

Morphotype	Taxa	MC 350-360cm Layer I	MC 390-400cm Layer J	MC 400-410cm Layer J	MC 420-430cm Layer J	MC 450-460cm Layer J
Cross variant 1, 5/6	N.D.Poaceae	6 1.94%	5 1.66%	5 1.64%	4 1.33%	8 2.62%
Bulliform	N.D.Poaceae	20 6.45%	17 5.63%	21 6.91%	12 4.00%	20 6.56%
Rondel	N.D.Poaceae	1 0.32%	1 0.33%	4 1.32%	0 0.00%	6 1.97%
Billobate	Panicoideae	22 7.10%	59 19.54%	47 15.46%	49 16.33%	32 10.49%
Polylobate	Panicoideae	0 0.00%	5 1.66%	0 0.00%	4 1.33%	1 0.33%
Long thin-shaft billobate	Aristidoideae	1 0.32%	0 0.00%	2 0.66%	2 0.67%	1 0.33%
Cross variant 3	Bambusoideae	1 0.32%	1 0.33%	4 1.32%	2 0.67%	2 0.66%
Spiney rondell	Bambusoideae	18 5.81%	7 2.32%	12 3.95%	4 1.33%	4 1.31%
Tall saddle	Bambusoideae	1 0.32%	3 0.99%	6 1.97%	1 0.33%	10 3.28%
Collapsed saddle	Bambusoideae	1 0.32%	4 1.32%	5 1.64%	1 0.33%	5 1.64%
Flared bulliform	Bambusoideae	0 0.00%	2 0.66%	6 1.97%	0 0.00%	5 1.64%
Short saddle	Chloridoideae	1 0.32%	8 2.65%	2 0.66%	3 1.00%	1 0.33%
Keystone bulliform	Oryzeae	3 0.97%	4 1.32%	2 0.66%	7 2.33%	10 3.28%
Scooped billobate	Oryzeae	4 1.29%	5 1.66%	4 1.32%	2 0.67%	2 0.66%
Serrated Bodie	Oryza sp.	1 0.32%	2 0.66%	0 0.00%	2 0.67%	1 0.33%
Double-peaked glume	Oryza sp.	9 2.90%	13 4.30%	5 1.64%	12 4.00%	10 3.28%
Wavy-top rondel	Zea mays	1 0.32%	1 0.33%	1 0.33%	0 0.00%	2 0.66%
Total grasses	-	90 29.03%	137 45.36%	126 41.45%	105 35.00%	120 39.34%

APPENDIX 2:

Morphotype	Taxa	MC	MC	MC	MC	MC
		350-360cm Layer I	390-400cm Layer J	400-410cm Layer J	420-430cm Layer J	450-460cm Layer J
Leaf conical body	Cyperaceae	0 0.00%	0 0.00%	0 0.00%	2 0.67%	2 0.66%
Polygonal body	Cyperaceae	49 15.81%	50 16.56%	44 14.47%	42 14.00%	29 9.51%
Nodular globular	Marantaceae	27 8.71%	22 7.28%	21 6.91%	21 7.00%	31 10.16%
Seed conical body	Marantaceae	5 1.61%	1 0.33%	0 0.00%	3 1.00%	2 0.66%
Troughs body	Heliconiaceae	0 0.00%	3 0.99%	3 0.99%	3 1.00%	2 0.66%
Opaque perforated body	Asteraceae	1 0.32%	0 0.00%	2 0.66%	0 0.00%	0 0.00%
Total Herbs	-	82 26.45%	76 25.17%	70 23.03%	71 23.67%	66 21.64%
Stippled polygonal body	Burceraceae	0 0.00%	0 0.00%	0 0.00%	0 0.00%	0 0.00%
Globular echinate	Arecaceae	70 22.58%	17 5.63%	32 10.53%	49 16.33%	49 16.07%
Conical to hat-shape	Arecaceae	4 1.29%	2 0.66%	3 0.99%	4 1.33%	7 2.30%
Globular facetete	Annonaceae	0 0.00%	0 0.00%	0 0.00%	0 0.00%	0 0.00%
Stippled plate	<i>Celtis</i> sp.	0 0.00%	0 0.00%	0 0.00%	0 0.00%	0 0.00%
Tracheid/Sclereid	N.D. Arboreal	10 3.23%	21 6.95%	12 3.95%	20 6.67%	13 4.26%
Globular granulate	N.D. Arboreal	51 16.45%	47 15.56%	56 18.42%	48 16.00%	47 15.41%
Total Arboreal	-	135 43.55%	87 28.81%	103 33.88%	121 40.33%	116 38.03%
Scalloped sphere	<i>Cucurbita</i> sp.	3 0.97%	2 0.66%	2 0.66%	3 1.00%	3 0.98%
Bowl-shaped body	<i>Trichomanes</i> sp.	0 0.00%	0 0.00%	3 0.99%	0 0.00%	0 0.00%

APPENDIX 2:

Morphotype	Taxa	0-10 cm Ex4	10-20 cm Ex4	20-30 cm Ex4	30-40 cm Ex4	40-50 cm Ex4	50-60 cm Ex4	60-70 cm Ex4	70-80 cm Ex4	80-90 cm Ex4
Cross variant 1, 5/6	N.D.Poaceae	1	1	2	8	5	4	3	4	0
		0.30%	0.35%	0.70%	2.99%	1.92%	1.32%	0.99%	1.37%	0.00%
Bulliform	N.D.Poaceae	18	8	14	16	25	21	19	9	2
		6.06%	2.84%	4.91%	5.97%	9.62%	6.93%	6.25%	3.09%	0.75%
Rondel	N.D.Poaceae	22	31	21	5	9	8	3	6	12
		7.40%	10.96%	7.37%	1.87%	3.46%	2.64%	0.99%	2.06%	4.51%
Billobate	Panicoideae	1	3	1	6	12	4	11	7	4
		0.30%	1.05%	0.35%	2.24%	4.62%	1.32%	3.62%	2.41%	1.50%
Polylobate	Panicoideae	0	0	1	2	1	0	0	0	0
		0.00%	0.00%	0.35%	0.75%	0.38%	0.00%	0.00%	0.00%	0.00%
Long thin-shaft billobate	Aristidoideae	1	0	2	2	0	0	0	0	0
		0.30%	0.00%	0.70%	0.75%	0.00%	0.00%	0.00%	0.00%	0.00%
Cross variant 3	Bambusoideae	0	0	1	2	1	0	1	2	0
		0.00%	0.00%	0.35%	0.75%	0.38%	0.00%	0.33%	0.69%	0.00%
Spiney rondell	Bambusoideae	1	0	3	4	5	2	6	6	0
		0.30%	0.00%	1.05%	1.49%	1.92%	0.66%	1.97%	2.06%	0.00%
Tall saddle	Bambusoideae	0	0	1	2	1	0	0	2	0
		0.00%	0.00%	0.35%	0.75%	0.38%	0.00%	0.00%	0.69%	0.00%
Collapsed saddle	Bambusoideae	0	0	1	2	1	0	0	1	0
		0.00%	0.00%	0.35%	0.75%	0.38%	0.00%	0.00%	0.34%	0.00%
Flared bulliform	Bambusoideae	0	4	3	0	2	3	0	1	6
		0.00%	1.40%	1.05%	0.00%	0.77%	0.99%	0.00%	0.34%	2.26%
Short saddle	Chloridoideae	0	0	0	0	0	0	0	0	2
		0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.75%
Keystone bulliform	Oryzeae	0	4	4	2	0	4	0	1	1
		0.00%	1.40%	1.40%	0.75%	0.00%	1.32%	0.00%	0.34%	0.38%
Scooped billobate	Oryzeae	0	0	0	0	0	0	0	1	0
		0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.34%	0.00%
Serrated Bodie	Oryza sp.	0	0	0	0	0	0	0	0	0
		0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Double-peaked glume	Oryza sp.	0	0	0	0	0	0	0	0	0
		0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Wavy-top rondel	Zea mays	0	0	0	1	0	0	0	1	0
		0.00%	0.00%	0.00%	0.37%	0.00%	0.00%	0.00%	0.34%	0.00%
Total grasses	-	44	51	54	52	62	46	43	41	27
		14.66%	18.00%	18.95%	19.40%	23.85%	15.18%	14.14%	14.09%	10.15%

APPENDIX 2:

Morphotype	Taxa	0-10 cm Ex4	10-20 cm Ex4	20-30 cm Ex4	30-40 cm Ex4	40-50 cm Ex4	50-60 cm Ex4	60-70 cm Ex4	70-80 cm Ex4	80-90 cm Ex4
Leaf conical body	Cyperaceae	0	0	0	0	1	0	0	1	0
		0.00%	0.00%	0.00%	0.00%	0.38%	0.00%	0.00%	0.34%	0.00%
Polygonal body	Cyperaceae	11	5	4	2	6	2	4	3	4
		3.80%	1.75%	1.40%	0.75%	2.31%	0.66%	1.32%	1.03%	1.50%
Nodular globular	Marantaceae	17	19	29	23	24	31	19	27	15
		5.84%	6.65%	10.18%	8.58%	9.23%	10.23%	6.25%	9.28%	5.64%
Seed conical body	Marantaceae	0	3	7	4	1	3	3	3	0
		0.00%	1.05%	2.46%	1.49%	0.38%	0.99%	0.99%	1.03%	0.00%
Troughs body	Heliconiaceae	0	0	2	0	1	0	0	2	0
		0.00%	0.00%	0.70%	0.00%	0.38%	0.00%	0.00%	0.69%	0.00%
Opaque perforated body	Asteraceae	58	51	55	31	23	10	19	16	5
		19.55%	18.30%	19.30%	11.57%	8.85%	3.30%	6.25%	5.50%	1.88%
Total Herbs	-	86	78	97	60	56	46	45	52	24
		29.19%	27.75%	34.04%	22.39%	21.54%	15.18%	14.80%	17.87%	9.02%
Stippled polygonal body	Burceraceae	0	0	0	0	0	0	0	1	0
		0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.34%	0.00%
Globular echinate	Arecaceae	39	29	29	35	37	63	34	20	26
		13.10%	10.17%	10.18%	13.06%	14.23%	20.79%	11.18%	5.84%	9.77%
Conical to hat- shape	Arecaceae	18	10	11	15	10	11	5	3	7
		6.07%	3.51%	3.86%	5.60%	3.85%	3.63%	1.64%	1.03%	2.63%
Globular facetete	Annonaceae	1	1	0	0	1	1	0	1	0
		0.30%	0.35%	0.00%	0.00%	0.38%	0.33%	0.00%	0.34%	0.00%
Stippled plate	Celtis sp.	0	0	2	0	2	0	0	3	0
		0.00%	0.00%	0.70%	0.00%	0.77%	0.00%	0.00%	1.03%	0.00%
Tracheid/Sclereid	N.D. Arboreal	39	46	44	12	10	18	75	76	74
		13.13%	16.70%	15.44%	4.48%	3.20%	5.94%	24.67%	26.12%	27.81%
Globular granulate	N.D. Arboreal	66	59	45	89	78	100	100	93	100
		22.87%	21.00%	15.79%	33.21%	30%	33.00%	32.89%	31.95%	37.59%
Total Arboreal	-	163	145	131	151	138	193	214	197	207
		55.47%	51.73%	45.96%	56.34%	52.43%	63.70%	70.39%	66.65%	77.81%
Scalloped sphere	Cucurbita sp.	4	4	1	2	1	18	2	1	0
		1.20%	1.40%	0.35%	0.75%	0.38%	5.94%	0.66%	0.34%	0.00%
Bowl-shaped body	Trichomanes sp.	0	0	2	3	2	0	0	0	2
		0.00%	0.00%	0.70%	1.12%	0.77%	0.00%	0.00%	0.00%	0.75%

APPENDIX 2:

Morphotype	Taxa	0-10cm TP1	10-20cm TP1	20-30cm TP1	30-40cm TP1	40-50cm TP1	50-60cm TP1	60-70cm TP1	70-80cm TP1	80-90cm TP1	90-100cm TP1	100-110cm TP1
Cross variant 1, 5/6	N.D.Poaceae	1 0.40%	0 0.00%	4 1.34%	4 1.36%	1 0.35%	0 0.00%	5 1.53%	1 0.33%	3 0.98%	2 0.66%	0 0.00%
Bulliform	N.D.Poaceae	32 13.11%	19 5.29%	29 9.70%	16 5.42%	22 7.80%	23 8.13%	15 4.59%	19 6.33%	27 8.79%	15 4.92%	14 4.46%
Rondel	N.D.Poaceae	9 3.59%	23 6.41%	23 7.69%	10 3.39%	19 6.74%	3 1.06%	8 2.45%	6 2%	3 0.98%	11 3.61%	4 1.27%
Billobate	Panicoideae	1 0.40%	7 1.95%	0 0.00%	1 0.34%	8 2.84%	7 2.47%	0 0.00%	3 1%	14 4.56%	9 2.95%	5 1.59%
Polylobate	Panicoideae	0 0.00%	1 0.28%	0 0.00%	0 0.00%	0 0.00%	1 0.35%	0 0.00%	0 0.00%	2 0.65%	0 0.00%	0 0.00%
Long thin-shaft billobate	Aristidoideae	0 0.00%	0 0.00%	0 0.00%	0 0.00%	0 0.00%	0 0.00%	3 0.92%	0 0.00%	0 0.00%	0 0.00%	0 0.00%
Cross variant 3	Bambusoideae	0 0.00%	1 0.28%	2 0.67%	0 0.00%	0 0.00%	0 0.00%	0 0.00%	0 0.00%	2 0.65%	0 0.00%	0 0.00%
Spiny rondell	Bambusoideae	0 0.00%	9 2.51%	14 4.68%	6 2.03%	12 4.26%	2 0.71%	15 4.59%	8 2.67%	10 3.26%	10 3.28%	9 2.87%
Tall saddle	Bambusoideae	0 0.00%	0 0.00%	0 0.00%	1 0.34%	0 0.00%	0 0.00%	1 0.31%	1 0.33%	0 0.00%	0 0.00%	0 0.00%
Collapsed saddle	Bambusoideae	0 0.00%	0 0.00%	0 0.00%	1 0.34%	0 0.00%	0 0.00%	1 0.31%	1 0.33%	2 0.65%	0 0.00%	0 0.00%
Flared bulliform	Bambusoideae	1 0.40%	6 1.67%	0 0.00%	0 0.00%	2 0.71%	0 0.00%	0 0.00%	0 0.00%	4 1.30%	0 0.00%	0 0.00%
Short saddle	Chloridoideae	0 0.00%	3 0.50%	2 0.67%	0 0.00%	0 0.00%	0 0.00%	2 0.61%	3 1%	0 0.00%	0 0.00%	0 0.00%
Keystone bulliform	Oryzeae	0 0.00%	3 0.50%	1 0.33%	0 0.00%	0 0.00%	1 0.35%	1 0.31%	4 1.33%	0 0.00%	1 0.33%	1 0.32%
Scooped billobate	Oryzeae	0 0.00%	0 0.00%	0 0.00%	0 0.00%	0 0.00%	0 0.00%	0 0.00%	0 0.00%	0 0.00%	0 0.00%	0 0.00%
Serrated Bodie	<i>Oryza</i> sp.	0 0.00%	0 0.00%	0 0.00%	0 0.00%	0 0.00%	0 0.00%	0 0.00%	0 0.00%	0 0.00%	0 0.00%	0 0.00%
Double-peaked glume	<i>Oryza</i> sp.	0 0.00%	0 0.00%	0 0.00%	0 0.00%	0 0.00%	0 0.00%	0 0.00%	0 0.00%	0 0.00%	0 0.00%	0 0.00%
Wavy-top rondel	<i>Zea mays</i>	0 0.00%	0 0.00%	0 0.00%	0 0.00%	0 0.00%	0 0.00%	0 0.00%	1 0.33%	0 0.00%	0 0.00%	0 0.00%
Total grasses	-	44 17.90%	72 19.38%	75 25.08%	39 13.22%	64 22.70%	37 13.07%	51 15.60%	47 15.67%	67 21.82%	48 15.74%	33 10.51%

APPENDIX 2:

Morphotype	Taxa	0-10cm TP1	10-20cm TP1	20-30cm TP1	30-40cm TP1	40-50cm TP1	50-60cm TP1	60-70cm TP1	70-80cm TP1	80-90cm TP1	90-100cm TP1	100-110cm TP1
Leaf conical body	Cyperaceae	0 0.00%	1 0.28%	0 0.00%	0 0.00%	0 0.00%	0 0.00%	0 0.00%	1 0.33%	0 0.00%	0 0.00%	0 0.00%
Polygonal body	Cyperaceae	9 3.59%	12 3.34%	2 0.67%	5 1.69%	3 1.06%	1 0.35%	1 0.31%	8 2.67%	2 0.65%	2 0.66%	1 0.32%
Nodular globular	Marantaceae	10 3.98%	19 5.29%	35 11.71%	12 4.07%	15 5.32%	26 9.19%	23 7.03%	17 5.67%	20 6.51%	24 7.87%	11 3.50%
Seed conical body	Marantaceae	0 0.00%	2 0.56%	3 1.00%	1 0.34%	0 0.00%	2 0.71%	3 0.92%	4 1.33%	1 0.33%	2 0.66%	0 0.00%
Troughs body	Heliconiaceae	0 0.00%	3 0.50%	0 0.00%	0 0.00%	2 0.71%	0 0.00%	0 0.00%	0 0.00%	0 0.00%	2 0.66%	2 0.64%
Opaque perforated body	Asteraceae	43 17.13%	72 20.06%	37 12.37%	42 14.24%	40 14.18%	32 11.31%	44 13.46%	49 16.33%	18 5.86%	14 4.59%	9 2.87%
Total Herbs	-	62 24.70%	109 30.03%	77 25.75%	60 20.34%	60 21.28%	61 21.55%	71 21.71%	79 26.33%	41 13.36%	44 14.43%	23 7.32%
Stippled polygonal body	Burceraceae	0 0.00%	0 0.00%	0 0.00%	0 0.00%	0 0.00%	0 0.00%	0 0.00%	0 0.00%	0 0.00%	0 0.00%	0 0.00%
Globular echinate	Arecaceae	26 10.36%	29 8.08%	15 5.02%	29 9.83%	23 8.16%	35 12.37%	19 5.81%	19 6.33%	35 11.40%	27 8.85%	48 15.29%
Conical to hat- shape	Arecaceae	20 7.97%	17 4.74%	8 2.68%	19 6.44%	9 3.19%	7 2.47%	1 0.31%	1 0.33%	4 1.30%	6 1.97%	6 1.92%
Globular facetete	Annonaceae	0 0.00%	0 0.00%	0 0.00%	1 0.34%	0 0.00%	0 0.00%	0 0.00%	0 0.00%	1 0.33%	2 0.66%	0 0.00%
Stippled plate	<i>Celtis</i> sp.	0 0.00%	3 0.50%	0 0.00%	2 0.68%	0 0.00%	0 0.00%	3 0.92%	0 0.00%	0 0.00%	0 0.00%	0 0.00%
Tracheid/Sclereid	N.D. Arboreal	31 12.35%	31 8.64%	27 9.03%	36 12.20%	36 12.77%	40 14.13%	62 18.96%	44 14.67%	57 18.57%	78 25.57%	93 29.62%
Globular granulate	N.D. Arboreal	59 24.18%	96 26.74%	95 31.77%	100 33.90%	90 31.91%	100 35.34%	100 30.58%	100 33.33%	100 32.57%	100 32.79%	100 31.85%
Total Arboreal	-	136 54.86%	176 48.69%	145 48.49%	187 63.39%	158 56.03%	182 64.31%	185 56.57%	165 54.67%	197 64.17%	213 69.84%	247 78.66%
Scalloped sphere	<i>Cucurbita</i> sp.	2 0.80%	9 2.51%	2 0.67%	9 3.05%	0 0.00%	3 1.06%	17 5.20%	10 3.33%	2 0.65%	0 0.00%	11 3.50%
Bowl-shaped body	<i>Trichomanes</i> sp.	0 0.00%	0 0.00%	0 0.00%	0 0.00%	0 0.00%	0 0.00%	3 0.92%	2 0.67%	0 0.00%	0 0.00%	0 0.00%

APPENDIX 2:

Morphotype	Taxa	0-10 cm TP2	10-20 cm TP2	20-30 cm TP2	30-40 cm TP2	40-50 cm TP2	50-60 cm TP2
Cross variant 1, 5/6	N.D.Poaceae	2 0.69%	2 0.63%	2 0.70%	4 1.36%	1 0.36%	0 0.00%
Bulliform	N.D.Poaceae	23 7.96%	23 7.30%	10 3.52%	21 7.12%	19 6.79%	13 5.14%
Rondel	N.D.Poaceae	14 4.84%	18 5.71%	8 2.82%	2 0.68%	5 1.79%	4 1.58%
Billobate	Panicoideae	1 0.35%	3 0.95%	3 1.06%	3 1.02%	6 2.14%	3 1.19%
Polylobate	Panicoideae	0 0.00%	0 0.00%	0 0.00%	0 0.00%	1 0.36%	2 0.79%
Long thin-shaft billobate	Aristidoideae	2 0.69%	0 0.00%	3 1.06%	0 0.00%	0 0.00%	0 0.00%
Cross variant 3	Bambusoideae	0 0.00%	0 0.00%	1 0.35%	1 0.34%	0 0.00%	0 0.00%
Spiney rondell	Bambusoideae	1 0.35%	2 0.63%	9 3.17%	11 3.73%	8 2.86%	3 1.19%
Tall saddle	Bambusoideae	0 0.00%	0 0.00%	1 0.35%	1 0.34%	1 0.36%	2 0.79%
Collapsed saddle	Bambusoideae	0 0.00%	0 0.00%	1 0.35%	1 0.34%	1 0.36%	1 0.40%
Flared bulliform	Bambusoideae	0 0.00%	0 0.00%	0 0.00%	3 1.02%	2 0.71%	1 0.40%
Short saddle	Chloridoideae	0 0.00%	0 0.00%	3 1.06%	2 0.68%	0 0.00%	0 0.00%
Keystone bulliform	Oryzeae	0 0.00%	1 0.32%	1 0.35%	2 0.68%	4 1.43%	1 0.40%
Scooped billobate	Oryzeae	0 0.00%	0 0.00%	0 0.00%	0 0.00%	0 0.00%	0 0.00%
Serrated Bodie	Oryza sp.	0 0.00%	0 0.00%	0 0.00%	0 0.00%	0 0.00%	0 0.00%
Double-peaked glume	Oryza sp.	0 0.00%	0 0.00%	1 0.35%	0 0.00%	1 0.36%	0 0.00%
Wavy-top rondel	Zea mays	0 0.00%	0 0.00%	0 0.00%	1 0.34%	0 0.00%	0 0.00%
Total grasses	-	43 14.88%	49 15.56%	43 15.14%	52 17.63%	49 17.50%	30 11.86%

APPENDIX 2:

Morphotype	Taxa	0-10 cm TP2	10-20 cm TP2	20-30 cm TP2	30-40 cm TP2	40-50 cm TP2	50-60 cm TP2
Leaf conical body	Cyperaceae	1 0.35%	0 0.00%	0 0.00%	0 0.00%	2 0.71%	0 0.00%
Polygonal body	Cyperaceae	11 3.81%	4 1.27%	1 0.35%	5 1.69%	7 2.50%	4 1.58%
Nodular globular	Marantaceae	17 5.88%	16 5.08%	20 7.04%	19 6.44%	19 6.79%	14 5.53%
Seed conical body	Marantaceae	1 0.35%	0 0.00%	3 1.06%	3 1.02%	6 2.14%	0 0.00%
Troughs body	Heliconiaceae	0 0.00%	3 0.95%	2 0.70%	0 0.00%	0 0.00%	0 0.00%
Opaque perforated body	Asteraceae	60 20.76	88 27.94%	25 8.80%	34 11.53%	22 7.86%	12 4.47%
Total Herbs	-	90 31.14%	111 35.23%	51 17.96%	61 20.68%	56 20%	30 11.86%
Stippled polygonal body	Burceraceae	0 0.00%	0 0.00%	0 0.00%	0 0.00%	0 0.00%	0 0.00%
Globular echinate	Arecaceae	35 12.11%	29 9.21%	23 8.10%	32 10.85%	9 3.21%	10 3.95%
Conical to hat- shape	Arecaceae	12 4.15%	5 1.5873	4 1.41%	5 1.69%	2 0.71%	4 1.58%
Globular facetete	Annonaceae	0 0.00%	0 0.00%	0 0.00%	0 0.00%	0 0.00%	0 0.00%
Stippled plate	<i>Celtis</i> sp.	0 0.00%	0 0.00%	2 0.70%	1 0.34%	2 0.71%	0 0.00%
Tracheid/Sclereid	N.D. Arboreal	30 10.38%	19 6.03%	56 19.72%	41 13.90%	55 19.64%	74 29.25%
Globular granulate	N.D. Arboreal	77 26.64%	100 31.75%	100 35.21%	88 29.83%	100 35.71%	100 39.53%
Total Arboreal	-	154 53.29%	153 48.57%	185 65.14%	167 56.61%	168 60%	188 74.31%
Scalloped sphere	<i>Cucurbita</i> sp.	2 0.69%	2 0.63%	5 1.76%	12 4.07%	7 2.50%	5 1.98%
Bowl-shaped body	<i>Trichomanes</i> sp.	0 0.00%	0 0.00%	0 0.00%	3 1.02%	0 0.00%	0 0.00%

APPENDIX 2:

Morphotype	Taxa	0-10 cm TP3	10-20 cm TP3	20-30 cm TP3	30-40 cm TP3	42cm TP3	40-50 cm TP3	50-60 cm TP3
Cross variant 1, 5/6	N.D.Poaceae	4	2	4	5	2	8	0
		1.43%	0.60%	1.40%	1.78%	0.83%	2.89%	0.00%
Bulliform	N.D.Poaceae	26	24	26	16	10	19	0
		9.29%	7.16%	9.09%	5.69%	4.17%	6.86%	0.00%
Rondel	N.D.Poaceae	16	9	6	4	9	3	13
		5.71%	2.69%	2.10%	1.42%	3.75%	1.08%	4.69%
Billobate	Panicoideae	5	2	1	11	10	9	9
		1.79%	0.60%	0.35%	3.91%	4.17%	3.25%	3.25%
Polylobate	Panicoideae	0	0	0	1	0	2	3
		0.00%	0.00%	0.00%	0.36%	0.00%	0.72%	1.08%
Long thin-shaft billobate	Aristidoideae	0	2	0	0	0	0	2
		0.00%	0.60%	0.00%	0.00%	0.00%	0.00%	0.72%
Cross variant 3	Bambusoideae	0	0	2	0	0	0	0
		0.00%	0.00%	0.70%	0.00%	0.00%	0.00%	0.00%
Spiney rondell	Bambusoideae	4	2	9	9	4	5	3
		1.43%	0.60%	3.15%	3.20%	1.67%	1.81%	1.08%
Tall saddle	Bambusoideae	0	0	0	1	0	1	0
		0.00%	0.00%	0.00%	0.36%	0.00%	0.36%	0.00%
Collapsed saddle	Bambusoideae	0	0	1	0	0	1	0
		0.00%	0.00%	0.35%	0.00%	0.00%	0.36%	0.00%
Flared bulliform	Bambusoideae	0	0	0	2	0	1	0
		0.00%	0.00%	0.00%	0.71%	0.00%	0.36%	0.00%
Short saddle	Chloridoideae	0	3	2	0	1	1	0
		0.00%	0.90%	0.70%	0.00%	0.42%	0.36%	0.00%
Keystone bulliform	Oryzeae	0	1	1	5	2	2	1
		0.00%	0.30%	0.35%	1.78%	0.83%	0.72%	0.36%
Scooped billobate	Oryzeae	0	0	0	0	0	1	0
		0.00%	0.00%	0.00%	0.00%	0.00%	0.36%	0.00%
Serrated Bodie	<i>Oryza</i> sp.	0	0	0	0	0	0	0
		0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Double-peaked glume	<i>Oryza</i> sp.	0	0	0	0	0	1	0
		0.00%	0.00%	0.00%	0.00%	0.00%	0.36%	0.00%
Wavy-top rondel	<i>Zea mays</i>	0	0	0	0	1	1	0
		0.00%	0.00%	0.00%	0.00%	0.42%	0.36%	0.00%
Total grasses	-	55	45	52	54	39	55	31
		19.64%	13.43%	18.18%	19.22%	16.25%	19.86%	11.19%

APPENDIX 2:

Morphotype	Taxa	0-10 cm TP3	10-20 cm TP3	20-30 cm TP3	30-40 cm TP3	42cm TP3	40-50 cm TP3	50-60 cm TP3
Leaf conical body	Cyperaceae	2 0.71%	1 0.30%	0 0.00%	0 0.00%	1 0.42%	1 0.36%	0 0.00%
Polygonal body	Cyperaceae	8 2.86%	8 2.39%	8 2.80%	6 2.14%	3 1.25%	9 3.25%	1 0.36%
Nodular globular	Marantaceae	27 9.64%	19 5.67%	16 5.59%	15 5.34%	16 6.67%	15 5.42%	15 5.42%
Seed conical body	Marantaceae	2 0.71%	5 1.49%	2 0.70%	1 0.36%	4 1.67%	2 0.72%	1 0.36%
Troughs body	Heliconiaceae	0 0.00%	0 0.00%	1 0.35%	0 0.00%	2 0.83%	2 0.72%	0 0.00%
Opaque perforated body	Asteraceae	29 10.36%	81 24.18%	50 17.48%	35 12.46%	15 6.25%	29 10.47%	13 4.69%
Total Herbs	-	68 24.29%	114 34.03%	77 26.92%	57 20.28%	41 17.08%	58 20.94%	30 10.83%
Stippled polygonal body	Burceraceae	0 0.00%	0 0.00%	0 0.00%	0 0.00%	0 0.00%	0 0.00%	0 0.00%
Globular echinate	Arecaceae	24 8.57%	20 5.97%	18 6.29%	28 9.96%	31 12.92%	38 13.72%	26 9.39%
Conical to hat- shape	Arecaceae	9 3.21%	8 2.39%	5 1.75%	7 2.49%	6 2.50%	8 2.89%	3 1.08%
Globular facetete	Annonaceae	0 0.00%	0 0.00%	0 0.00%	0 0.00%	0 0.00%	0 0.00%	0 0.00%
Stippled plate	<i>Celtis</i> sp.	0 0.00%	3 0.90%	2 0.70%	0 0.00%	2 0.83%	1 0.36%	1 0.36%
Tracheid/Sclereid	N.D. Arboreal	47 16.79%	31 9.25%	30 10.49%	31 11.03%	32 13.33%	41 14.80%	83 26.96%
Globular granulate	N.D. Arboreal	73 26.07%	100 29.85%	98 34.27%	100 35.59%	84 35.00%	68 24.55%	100 36.10%
Total Arboreal	-	153 54.64%	162 48.36%	153 53.50%	166 59.07%	155 64.58%	156 56.32%	213 76.90%
Scalloped sphere	<i>Cucurbita</i> sp.	4 1.43%	14 4.18%	2 0.70%	3 1.07%	5 2.08%	8 2.89%	1 0.36%
Bowl-shaped body	<i>Trichomanes</i> sp.	0 0.00%	0 0.00%	2 0.70%	1 0.36%	0 0.00%	0 0.00%	2 0.72%

APPENDIX 2:

Morphotype	Taxa	0-10 cm TP4	10-20 cm TP4	20-30 cm TP4	30-40 cm TP4	40-50 cm TP4
Cross variant 1, 5/6	N.D.Poaceae	1 0.35%	2 0.65%	1 0.28%	2 0.67%	0 0.00%
Bulliform	N.D.Poaceae	17 5.99%	27 8.71%	31 8.59%	17 5.69%	7 2.61%
Rondel	N.D.Poaceae	16 5.63%	11 3.55%	10 2.77%	13 4.35%	0 0.00%
Billobate	Panicoideae	10 3.52%	6 1.94%	10 2.77%	11 3.68%	0 0.00%
Polylobate	Panicoideae	0 0.00%	0 0.00%	0 0.00%	0 0.00%	0 0.00%
Long thin-shaft billobate	Aristidoideae	0 0.00%	0 0.00%	0 0.00%	0 0.00%	0 0.00%
Cross variant 3	Bambusoideae	0 0.00%	0 0.00%	0 0.00%	1 0.33%	0 0.00%
Spiney rondel	Bambusoideae	4 1.41%	3 0.97%	4 1.11%	4 1.34%	3 1.12%
Tall saddle	Bambusoideae	0 0.00%	1 0.32%	0 0.00%	4 1.34%	3 1.12%
Collapsed saddle	Bambusoideae	0 0.00%	1 0.32%	0 0.00%	1 0.33%	2 0.75%
Flared bulliform	Bambusoideae	0 0.00%	0 0.00%	6 1.66%	0 0.00%	2 0.75%
Short saddle	Chloridoideae	2 0.70%	1 0.32%	2 0.55%	1 0.33%	2 0.75%
Keystone bulliform	Oryzeae	1 0.35%	1 0.32%	1 0.28%	2 0.67%	0 0.00%
Scooped billobate	Oryzeae	0 0.00%	0 0.00%	0 0.00%	0 0.00%	0 0.00%
Serrated Bodie	<i>Oryza</i> sp.	0 0.00%	0 0.00%	0 0.00%	0 0.00%	0 0.00%
Double-peaked glume	<i>Oryza</i> sp.	0 0.00%	0 0.00%	0 0.00%	0 0.00%	0 0.00%
Wavy-top rondel	<i>Zea mays</i>	0 0.00%	0 0.00%	0 0.00%	0 0.00%	0 0.00%
Total grasses	-	51 17.96%	53 17.10%	65 18.01%	56 18.73%	19 7.06%

APPENDIX 2:

Morphotype	Taxa	0-10 cm TP4	10-20 cm TP4	20-30 cm TP4	30-40 cm TP4	40-50 cm TP4
Leaf conical body	Cyperaceae	0 0.00%	0 0.00%	0 0.00%	0 0.00%	0 0.00%
Polygonal body	Cyperaceae	13 4.58%	11 3.55%	2 0.55%	1 0.33%	0 0.00%
Nodular globular	Marantaceae	0 0.00%	2 0.65%	1 0.28%	5 1.67%	1 0.37%
Seed conical body	Marantaceae	0 0.00%	0 0.00%	0 0.00%	0 0.00%	0 0.00%
Troughs body	Heliconiaceae	0 0.00%	0 0.00%	2 0.55%	1 0.33%	0 0.00%
Opaque perforated body	Asteraceae	80 28.17%	129 41.61%	100 27.70%	52 17.39%	23 8.58%
Total Herbs	-	93 32.75%	142 45.81%	105 29.09%	59 19.73%	24 8.96%
Stippled polygonal body	Burceraceae	0 0.00%	0 0.00%	0 0.00%	0 0.00%	0 0.00%
Globular echinate	Arecaceae	22 7.75%	6 1.94%	32 8.86%	15 5.02%	21 7.84%
Conical to hat- shape	Arecaceae	14 4.93%	1 0.32%	14 3.88%	2 0.67%	2 0.75%
Globular facetete	Annonaceae	0 0.00%	0 0.00%	0 0.00%	0 0.00%	0 0.00%
Stippled plate	<i>Celtis</i> sp.	0 0.00%	0 0.00%	0 0.00%	1 0.33%	0 0.00%
Tracheid/Sclereid	N.D. Arboreal	27 9.51%	10 3.23%	45 12.47%	62 20.74%	100 37.31%
Globular granulate	N.D. Arboreal	76 26.76%	97 31.29%	100 27.70%	100 33.44%	100 37.31%
Total Arboreal	-	139 48.94%	114 36.77%	191 52.91%	180 60.20%	223 83.21%
Scalloped sphere	<i>Cucurbita</i> sp.	1 0.35%	1 0.32%	0 0.00%	1 0.33%	2 0.75%
Bowl-shaped body	<i>Trichomanes</i> sp.	0 0.00%	0 0.00%	0 0.00%	3 1.00%	0 0.00%

**APPENDIX 3:
ORYZA DOUBLE PEAKED GLUME MEASUREMENTS**

Archaeological layers	Top Width	Maximum Width	Curve Depth	Height 1	Height 2
A	39.388	47.615	6.486	19.173	14.944
A	27.529	71.608	1.383	32.068	28.925
A	34.54	64.008	5.851	32.338	28.15
A	21.587	70.107	2.07	30.433	21.587
A	19.795	64.76	3.106	27.113	26.023
A	38.085	60.954	3.031	25.52	24.416
A	54.339	76.174	10.539	33.271	27.02
A	34.266	51.121	6.81	25.892	25.713
A	37.419	58.817	5.565	24.774	24.746
A	43.386	59.806	8.28	23.439	21.579
A	37.532	52.007	5.63	22.463	18.178
A	38.072	54.828	6.646	25.974	22.692
A	46.25	62.434	4.276	23.06	22.273
A	43.842	55.534	4.704	22.353	17.213
A	39.199	49.407	4.316	21.341	18.212
A	36.598	46.127	7.292	22.818	21.55
A	32.214	50.558	6.575	23.446	22.2
A	37.028	58.276	4.788	28.765	25.421
A	33.269	46.742	5.809	26.499	19.764
A	35.727	42.583	5.774	21.548	20.373
B	44.262	52.873	8.694	32.211	29.546
B	40.491	51.157	5.304	25.725	15.745
B	36.439	51.028	3.527	22.352	18.224
B	35.931	51.645	4.63	22.927	20.352
B	34.694	41.818	3.049	17.767	16.626
B	43.612	51.095	3.14	16.057	15.852
B	35.275	48.899	4.642	22.07	19.589
B	43.87	50.867	5.058	20.153	19.569
B	34.905	49.041	6.266	22.2	21.452
B	35.76	44.76	5.637	24.524	22.604
B	36.189	49.708	4.72	24.318	23.455
B	37.567	53.632	5.533	28.041	23.619
B	31.761	48.36	6.625	24.141	24.039
B	41.484	54.213	3.835	23.423	21.665
B	37.345	46.861	7.921	25.013	22.948
B	29.044	37.386	4.906	16.093	13.496
B	43.347	59.799	2.737	24.5	22.544
B	36.188	46.465	7.946	21.451	19.15
B	29.738	48.671	4.162	20.548	19.398
B	43.385	52.767	5.578	17.714	15.354
C	48.597	54.749	6.04	19.494	16.828
C	47.669	54.546	6.957	29.696	20.165
C	33.677	43.454	3.763	18.357	16.923
C	27.238	44.85	4.386	16.751	14.606

C	38.005	56.127	5.228	21.399	17.042
C	43.831	49.541	7.433	29.188	27.209
C	48.827	61.611	4.368	24.865	22.232
C	48.726	58.699	4.06	22.717	22.181
C	50.013	54.801	4.544	22.325	18.901
C	43.764	66.042	3.87	19.007	18.577
C	20.502	30.331	5.433	17.563	16.147
C	44.908	53.865	4.7	21.643	17.095
C	39.555	57.878	9.86	18.477	17.012
C	31.656	46.48	4.306	20.737	18.616
C	43.384	57.085	2.681	23.905	21.269
C	38.487	47.808	4.886	17.698	17.505
C	51.787	72.396	10.795	23.95	23.919
C	44.738	60.69	2.258	23.981	22.815
C	43.641	55.606	7.515	18.353	18.236
C	46.027	56.438	5.091	25.847	18.353
D 90-100cm	43.191	55.872	3.08	21.486	20.403
D 90-100cm	52.26	64.223	3.259	24.432	23.702
D 90-100cm	50.114	50.523	2.272	12.969	11.69
D 90-100cm	42.512	53.338	1.613	17.328	16.532
D 90-100cm	41.503	58.696	1.952	22.465	19.83
D 90-100cm	39.918	53.371	6.49	22.875	19.94
D 90-100cm	57.446	75.337	1.784	21.287	18.23
D 90-100cm	38.851	43.771	5.543	17.148	17.147
D 90-100cm	29.577	46.156	6.834	22.269	20.937
D 90-100cm	29.441	48.191	6.275	18.563	17.128
D 90-100cm	44.723	43.942	2.89	18.537	16.495
D 90-100cm	44.97	47.127	3.402	13.198	10.196
D 90-100cm	30.243	39.47	5.629	11.922	11.529
D 90-100cm	45.145	52.905	6.742	19.438	18.678
D 90-100cm	25.203	42.605	4.126	19.916	19.768
D 90-100cm	45.068	58.456	6.691	15.624	13.939
D 90-100cm	35.001	43.072	3.752	16.429	16.266
D 90-100cm	45.954	52.599	3.095	17.934	17.205
D 90-100cm	32.215	50.887	2.014	21.353	19.995
D 90-100cm	43.855	51.897	6.321	19.383	16.051
D 130cm	43.076	68.35	2.885	28.151	25.904
D 130cm	23.185	29.736	3.32	17.902	15.582
D 130cm	37.72	46.577	4.166	17.458	15.195
D 130cm	37.979	45.333	6.027	24.896	22.815
D 130cm	38.558	45.968	5.488	28.906	26.302
D 130cm	25.885	42.168	6.045	23.77	21.903
D 130cm	42.402	49.571	2.239	21.553	17.386
D 130cm	39.547	57.563	2.546	16.819	15.206
D 130cm	40.992	58.042	4.904	17.666	16.292

D 130cm	40.904	44.954	5.723	21.666	14.912
D 130cm	23.118	43.809	4.794	25.444	25.217
D 130cm	34.234	52.735	1.554	21.669	19.04
D 130cm	50.529	51.825	4.288	19.98	15.14
D 130cm	22.894	40.278	6.184	21.926	21.627
D 130cm	40.957	56.812	4.029	17.288	15.797
D 130cm	45.114	56.086	4.178	17.309	14.967
D 130cm	41.247	45.655	4.931	18.931	18.431
D 130cm	39.79	57.1	4.303	18.837	17.827
D 130cm	40.689	47.602	1.355	15.923	15.126
D 130cm	42.34	52.644	2.208	12.013	11.395
D 130-140cm	43.191	55.872	3.08	21.486	20.403
D 130-140cm	52.26	64.223	3.259	24.432	23.702
D 130-140cm	50.114	50.523	2.272	12.969	11.69
D 130-140cm	42.512	53.338	1.613	17.328	16.532
D 130-140cm	41.503	58.696	1.952	22.465	19.83
D 130-140cm	39.918	53.371	6.49	22.875	19.94
D 130-140cm	57.446	75.337	1.784	21.287	18.23
D 130-140cm	38.851	43.771	5.543	17.148	17.147
D 130-140cm	29.577	46.156	6.834	22.269	20.937
D 130-140cm	29.441	48.191	6.275	18.563	17.128
D 130-140cm	44.723	43.942	2.89	18.537	16.495
D 130-140cm	44.97	47.127	3.402	13.198	10.196
D 130-140cm	30.243	39.47	5.629	11.922	11.529
D 130-140cm	45.145	52.905	6.742	19.438	18.678
D 130-140cm	25.203	42.605	4.126	19.916	19.768
D 130-140cm	45.068	58.456	6.691	15.624	13.939
D 130-140cm	35.001	43.072	3.752	16.429	16.266
D 130-140cm	45.954	52.599	3.095	17.934	17.205
D 130-140cm	32.215	50.887	2.014	21.353	19.995
D 130-140cm	43.855	51.897	6.321	19.383	16.051
D-E	47.848	32.803	4.97	18.737	13.817
D-E	37.033	45.593	4.09	21.776	15.3
D-E	60.516	65.631	3.575	16.194	15.308
D-E	43.885	50.961	5.593	22.365	21.737
D-E	41.226	55.988	6.368	23.287	21.186
D-E	49.958	61.857	5.292	19.911	16.453
D-E	33.185	37.833	4.543	18.554	17.862
D-E	40.948	54.4	5.21	19.422	18.286
D-E	42.488	44.745	6.044	16.449	13.401
D-E	50.565	58.115	7.032	15.492	14.149
D-E	39.854	51.148	1.728	15.877	11.676
D-E	48.878	58.851	7.288	23.3	18.824
D-E	42.381	34.901	2.792	23.395	16.068
D-E	21.499	57.649	6.834	21.602	20.657

D-E	38.943	47.339	5.158	19.31	17.005
D-E	27.234	39.949	2.329	15.245	14.339
D-E	30.901	41.578	2.978	17.05	16.377
D-E	45.49	56.357	5.488	20.137	18.408
D-E	38.645	52.028	5.363	20.825	17.385
D-E	42.896	49.274	5.51	22.51	21.088
E	38.107	49.39	4.422	19.773	18.004
E	43.127	58.791	1.796	18.255	16.695
E	30.692	42.907	5.765	22.674	22.278
E	33.559	39.794	4.368	11.301	10.263
E	35.475	48.681	4.04	17.14	15.452
E	37.36	46.166	4.578	30.893	29.825
E	22.566	33.996	3.584	16.271	14.674
E	31.577	44.28	3.923	17.194	14.662
E	28.998	40.762	3.564	17.958	17.662
E	41.171	53.96	6.726	22.066	20.372
E	36.607	42.859	3.801	17.839	17.087
E	28.909	41.222	3.218	14.676	14.368
E	41.409	58.793	1.606	17.101	15.625
E	41.843	48.914	3.368	13.394	13.22
E	40.338	49.027	2.272	20.562	20.048
E	40.533	50.11	1.967	16.346	15.156
E	41.648	47.61	4.265	19.726	17.935
E	33.882	49.04	2.643	21.814	18.591
E	27.635	35.801	5.514	21.03	20.976
E	28.482	37.122	5.618	17.999	17.058
F	35.039	49.266	2.535	17.545	14.91
F	29.902	43.372	3.37	14.515	13.534
F	38.608	44.539	2.681	17.3	13.52
F	38.619	42.73	2.498	12.689	10.631
F	34.287	44.295	3.417	15.326	12.584
F	48.452	61.025	4.449	21.388	15.849
F	40.156	46.121	4.266	26.531	20.113
F	39.534	46.987	4.018	15.69	13.881
F	40.161	54.771	1.128	19.108	18.852
F	51.57	53.662	4.262	20.313	15.173
F	37.13	51.161	2.201	16.757	12.431
F	34.094	56.206	1.075	22.875	22.35
F	32.905	40.724	9.268	27.708	22.38
F	23.965	34.989	2.624	11.828	11.198
F	48.058	64.019	6.403	15.955	15.85
F	30.891	48.837	2.219	17.137	16.791
F	27.955	41.772	2.779	17.397	14.987
F	47.569	61.899	6.44	20.526	19.638
F	23.497	45.96	4.072	25.701	22.644

F	44.945	58.603	3.525	21.768	18.307
G	34.221	43.496	1.797	12.489	11.432
G	39.229	42.516	0.764	13.265	12.486
G	36.858	46.645	3.412	14.879	13.983
G	39.859	50.229	2.947	17.99	17.516
G	27.807	36.044	3.313	11.702	11.05
G	56.079	60.835	5.984	29.133	25.273
G	34.627	46.769	3.295	15.852	14.902
G	54.224	62.961	2.847	18.293	16.204
G	54.049	75.443	6.009	20.941	20.923
G	34.521	42.764	7.543	17.143	16.834
G	35.23	42.675	2.215	14.037	13.633
G	43.851	55.387	5.342	35.347	29.922
G	34.351	48.507	4.604	19.172	17.089
G	36.463	48.442	5.277	23.996	21.075
G	39.191	42.434	3.019	14.984	14.387
G	43.275	48.591	2.497	14.921	12.597
G	41.069	50.942	1.826	12.705	12.425
G	19.193	50.936	3.412	20.882	19.193
G	42.139	49.93	3.7	16.618	12.043
G	34.861	43.427	3.884	15.627	14.208
H	33.958	43.931	5.408	15.35	13.236
H	44.921	52.338	2.732	19.141	18.351
H	32.408	53.943	4.603	19.075	18.256
H	35.973	55.03	4.45	27.417	19.717
H	36.561	56.064	4.207	24.361	23.421
H	21.811	38.932	2.541	17.482	17.316
H	30.351	45.201	4.105	16.803	14.628
H	28.253	43.373	1.276	14.743	10.15
H	36.369	66.973	4.18	32.634	27.45
H	37.73	42.613	4.578	18.777	12.77
H	33.255	52.612	1.261	25.364	22.657
H	24.221	68.254	1.358	32.439	31.006
H	30.682	42.202	4.316	22.177	21.201
H	38.452	45.668	2.939	14.711	14.003
H	32.811	50.135	4.786	22.976	22.305
H	40.344	46.347	2.596	15.969	13.081
H	28.733	55.085	0.845	18.632	16.675
H	30.421	49.364	4.646	23.552	17.19
H	23.437	34.994	2.006	15.145	14.133
H	41.896	48.862	4.487	23.323	19.336
I	12.959	19.478	0.702	4.559	3.883
I	17.544	22.56	0.941	10.138	8.568
I	22.997	30.891	3.661	11.504	8.262
I	22.874	27.125	2.504	11.511	8.204

I	15.373	23.363	1.138	20.644	10.683
I	46.389	48.996	4.457	21.281	8.505
I	38.146	42.198	2.199	10.052	12.89
I	38.071	50.885	1.975	20.145	15.143
I	35.279	43.698	3.364	14.983	15.074
I	47.405	53.145	2.957	16.812	15.074
I	32.298	52.521	4.986	31.29	28.335
I	39.207	58.511	4.313	26.812	25.495
I	48.514	57.198	4.918	16.641	14.351
I	50.758	53.033	1.394	15.744	14.897
I	42.556	51.276	3.031	18.347	17.922
I	43.293	46.527	5.318	19.16	14.739
I	47.785	65.472	2.862	19.232	18.627
I	43.103	46.995	5.57	17.35	14.716
I	47.343	49.866	4.268	26.513	18.722
I	39.047	50.489	2.373	16.971	15.575
J 390-400cm	31.815	43.874	3.153	19.045	17.338
J 390-400cm	40.282	55.765	2.858	17.326	15.009
J 390-400cm	41.042	45.862	8.311	20.406	19.017
J 390-400cm	46.815	51.882	3.042	16.35	11.916
J 390-400cm	41.349	51.634	4.208	20.29	17.277
J 390-400cm	35.744	39.835	3.219	14.265	10.868
J 390-400cm	39.2	43.636	3.794	20.851	19.803
J 390-400cm	25.862	34.257	3.218	16.841	14.901
J 390-400cm	37.97	57.258	2.624	24.025	20.474
J 390-400cm	36.028	44.235	1.97	12.504	12.135
J 390-400cm	40.405	52.853	1.71	11.195	9.933
J 390-400cm	33.898	47.312	2.161	17.408	17.045
J 390-400cm	35.354	48.837	3.024	20.752	19.81
J 390-400cm	41.545	45.619	5.157	23.381	23.066
J 390-400cm	39.684	47.715	1.63	12.576	11.437
J 390-400cm	32.843	41.654	3.543	12.41	11.367
J 390-400cm	34.467	39.963	4.813	16.758	16.701
J 390-400cm	35.571	51.177	3.139	17.536	16.689
J 390-400cm	20.034	25.503	2.523	12.027	10.91
J 390-400cm	44.727	52.836	1.652	15.587	15.099
J 400-410cm	24.454	30.65	1.732	17.502	16.276
J 400-410cm	36.155	68.074	2.657	23.234	22.523
J 400-410cm	43.155	46.778	3.619	13.499	11.908
J 400-410cm	24.774	36.787	4.088	21.428	14.811
J 400-410cm	31.75	37.664	4.505	15.106	14.726
J 400-410cm	34.07	43.584	3.088	17.97	16.708
J 400-410cm	30.359	48.209	1.153	21.081	19.645
J 400-410cm	30.257	46.004	3.159	15.705	14.578
J 400-410cm	30.059	47.622	1.304	15.645	13.477
J 400-410cm	35.031	61.993	3.047	29.694	25.266

J 400-410cm	33.08	48.872	2.527	14.913	14.29
J 400-410cm	37.88	39.946	2.816	12.334	10.172
J 400-410cm	42.939	49.846	3.42	17.676	13.066
J 400-410cm	42.089	51.758	5.223	30.145	24.37
J 400-410cm	30.793	47.577	4.735	18.616	16.67
J 400-410cm	37.424	49.546	0.789	16.082	14.175
J 400-410cm	41.566	46.404	3.596	15.894	15.382
J 400-410cm	40.149	45.017	9.484	26.054	16.568
J 400-410cm	30.457	39.369	3.768	22.708	11.51
J 400-410cm	41.306	57.179	0.963	14.676	12.909
J 420-430cm	45.282	49.052	3.771	19.69	18.394
J 420-430cm	35.169	48.269	0.305	15.952	15.209
J 420-430cm	24.735	34.77	2.55	10.775	10.113
J 420-430cm	33.246	49.006	1.856	14.38	12.533
J 420-430cm	32.829	48.193	2.804	16.097	14.754
J 420-430cm	36.388	53.192	3.297	18.446	14.549
J 420-430cm	28.782	51.694	2.048	17.945	14.77
J 420-430cm	31.552	7.318	5.353	12.782	11.759
J 420-430cm	30.872	35.663	3.665	11.681	11.372
J 420-430cm	28.544	36.262	4.007	17.584	17.526
J 420-430cm	22.227	32.305	2.038	12.445	12.133
J 420-430cm	40.765	47.459	5.727	20.313	16.274
J 420-430cm	32.212	42.858	1.555	14.42	13.662
J 420-430cm	40.286	56.681	5.488	20.2	15.457
J 420-430cm	29.756	45.55	2.03	12.341	10.015
J 420-430cm	40.687	44.123	3.164	21.144	20.95
J 420-430cm	36.267	51.667	3.542	14.435	12.115
J 420-430cm	35.63	48.962	1.888	19.007	18.975
J 420-430cm	45.966	55.495	1	16.832	14.228
J 420-430cm	38.917	44.158	3.516	15.06	13.948
J 450-460cm	28.578	47.044	4.515	23.154	17.75
J 450-460cm	13.087	41.445	3.924	13.31	13.087
J 450-460cm	23.015	38.617	0.644	12.98	12.699
J 450-460cm	32.222	51.925	1.491	19.692	19.181
J 450-460cm	35.81	54.923	0.897	21.206	19.16
J 450-460cm	51.143	53.766	4.338	17.123	11.875
J 450-460cm	47.757	60.014	2.854	20.748	18.659
J 450-460cm	35.341	44.773	2.148	12.754	11.841
J 450-460cm	43.925	47.375	3.533	15.654	14.133
J 450-460cm	33.989	47.618	2.64	15.42	13.703
J 450-460cm	40.307	55.745	1.601	17.548	14.524
J 450-460cm	40.034	53.56	1.29	17.366	16.767
J 450-460cm	36.637	58.522	2.03	19.447	17.664
J 450-460cm	32.832	51.472	2.3	14.848	13.689
J 450-460cm	28.954	49.401	0.377	17.525	13.939

J 450-460cm	51.23	39.789	2.162	14.771	14.265
J 450-460cm	34.023	50.049	4.144	18.164	16.674
J 450-460cm	39.178	48.846	3.108	27.869	24.771
J 450-460cm	26.823	32.523	1.791	15.226	13.656
J 450-460cm	35.265	39.054	3.17	12.279	8.522
Specimen	Top Width	Maximum Width	Curve Depth	Height 1	Height 2
<i>O grandiglumis</i> PA-1	35.348	50.399	5.815	21.784	18.168
<i>O grandiglumis</i> PA-1	35.651	41.8	3.293	15.998	13.515
<i>O grandiglumis</i> PA-1	29.371	36.091	4.991	12.467	11.434
<i>O grandiglumis</i> PA-1	31.867	37.002	3.446	19.06	16.055
<i>O grandiglumis</i> PA-1	22.971	27.681	8.284	19.565	16.309
<i>O grandiglumis</i> PA-1	21.526	26.665	3.716	9.365	8.082
<i>O grandiglumis</i> PA-1	33.267	40.812	8.005	20.016	16.363
<i>O grandiglumis</i> PA-1	29.648	34.686	5.576	15.1	13.38
<i>O grandiglumis</i> PA-1	30.453	37.228	5.501	13.385	14.051
<i>O grandiglumis</i> PA-1	40.928	54.123	0.617	17.194	12.23
<i>O grandiglumis</i> PA-1	22.462	31.665	4.152	15.964	15.557
<i>O grandiglumis</i> PA-1	18.335	25.277	6.481	13.115	13.114
<i>O grandiglumis</i> PA-1	22.933	36.951	5.439	24.178	20.081
<i>O grandiglumis</i> PA-1	35.174	41.22	7.589	13.853	13.814
<i>O grandiglumis</i> PA-1	26.113	31.065	6.596	11.139	11.035
<i>O grandiglumis</i> PA-1	38.2	44.094	3.672	14.747	14.3
<i>O grandiglumis</i> PA-1	25.255	28.353	6.476	14.241	14.447
<i>O grandiglumis</i> PA-1	36.848	42.133	5.293	16.633	14.454
<i>O grandiglumis</i> PA-1	26.224	33.891	5.136	15.278	13.882
<i>O grandiglumis</i> PA-1	22.683	31.285	5.165	13.37	12.563
<i>O grandiglumis</i> So-23	29.971	33.255	7.16	17.401	16.021
<i>O grandiglumis</i> So-23	27.699	35.862	5.287	19.311	18.295
<i>O grandiglumis</i> So-23	23.038	29.619	4.857	12.809	9.613
<i>O grandiglumis</i> So-23	26.536	35.619	6.145	14.525	14.04
<i>O grandiglumis</i> So-23	27.093	36.289	6.066	13.679	13.396
<i>O grandiglumis</i> So-23	30.434	33.563	9.376	16.515	12.82
<i>O grandiglumis</i> So-23	24.575	28.669	8.736	23.639	16.404
<i>O grandiglumis</i> So-23	33.142	42.071	7.144	23.447	22.328
<i>O grandiglumis</i> So-23	24.31	28.583	5.179	17.727	13.144
<i>O grandiglumis</i> So-23	30.374	33.933	5.875	13.024	12.734
<i>O grandiglumis</i> So-23	27.514	30.919	9.707	16.394	13.153
<i>O grandiglumis</i> So-23	31.414	33.783	7.331	12.927	14.002
<i>O grandiglumis</i> So-23	32.164	33.393	2.442	12.472	10.845
<i>O grandiglumis</i> So-23	27.383	33.119	5.568	15.92	14.483
<i>O grandiglumis</i> So-23	30.635	33.088	6.246	17.683	14.757
<i>O grandiglumis</i> So-23	24.104	27.981	3.183	10.5	10.023
<i>O grandiglumis</i> So-23	20.941	26.967	7.557	16.64	16.365
<i>O grandiglumis</i> So-23	22.763	29.421	3.911	11.06	8.572
<i>O grandiglumis</i> So-23	33.317	36.066	5.52	22.2	17.911

<i>O.grandiglumis</i> So-23	23.706	25.432	5.092	11.494	9.498
<i>O.grandiglumis</i> PU-1	34.21	38.973	4.925	14.597	12.943
<i>O.grandiglumis</i> PU-1	45.934	48.499	3.092	13.85	11.608
<i>O.grandiglumis</i> PU-1	44.377	48.243	7.235	22.21	17.381
<i>O.grandiglumis</i> PU-1	30.963	34.162	5.088	17.226	16.157
<i>O.grandiglumis</i> PU-1	35.661	39.173	5.163	14.022	12.925
<i>O.grandiglumis</i> PU-1	21.262	26.128	4.224	10.829	9.48
<i>O.grandiglumis</i> PU-1	40.871	49.964	3.363	17.932	17.166
<i>O.grandiglumis</i> PU-1	19.082	28.338	5.098	14.326	12.012
<i>O.grandiglumis</i> PU-1	41.269	42.269	4.894	17.763	15.866
<i>O.grandiglumis</i> PU-1	23.005	33.882	6.355	17.669	13.338
<i>O.grandiglumis</i> PU-1	38.814	38.877	5.943	19.357	18.689
<i>O.grandiglumis</i> PU-1	45.009	44.712	5.044	12.36	9.913
<i>O.grandiglumis</i> PU-1	37.261	42.249	10.969	22.052	16.987
<i>O.grandiglumis</i> PU-1	22.962	27.162	6.923	13.229	11.149
<i>O.grandiglumis</i> PU-1	32.523	35.14	8.253	18.956	16.658
<i>O.grandiglumis</i> PU-1	35.367	39.635	8.622	19.667	19.205
<i>O.grandiglumis</i> PU-1	30.531	32.748	6.754	17.446	15.554
<i>O.grandiglumis</i> PU-1	21.203	26.556	5.347	14.145	12.732
<i>O.grandiglumis</i> PU-1	44.361	50.162	6.507	19.941	16.379
<i>O.grandiglumis</i> PU-1	26.893	32.155	7.385	16.031	14.745
<i>O.grandiglumis</i> R.japurá	34.174	40.81	4.923	18.293	12.125
<i>O.grandiglumis</i> R.japurá	32.011	38.252	7.063	17.424	15.62
<i>O.grandiglumis</i> R.japurá	17.03	23.817	4.511	13.74	6.212
<i>O.grandiglumis</i> R.japurá	33.008	36.75	8.049	18.77	15.462
<i>O.grandiglumis</i> R.japurá	34.966	38.746	6.964	14.279	12.244
<i>O.grandiglumis</i> R.japurá	26.631	33.481	4.694	11.636	10.821
<i>O.grandiglumis</i> R.japurá	31.463	33.975	7.786	16.114	15.969
<i>O.grandiglumis</i> R.japurá	42.877	45.938	4.761	14.636	14.19
<i>O.grandiglumis</i> R.japurá	23.312	32.517	5.112	16.76	12.285
<i>O.grandiglumis</i> R.japurá	35.144	40.189	5.237	13.634	8.875
<i>O.grandiglumis</i> R.japurá	29.763	32.726	4.139	13.036	9.987
<i>O.grandiglumis</i> R.japurá	23.195	31.407	6.378	15.495	13.772
<i>O.grandiglumis</i> R.japurá	32.609	42.914	3.916	16.752	12.724
<i>O.grandiglumis</i> R.japurá	19.872	26.564	4.305	15.415	14.945
<i>O.grandiglumis</i> R.japurá	22.026	36.384	8.24	19.398	19.067
<i>O.grandiglumis</i> R.japurá	24.858	32.044	2.92	16.869	15.015
<i>O.grandiglumis</i> R.japurá	42.542	44.201	8.476	14.699	12.462
<i>O.grandiglumis</i> R.japurá	26.423	29.077	3.975	16.612	10.296
<i>O.grandiglumis</i> R.japurá	26.086	31.199	4.837	18.596	15.525
<i>O.grandiglumis</i> R.japurá	27.45	33.364	2.124	12.433	10.733
<i>O.glumaepatula</i> SO-17	33.96	34.161	3.785	15.506	9.358
<i>O.glumaepatula</i> SO-17	50.78	58.774	2.533	22.122	18.866
<i>O.glumaepatula</i> SO-17	35.171	40.752	3.6	16.525	14.58
<i>O.glumaepatula</i> SO-17	48.65	58.368	3.042	20.564	16.958
<i>O.glumaepatula</i> SO-17	24.338	27.275	2.377	12.018	11.907

<i>O. glumaepatula</i> SO-17	42.807	49.375	4.522	16.335	12.889
<i>O. glumaepatula</i> SO-17	27.451	30.59	1.548	13.436	11.763
<i>O. glumaepatula</i> SO-17	30.64	37.203	0.582	15.787	15.047
<i>O. glumaepatula</i> SO-17	44.038	57.097	4.472	19.271	18.935
<i>O. glumaepatula</i> SO-17	42.549	50.732	4.784	13.67	13.497
<i>O. glumaepatula</i> SO-17	41.691	44.823	2.117	15.392	13.481
<i>O. glumaepatula</i> SO-17	35.259	49.958	3.013	14.39	10.426
<i>O. glumaepatula</i> SO-17	34.592	36.812	0.288	12.339	10.485
<i>O. glumaepatula</i> SO-17	21.625	25.796	3.014	15.023	13.812
<i>O. glumaepatula</i> SO-17	45.648	52.287	4.182	14.798	14.653
<i>O. glumaepatula</i> SO-17	37.74	42.989	1.981	14.035	12.991
<i>O. glumaepatula</i> SO-17	43.9	46.919	4.107	17.406	14.696
<i>O. glumaepatula</i> SO-17	24.191	30.946	3.213	13.896	13.67
<i>O. glumaepatula</i> SO-17	29.042	35.135	2.298	15.215	11.817
<i>O. glumaepatula</i> SO-17	44.987	48.432	2.565	14.744	18.117
<i>O. glumaepatula-Devevú</i>	38.486	42.763	1.16	10.842	10.627
<i>O. glumaepatula-Devevú</i>	27.402	39.108	3.414	10.738	10.424
<i>O. glumaepatula-Devevú</i>	35.743	36.986	4.478	7.907	7.85
<i>O. glumaepatula-Devevú</i>	27.768	31.474	1.898	12.826	12.617
<i>O. glumaepatula-Devevú</i>	38.971	42.801	2.105	9.873	8.113
<i>O. glumaepatula-Devevú</i>	17.475	27.389	2.432	13.827	13.103
<i>O. glumaepatula-Devevú</i>	22.148	35.239	2.943	14.806	14.23
<i>O. glumaepatula-Devevú</i>	25.75	28.831	3.387	9.78	9.129
<i>O. glumaepatula-Devevú</i>	29.873	37.774	3.186	10.994	9.7
<i>O. glumaepatula-Devevú</i>	22.199	28.006	1.313	9.912	9.775
<i>O. glumaepatula-Devevú</i>	20.187	27.464	2.493	12.414	11.86
<i>O. glumaepatula-Devevú</i>	43.165	45.665	4.233	12.529	8
<i>O. glumaepatula-Devevú</i>	30.987	36.399	3.16	10.432	8.343
<i>O. glumaepatula-Devevú</i>	21.338	25.824	2.174	7.645	7.53
<i>O. glumaepatula-Devevú</i>	18.525	23.308	2.228	7.718	7.434
<i>O. glumaepatula-Devevú</i>	24.941	34.541	2.241	10.572	9.667
<i>O. glumaepatula-Devevú</i>	43.001	46.286	4.121	11.916	10.826
<i>O. glumaepatula-Devevú</i>	36.748	41.951	3.666	10.865	10.742
<i>O. glumaepatula-Devevú</i>	28.845	36.131	2.69	11.216	9.328
<i>O. glumaepatula-Devevú</i>	38.486	42.763	1.16	10.842	10.627
<i>O. glumaepatula</i> kiv	15.962	25.225	2.442	10.07	9.268
<i>O. glumaepatula</i> kiv	55.633	59.196	1.509	12.963	12.904
<i>O. glumaepatula</i> kiv	44.642	49.218	4.192	16.908	14.081
<i>O. glumaepatula</i> kiv	21.982	33.6	1.117	15.255	13.639
<i>O. glumaepatula</i> kiv	32.266	41.209	3.476	13.977	13.398

<i>O.glumaepatula</i> kiv	41.805	47.086	2.856	15.086	12.863
<i>O.glumaepatula</i> kiv	28.122	34.385	0.28	10.15	6.217
<i>O.glumaepatula</i> kiv	31.742	40.363	4.559	15.573	15.116
<i>O.glumaepatula</i> kiv	30.612	40.376	2.816	17.313	16.279
<i>O.glumaepatula</i> kiv	33.61	37.56	0.606	12.433	11.385
<i>O.glumaepatula</i> kiv	33.833	42.146	2.463	15.383	14.337
<i>O.glumaepatula</i> kiv	46.766	50.116	2.88	14.926	14.753
<i>O.glumaepatula</i> kiv	34.153	36.848	3.986	17.222	15.869
<i>O.glumaepatula</i> kiv	49.035	54.552	1.553	10.925	9.088
<i>O.glumaepatula</i> kiv	40.638	42.803	5.099	14.182	13.955
<i>O.glumaepatula</i> kiv	60.822	65.967	0.824	14.118	13.216
<i>O.glumaepatula</i> kiv	31.224	46.915	2.895	21.959	14.617
<i>O.glumaepatula</i> kiv	35.261	43.808	0.68	13.358	12.912
<i>O.glumaepatula</i> kiv	32.906	39.941	4.488	20.857	14.046
<i>O.glumaepatula</i> kiv	37.299	43.424	3.283	14.692	14.15
<i>O.glumaepatula</i> PU-1	43.803	49.787	3.807	9.654	8.415
<i>O.glumaepatula</i> PU-1	30.226	34.877	2.767	11.557	11.159
<i>O.glumaepatula</i> PU-1	42.744	50.679	1.391	9.882	9.7
<i>O.glumaepatula</i> PU-1	40.522	47.964	3.561	13.171	11.494
<i>O.glumaepatula</i> PU-1	46.11	49.777	0.363	10.317	9.349
<i>O.glumaepatula</i> PU-1	38.079	41.893	2.265	9.831	9.087
<i>O.glumaepatula</i> PU-1	23.401	30.262	2.124	7.184	6.98
<i>O.glumaepatula</i> PU-1	39.952	44.994	2.291	12.838	12.716
<i>O.glumaepatula</i> PU-1	40.243	45.286	2.547	11.351	10.887
<i>O.glumaepatula</i> PU-1	44.656	53.291	2.011	16.48	12.308
<i>O.glumaepatula</i> PU-1	31.301	40.523	1.307	10.405	8.299
<i>O.glumaepatula</i> PU-1	38.675	43.765	2.393	12.972	9.648
<i>O.glumaepatula</i> PU-1	42.407	49.795	2.148	14.097	10.421
<i>O.glumaepatula</i> PU-1	36.222	43.972	1.665	12.992	12.468
<i>O.glumaepatula</i> PU-1	37.585	44.828	1.573	14.703	14.578
<i>O.glumaepatula</i> PU-1	34.325	40.711	3.911	12.319	12.311
<i>O.glumaepatula</i> PU-1	41.586	44.325	3.794	13.294	12.59
<i>O.glumaepatula</i> PU-1	28.086	32.909	1.749	10.805	7.139
<i>O.glumaepatula</i> PU-1	27.866	34.562	1.598	10.318	8.726
<i>O.glumaepatula</i> PU-1	31.877	38.647	1.55	11.872	11.683
<i>O.latifolia</i> ARg7	44.308	41.941	4.139	19.592	18.377
<i>O.latifolia</i> ARg7	38.629	38.729	7.681	15.48	14.458
<i>O.latifolia</i> ARg7	44.708	51.026	7.915	17.419	17.172
<i>O.latifolia</i> ARg7	35.118	33.985	6.17	15.371	14.755
<i>O.latifolia</i> ARg7	35.674	33.859	3.156	13.7	11.013
<i>O.latifolia</i> ARg7	36.048	33.656	1.607	7.231	6.424
<i>O.latifolia</i> ARg7	27.985	26.06	5.951	13.696	12.693
<i>O.latifolia</i> ARg7	34.856	35.308	2.413	12.383	11.058
<i>O.latifolia</i> ARg7	28.067	35.38	2.527	14.651	14.651
<i>O.latifolia</i> ARg7	35.102	35.379	1.702	12.663	10.805

<i>O.latifolia</i> ARg7	35.599	40.639	0.617	9.215	7.011
<i>O.latifolia</i> ARg7	36.639	33.622	7.799	16.991	15.853
<i>O.latifolia</i> ARg7	41.143	43.88	5.295	18.922	18.162
<i>O.latifolia</i> ARg7	24.446	29.214	1.568	9.694	8.926
<i>O.latifolia</i> ARg7	30.78	35.75	4.55	10.448	7.781
<i>O.latifolia</i> ARg7	33.023	25.83	1.921	11.377	10.573
<i>O.latifolia</i> ARg7	33.531	30.575	2.145	9.802	8.204
<i>O.latifolia</i> ARg7	46.899	55.106	6.999	20.52	17.623
<i>O.latifolia</i> ARg7	44.449	42.725	2.948	12.268	11.095
<i>O.latifolia</i> ARg7	41.063	34.525	2.301	12.651	12.548
<i>O.latifolia</i> arg-8	57.74	65.529	3.433	20.094	17.763
<i>O.latifolia</i> arg-8	39.039	42.798	5.073	15.599	15.437
<i>O.latifolia</i> arg-8	50.921	51.039	4.975	19.836	18.259
<i>O.latifolia</i> arg-8	43.93	45.434	0.249	16.692	14.281
<i>O.latifolia</i> arg-8	41.542	46.911	4.221	14.921	14.57
<i>O.latifolia</i> arg-8	36.359	41.441	2.854	16.425	13.706
<i>O.latifolia</i> arg-8	50.964	51.448	3.596	15.12	13.386
<i>O.latifolia</i> arg-8	57.686	62.505	2.621	16.289	15.537
<i>O.latifolia</i> arg-8	64.345	64.978	4.092	15.912	15.658
<i>O.latifolia</i> arg-8	45.85	54.367	0.186	24.091	20.844
<i>O.latifolia</i> arg-8	38.483	45.012	3.597	20.817	19.895
<i>O.latifolia</i> arg-8	30.108	37.764	1.088	10.393	9.325
<i>O.latifolia</i> arg-8	33.93	34.77	2.199	13.571	12.788
<i>O.latifolia</i> arg-8	45.353	45.499	2.578	13.844	12.531
<i>O.latifolia</i> arg-8	41.377	49.962	4.202	19.508	17.292
<i>O.latifolia</i> arg-8	56.397	58.522	4.851	17.666	15.786
<i>O.latifolia</i> arg-8	52.783	56.143	0.768	13.904	13.433
<i>O.latifolia</i> arg-8	42.852	48.247	4.516	15.875	12.592
<i>O.latifolia</i> arg-8	43.355	44.399	2.77	14.433	13.416
<i>O.latifolia</i> arg-8	52.348	55.744	1.565	13.75	12.31
<i>O.latifolia</i> Arg-5	34.391	40.961	4.69	16.876	16.206
<i>O.latifolia</i> Arg-5	41.735	51.759	3.613	13.249	12.205
<i>O.latifolia</i> Arg-5	40.837	46.971	6.038	24.936	20.217
<i>O.latifolia</i> Arg-5	38.317	41.609	3.359	23.091	21.982
<i>O.latifolia</i> Arg-5	26.958	36.327	3.26	15.61	13.506
<i>O.latifolia</i> Arg-5	43.983	58.088	5.922	20.368	18.385
<i>O.latifolia</i> Arg-5	24.453	27.27	3.215	16.79	11.966
<i>O.latifolia</i> Arg-5	34.844	45.211	5.003	19.988	18.275
<i>O.latifolia</i> Arg-5	23.042	28.759	4.317	11.794	10.79
<i>O.latifolia</i> Arg-5	59.673	66.589	5.337	20.851	21.245
<i>O.latifolia</i> Arg-5	46.077	51.19	5.378	12.746	9.333
<i>O.latifolia</i> Arg-5	36.343	39.61	2.991	17.729	16.562
<i>O.latifolia</i> Arg-5	46.875	46.703	5.626	17.748	16.741
<i>O.latifolia</i> Arg-5	52.603	62.348	5.504	24.262	20.777
<i>O.latifolia</i> Arg-5	21.792	25.79	4.338	13.098	7.606
<i>O.latifolia</i> Arg-5	33.3	38.527	3.712	15.32	11.791

<i>O.latifolia</i> Arg-5	46.749	51.455	9.427	16.028	15.19
<i>O.latifolia</i> Arg-5	37.432	36.503	4.367	19.631	15.136
<i>O.latifolia</i> Arg-5	47.274	50.386	6.292	19.493	14.012
<i>O.latifolia</i> Arg-5	34.038	38.837	6.462	19.795	13.284
<i>O.latifolia</i> Arg11	39.702	43.614	4.345	16.662	15.894
<i>O.latifolia</i> Arg11	30.479	40.677	6.711	17.469	15.098
<i>O.latifolia</i> Arg11	33.81	39.035	5.168	17.487	15.654
<i>O.latifolia</i> Arg11	36.656	39.101	4.766	15.41	12.496
<i>O.latifolia</i> Arg11	38.096	47.128	3.813	14.182	11.908
<i>O.latifolia</i> Arg11	27.362	33.75	2.753	15.642	14.555
<i>O.latifolia</i> Arg11	40.914	44.241	7.042	20.096	13.479
<i>O.latifolia</i> Arg11	28.515	38.36	5.11	18.602	17.114
<i>O.latifolia</i> Arg11	30.751	37.666	5.65	16.25	14.816
<i>O.latifolia</i> Arg11	24.748	33.566	5.253	15.933	14.6
<i>O.latifolia</i> Arg11	33.493	40.972	8.844	21.84	18.684
<i>O.latifolia</i> Arg11	26.508	33.704	5.164	13.141	11.779
<i>O.latifolia</i> Arg11	23.992	31.427	6.289	12.979	12.785
<i>O.latifolia</i> Arg11	32.931	39.998	2.963	15.963	14.014
<i>O.latifolia</i> Arg11	39.689	45.212	6.571	19.254	19.01
<i>O.latifolia</i> Arg11	30.333	39.917	3.233	13.329	10.327
<i>O.latifolia</i> Arg11	31.82	35.608	3.138	18.238	15.036
<i>O.latifolia</i> Arg11	29.718	38.032	6.6682	21.089	19.724
<i>O.latifolia</i> Arg11	31.385	44.598	6.124	22.736	19.964
<i>O.latifolia</i> Arg11	35.514	39.521	6.199	11.917	11.579
<i>O.latifolia</i> 10	45.962	43.638	12.726	18.67	16
<i>O.latifolia</i> 10	38.675	34.408	11.361	14.718	12.403
<i>O.latifolia</i> 10	41.171	47.42	7.781	22.46	14.434
<i>O.latifolia</i> 10	37.976	40.279	7.967	16.014	14.058
<i>O.latifolia</i> 10	53.858	52.743	9.275	18.31	16.781
<i>O.latifolia</i> 10	19.46	25.541	4.476	15.127	13.951
<i>O.latifolia</i> 10	31.294	32.051	8.788	15.698	15.568
<i>O.latifolia</i> 10	30.067	33.274	9.747	17.48	17.05
<i>O.latifolia</i> 10	26.07	45.025	11.858	17.796	15.973
<i>O.latifolia</i> 10	37.225	38.022	11.648	17.798	16.584
<i>O.latifolia</i> 10	33.601	35.155	5.702	14.939	14.437
<i>O.latifolia</i> 10	34.996	38.992	8.643	17.785	16.103
<i>O.latifolia</i> 10	47.507	43.552	7.869	17.864	13.198
<i>O.latifolia</i> 10	34.039	36.579	6.743	16.535	12.633
<i>O.latifolia</i> 10	26.985	34.816	2.22	14.308	13.518
<i>O.latifolia</i> 10	37.181	34.584	6.33	16.478	14.557
<i>O.latifolia</i> 10	39.823	38.807	6.119	16.696	14.06
<i>O.latifolia</i> 10	46.326	43.447	11.737	18.099	17.606
<i>O.latifolia</i> 10	30.692	33.689	4.319	16.372	14.873
<i>O.latifolia</i> 10	33.901	36.228	2.166	17.948	17.362
<i>O.latifolia</i> 1	42.402	44.828	5.378	20.662	17.924

<i>O.latifolia</i> 1	42.407	49.854	3.142	15.136	13.56
<i>O.latifolia</i> 1	50.413	56.716	5.739	18.659	16.414
<i>O.latifolia</i> 1	31.313	35.077	2.292	13.481	12.878
<i>O.latifolia</i> 1	51.693	54.667	4.925	20.156	17.891
<i>O.latifolia</i> 1	21.697	24.604	3.152	11.846	10.081
<i>O.latifolia</i> 1	43.111	44.681	2.13	13.255	13.212
<i>O.latifolia</i> 1	48.628	53.082	6.362	15.729	15.305
<i>O.latifolia</i> 1	28.833	42.773	4.902	17.586	12.671
<i>O.latifolia</i> 1	33.961	40.392	4.9	15.555	13.349
<i>O.latifolia</i> 1	44.703	55.343	1.12	14.048	11.835
<i>O.latifolia</i> 1	44.925	45.457	5.898	19.482	18.952
<i>O.latifolia</i> 1	46.079	56.688	5.003	19.714	19.111
<i>O.latifolia</i> 1	39.834	43.675	4.246	14.073	14.005
<i>O.latifolia</i> 1	43.521	46.577	3.774	15.387	13.047
<i>O.latifolia</i> 1	45.536	46.032	4.256	17.703	15.788
<i>O.latifolia</i> 1	37.928	41.92	5.54	14.744	14.087
<i>O.latifolia</i> 1	27.201	36.576	5.005	16.832	13.133
<i>O.latifolia</i> 1	46.436	53.978	1.944	18.748	18.225
<i>O.latifolia</i> 1	39.615	47.918	6.515	14.924	14.322
<i>O.latifolia</i> 3	37.807	44.933	6.092	14.076	14.035
<i>O.latifolia</i> 3	37.332	43.611	3.661	16.696	12.265
<i>O.latifolia</i> 3	24.459	28.043	1.571	9.542	8.785
<i>O.latifolia</i> 3	26.482	34.258	1.5437	13.201	10.697
<i>O.latifolia</i> 3	29.969	35.032	2.934	12.94	9.601
<i>O.latifolia</i> 3	33.226	42.519	6.53	21.663	11.426
<i>O.latifolia</i> 3	34.393	40.09	2.833	16.367	14.186
<i>O.latifolia</i> 3	34.846	42.177	2.213	12.454	8.849
<i>O.latifolia</i> 3	24.218	42.849	3.853	22.351	20.452
<i>O.latifolia</i> 3	41.177	48.533	2.728	12.355	12.183
<i>O.latifolia</i> 3	45.706	50.307	4.151	14.277	11.669
<i>O.latifolia</i> 3	27.037	32.71	3.265	16.231	11.934
<i>O.latifolia</i> 3	34.856	42.709	3.911	12.972	12.812
<i>O.latifolia</i> 3	38.869	47.247	0.431	11.4	9.173
<i>O.latifolia</i> 3	41.371	45.378	4.072	20.265	14.122
<i>O.latifolia</i> 3	35.071	40.987	1.882	10.2	10.138
<i>O.latifolia</i> 3	31.372	38.344	2.43	11.595	10.055
<i>O.latifolia</i> 3	23.666	27.292	1.566	8.845	7.998
<i>O.latifolia</i> 3	27.632	39.662	4.507	15.147	12.744
<i>O.latifolia</i> 3	33.899	36.327	2.601	15.771	15.23
<i>O.latifolia</i> 2	23.3	32.466	6.318	14.574	12.042
<i>O.latifolia</i> 2	38.219	47.349	10.407	19.054	18.779
<i>O.latifolia</i> 2	34.816	46.582	3.774	17.598	15.514
<i>O.latifolia</i> 2	23.846	28.294	1.705	10.494	8.498
<i>O.latifolia</i> 2	30.847	42.205	7.391	14.604	13.148
<i>O.latifolia</i> 2	33.06	42.573	7.157	18.026	17.738
<i>O.latifolia</i> 2	58.621	64.384	11.059	20.806	19.849

<i>O.latifolia</i> 2	33.255	43.6	4.636	17.029	14.57
<i>O.latifolia</i> 2	43.467	50.996	5.187	18.832	17.851
<i>O.latifolia</i> 2	43.698	48.929	6.473	15.189	14.697
<i>O.latifolia</i> 2	36.518	45.815	7.184	19.55	19.468
<i>O.latifolia</i> 2	39.833	45.947	7.67	16.72	16.223
<i>O.latifolia</i> 2	34.838	41.987	7.91	16.212	15.889
<i>O.latifolia</i> 2	45.198	56.718	8.064	19.109	15.477
<i>O.latifolia</i> 2	44.168	50.265	9.077	18.969	18.548
<i>O.latifolia</i> 2	38.742	48.25	7.347	14.391	11.545
<i>O.latifolia</i> 2	40.878	48.851	8.015	19.692	19.61
<i>O.latifolia</i> 2	29.505	36.24	7.586	13.231	11.771
<i>O.latifolia</i> 2	23.731	30.282	4.841	12.296	11.595
<i>O.latifolia</i> 2	48.122	55.652	7.368	18.616	16.6
<i>O.latifolia</i> 4	37.208	43.528	2.495	18.261	15.377
<i>O.latifolia</i> 4	47.479	47.728	3.108	16.437	16.167
<i>O.latifolia</i> 4	50.682	51.646	2.269	14.175	14.09
<i>O.latifolia</i> 4	52.853	45.853	0.63	11.548	10.654
<i>O.latifolia</i> 4	38.192	43.59	2.703	13	11.67
<i>O.latifolia</i> 4	43.38	40.636	2.867	14.675	16.666
<i>O.latifolia</i> 4	48.003	52.197	3.662	15.674	14.53
<i>O.latifolia</i> 4	41.448	44.092	5.673	20.355	19.024
<i>O.latifolia</i> 4	53.951	59.349	3.194	15.876	15.495
<i>O.latifolia</i> 4	41.36	44.659	3.773	16.767	15.801
<i>O.latifolia</i> 4	41.36	36.064	3.42	13.218	11.467
<i>O.latifolia</i> 4	45.481	47.322	2.02	16.91	15.587
<i>O.latifolia</i> 4	50.171	52.074	3.884	16.852	16.142
<i>O.latifolia</i> 4	41.619	41.933	4.787	15.732	15.114
<i>O.latifolia</i> 4	50.605	45.893	1.851	13.992	12.091
<i>O.latifolia</i> 4	41.879	46.551	2.173	14.762	12.117
<i>O.latifolia</i> 4	40.12	42.435	3.039	15.471	14.11
<i>O.latifolia</i> 4	34.456	41.211	2.191	10.897	10.222
<i>O.latifolia</i> 4	54.417	62.462	5.045	18.534	17.898
<i>O.latifolia</i> 4	38.168	40.871	4.175	16.21	15.073
<i>O.alta</i> RI	30.419	34.486	5.995	15.489	15.252
<i>O.alta</i> RI	20.693	34.024	1.472	15.406	14.444
<i>O.alta</i> RI	38.134	46.356	4.47	24.373	23.094
<i>O.alta</i> RI	27.591	30.699	1.885	9.666	10.898
<i>O.alta</i> RI	38.195	40.075	6.278	17.913	16.191
<i>O.alta</i> RI	36.967	42.096	5.454	22.61	18.024
<i>O.alta</i> RI	30.262	39.777	5.335	16.391	12.32
<i>O.alta</i> RI	42.467	43.32	6.224	14.855	14.244
<i>O.alta</i> RI	28.941	36.119	2.664	14.148	11.869
<i>O.alta</i> RI	24.526	36.346	2.312	17.7	17.011
<i>O.alta</i> RI	34.96	40.699	2.62	26.051	21.565
<i>O.alta</i> RI	39.614	51.359	0.1	15.091	13.733
<i>O.alta</i> RI	25.462	41.819	6.305	20.647	19.172

<i>O.alta</i> RI	26.333	34.472	6.18	15.346	14.125
<i>O.alta</i> RI	40.614	53.235	4.848	24.166	21.391
<i>O.alta</i> RI	45.537	53.194	7.576	23.145	16.403
<i>O.alta</i> RI	32.136	39.908	4.019	14.72	13.455
<i>O.alta</i> RI	34.487	40.631	5.522	21	17.47
<i>O.alta</i> RI	43.405	48.366	4.329	16.608	16.171
<i>O.alta</i> AI-1	34.338	43.631	2.866	14.652	9.898
<i>O.alta</i> AI-1	25.665	27.937	3.774	8.861	8.382
<i>O.alta</i> AI-1	29.222	35.412	3.223	11.763	10.583
<i>O.alta</i> AI-1	27.807	30.199	3.711	13.534	13.083
<i>O.alta</i> AI-1	29.217	35.844	5.119	15.051	9.08
<i>O.alta</i> AI-1	30.782	39.255	4.592	13.955	11.115
<i>O.alta</i> AI-1	37.935	46.701	5	17.785	16.154
<i>O.alta</i> AI-1	23.212	30.986	1.126	11.239	10.694
<i>O.alta</i> AI-1	36.986	46.558	4.156	18.607	15.585
<i>O.alta</i> AI-1	33.797	43.623	3.623	15.346	15.202
<i>O.alta</i> AI-1	28.829	36.824	6.292	13.203	11.744
<i>O.alta</i> AI-1	29.748	41.041	2.906	16.188	15.297
<i>O.alta</i> AI-1	26.962	30.463	1.797	14.471	13.012
<i>O.alta</i> AI-1	40.509	44.733	4.686	13.329	12.99
<i>O.alta</i> AI-1	31.137	31.569	6.254	16.72	13.849
<i>O.alta</i> AI-1	30.866	43.405	4.184	18.649	15.992
<i>O.alta</i> AI-1	37.161	42.002	1.934	18.15	13.82
<i>O.alta</i> AI-1	33.737	47.234	3.647	20.358	18.288
<i>O.alta</i> AI-1	24.224	32.044	4.993	19.06	14.831
<i>O.alta</i> AI-1	41.743	47.252	9.278	21.753	21.373

Total double peaked glume:700 Total measurements: 3,500

**APPENDIX 4:
ORYZA AVERAGE MEASUREMENTS**

Layer/Specie	Depth	TW	MW	CD	H1	H2
CAMADA A	30-40 cm	36.50325	57.1733	5.44655	25.6144	22.54895
CAMADA B	50-60 cm	37.56435	49.55225	5.1955	22.3403	20.48245
CAMADA C	70-80 cm	41.7516	54.14985	5.4087	21.7918	19.2874
CAMADA D PN75	90-100 cm	40.93475	51.08335	4.15695	19.11255	17.63315
CAMADA D PN1003	130 cm	40.8595	51.6219	4.1882	18.7278	17.28305
CAMADA D PN64	130-140 cm	37.558	49.6404	4.05835	20.40535	18.3032
CAMADA D-E PN65	140 cm	41.21865	49.85	4.90925	19.5719	16.9663
CAMADA E	140-150 cm	35.1959	45.96125	3.8519	18.7006	17.49755
CAMADA F PN111	200-210 cm	37.36685	49.5469	3.6615	18.90285	16.28115
CAMADA G PN1007.2	220-230 cm	36.23215	46.66905	3.39665	16.93395	15.53115
CAMADA H PN126	260-270 cm	33.12935	49.59605	3.366	21.00355	18.3441
CAMADA I	350-360 cm	38.35115	47.21325	3.29745	17.70005	16.15425
CAMADA j C PN112	390-400 cm	36.73175	46.08535	3.28745	17.07665	15.53975
CAMADA J PN137	400-410 cm	34.88735	47.14395	3.28365	18.9981	15.9515
CAMADA J PN142	420-430 cm	34.5056	44.13385	2.9802	16.07645	14.4368
CAMADA J PN159	450-460 cm	36.048	48.3516	2.5464	17.15515	15.18765
<i>O. alta</i>	-	32.541425	40.096225	4.322375	16.906425	14.844825
<i>O. latifolia</i>	-	38.38048889	43.00164444	4.733855	16.12187222	14.36508889
<i>O. glumeopatula</i>	-	35.11345	41.3339	2.61655	13.293975	11.868975
<i>O. grandiglumis</i>	-	29.5424625	35.12725	5.6257375	15.8327125	13.6804125

APPENDIX 5:

**PAIRWISE COMPARISON OF OVERALL *ORYZA*
PHYTOLITH SIZE**

	A	B	C	D	DE	E	F	G	H	I	J	OA LT	OG G	OG P
B	0.53 7													
C	1.00 0	1.00 0												
D	0.00 0	1.00 0	0.62 2											
DE	0.00 2	1.00 0	1.00 0	1.00 0										
E	0.00 0	0.49 5	0.02 6	1.00 0	1.00 0									
F	0.00 0	1.00 0	0.14 1	1.00 0	1.00 0	1.00 0								
G	0.00 0	1.00 0	0.23 8	1.00 0	1.00 0	1.00 0	1.00 0							
H	0.00 2	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0						
I	0.00 0	0.05 6	0.00 2	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0	1.00 0					
J	0.00 0	0.00 0	0.00 0	0.00 4	0.52 2	1.00 0	1.00 0	1.00 0	0.71 9	1.00 0				
OA LT	0.00 0	0.00 0	0.00 0	0.00 0	0.00 6	1.00 0	0.34 8	0.19 3	0.00 9	1.00 0	1.00 0			
OG G	0.00 0	0.00 0	0.00 0	0.00 0	0.00 0	0.00 2	0.00 0	0.00 0	0.00 0	0.05 9	0.00 0	1.00 0		
OG P	0.00 0	0.00 0	0.00 0	0.00 0	0.00 0	0.00 1	0.00 0	0.00 0	0.00 0	0.04 1	0.00 0	1.00 0	1.00 0	
OL AT	0.00 0	0.00 0	0.00 0	0.00 0	0.01 1	1.00 0	0.98 2	0.52 6	0.01 9	1.00 0	1.00 0	1.00 0	0.00 1	0.00 0

Results of pairwise comparison of overall phytolith size (mean Height * mean Width) of archaeological and wild reference specimens using a Bonferroni corrected p-value. Highly significant differences among samples ($p < 0.001$) are shaded in dark grey. Significantly different specimens ($p < 0.05 - 0.01$) are shown in light grey. Phytoliths in the A layer are largest compared to all specimens, and phytoliths in the DE layers show a shift towards larger specimens.

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