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Domestication in Motion: Macrofossils of Pre-Colonial Brazilian Nuts, Palms and Other Amazonian Planted Tree Species Found in the Upper Purus

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1. Introduction

Decades ago, some scholars already doubted the generalised theory of the pristine Amazonian forest (Balée, 1989; Denevan, 1992). However, it has only been due to the advance of contemporary deforestation, and archaeological research conducted in the Lower and Central Amazon river, in the Xingú as well as in the Bolivian Mojos and Baures regions (Erickson, 2000, 2006; Heckenberger et al., 2003; Heckenberger et al., 2008; Neves and Petersen, 2006; Roosevelt, 2013; Roosevelt et al., 1991) that our understanding of past human impact on Amazonia has started to change. Most notably, the recent discovery of ancient roads and more than 500 geoglyph-type earthwork sites in southwestern Amazonia, especially in the Brazilian Acre state, covering about 60,000 km² of currently deforested area (Fig. 1), revolutionised academic thinking about human occupation and anthropogenic forests in South America. Not only floodplains, but also interfluvial *terra firme* environments have supported dense human populations (Pärssinen et al., 2003; Pärssinen et al., 2009; Ranzi and Simas de Aguiar, 2001). In general, most ditched geometric earthworks in the Purus River Basin seem to have been built between *ca.* 250 BC and 950 AD, and there is evidence that they were ceremonial sites (Saunaluoma, 2013; Saunaluoma et al., 2018; Schaan et al., 2012; Virtanen and Saunaluoma,

2017). These earthwork-building societies have challenged the existing theories of human-environment interactions and pre-colonial crop-domestication (Clements et al., 2010; Levis et al., 2017; Virtanen and Saunaluoma, 2017; Watling et al., 2015, 2017).

The oldest known carbonized Brazil nuts (*Bertholletia excelsa*) as well as *Attalea microcarpa* and *Astrocaryum vulgare* palm seed remains used by humans were found in the Pedra Pintada Cave, dated to 11,000 BP (Roosevelt et al., 1996). According to current evidence, the actual domestication of many Amazonian rainforest fruits, nuts, and root plants started around 8,000 BP (Clement et al., 2010; see also Levis et al., 2017; Piperno, 2011; Thomas et al., 2015). In this article, we identify which tree species were cultivated in two pre-colonial archaeological sites discovered in the Purus River Basin and explore their management. We show how the management of some tree species, and palms in particular, was based on indigenous ideas of care, respect, and protection, as well as complex parallel and non-linear domestication activities.

The concept of plant domestication has generally been understood as a continuous and lineal process of human and botanical interaction starting with the systematic use of wild plants by people and continuing through different intermediate stages to full domestication, distinguished by clear and observable genetic differences compared to wild ancestors. Recent genetic studies have isolated many determinants of domestication-related traits, and in fact, even in cases where the level of full domestication has been reached earlier in the past, additional *improvements* can regularly be detected (e.g. Olsen and Wendel, 2013). Furthermore, according to Pickersgill (2007), genetic modifications “constitute the domestication syndrome and generally render the domesticate less capable of survival” in the natural environment.

Defining domestication in the Amazonian context, nevertheless, is quite a complex issue due to various factors. For example, the constitution of the domestication syndrome is difficult to confirm before the level of domestication of each species can be defined. It must be also noted that even though pollen and macrofossil analysis of sediment samples have been extremely useful in detecting the presence of wild and domesticated plant species, pollen and macro-remains rarely survive in acidic and weathered Amazonian soil, and permanent lakes with pollen or macrofossils in their sediments are equally rare in interfluvial archaeological sites. The interfluvial *terra firme* zone seems to form more than 85% of the entire Amazonia (Bush et al., 2015; Hess et al., 2015). Phytoliths survive better in tropical soil and this is why phytolith studies are currently an important line of research in Amazonian palaeobotanical studies. Phytoliths have often allowed the identification of plant families, such as palms (*Arecaceae*) (Piperno et al., 2015) or even domesticated species, such as corn (*Zea mays*) and squash (*Cucurbita* sp.) (e.g. Watling et al., 2015). However, plants like chili pepper (*Capsicum* sp.) and sweet potato (*Ipomoea batatas*), or many Amazonian trees do not produce diagnostic phytoliths. Therefore, Amazonian phytolith studies have their obvious limitations. Even when the presence of palm trees can be detected by analysing phytoliths, their species may remain unknown as well as whether these are wild or domesticated plants. These limitations complicate our understanding of domestication, even if new terms have been introduced, such as “semidomesticated plants” (e.g. Balée, 1989; Heckenberger and Neves 2009), or more detailed definitions, such as “incidentally co-evolved” and “incipiently domesticated” plants, which are aimed at describing varieties classified as neither wild nor semi-domesticated, but something in between (Clement, 1999). These more fine-graded studies, in turn, are used to analyse contemporary plant species, such as peach palm, and the measurements are based on the size or weight of their fruits (Clement et al.,

2010, 2017; Henderson, 2000; Mora-Urpí et al., 1997). Unfortunately, in an archaeological context the original weight of the fruits may be hard to establish by using silted or carbonized pieces and even the size can only be measured when a macrofossil is not too fragmented. Nevertheless, macrofossils are among the most important first-hand pieces of evidence of consumed and otherwise used plants of ancient societies in the past.

Recently, through phytolith analysis, it has been demonstrated that at least corn (*Zea mays*) and squash (*Cucurbita* sp.) were present in the strata excavated in 2012 and dated between the first and seventh century AD of the Tequinho earthwork site located in the Brazilian State of Acre. Phytoliths of *Heliconia* and Strelitziaceae as well as of many palms were also recovered, but the exact species were undetermined (Watling et al., 2015). Nevertheless, during our archaeological excavations carried out in 2013 and 2014 in the same Tequinho site, 210 macrofossils were sampled, of which 192 were identifiable. Furthermore, in the Cruzeirinho site, six additional macrofossils were identified. Even if the earthwork sites were used as ceremonial sites without permanent occupation, these findings shed new light on the consumption practices by the builders and the people participating in the religious ceremonies organised in these sites, especially regarding the use of Brazil nuts and palm fruits, and consequently indigenous plant domestication processes in southwestern Amazonia. Domestication seems to have formed a part of multifaceted plant management system created by people constructing roads and ceremonial centres; so one could say that these people were “domesticating entire landscapes” (see, e.g. Erickson, 2006; Levis et al., 2018).

2. Studied sites, material and methods

Our main study area was the site of Tequinho, which is located in a *terra firme* of southwestern Amazonia drained by the upper tributaries of the Purus River, situated near the Acre state capital Rio Branco (Fig.1). Currently, the entire area is heavily deforested due to farming activities. The typical vegetation found in the region is a mosaic of *terra firme* forest formed by two forest types: (1) a more heterogeneous, tree-rich forest with a dominant palm stand in the forest understory (“palm open forest”), and (2) a more homogeneous forest, with a poor tree stand and an understory dominated by a few arborescent bamboo species (*Guadua* spp.) (“bamboo open forest”) (Acre, 2006). Within both forest types it is possible to find a variety of palm species and Brazil nut trees. Furthermore, Balée et al. (2014) did a forest inventory atop an earthwork (Três Vertentes), located some 45 km northeast of the Tequinho archaeological site, and classified the vegetation as liana forest with some remnants of open palm forest.

The Tequinho geoglyph site covers an area of approximately 15 hectares, consisting of a ditched enclosure with three concentric ditches and adjacent embankments, as well as a structure which currently forms a three-sided square (U-form) with two concentric ditches. Additional embankments can also be observed inside and outside of the main enclosure (Fig. 2). Roads radiate from the largest enclosure in the four cardinal directions, and some other direct roads connect the two ditched enclosures (Virtanen and Saunaluoma, 2017). During the years 2012 – 2014, 17 test pits and a 24-meter-long trench were excavated in Tequinho. The archaeological excavations were mainly realised inside of the main enclosure with three concentric ditches. Because the interior open square of the main structure seems to have been cleared of all waste after each ceremony, the archaeological findings concentrated on the small mounds, embankments and ditches. It is important to note, nevertheless, that the small mounds seem to have been points of different ceremonial activities, and not permanent residential mounds.

The first eight pits (1x1 m) were excavated in 2012 and 2013 as part of familiarisation courses for local school children and university students under the direction of Dr. Denise Schaan and Dr. Sanna Saunaluoma. The results of these preliminary excavations are not included in this article. Nevertheless, we conducted mayor excavations in 2013 and 2014 in Tequinho on the mound where our colleagues had excavated Test Pits 1 and 2. On the northern side of those two test pits we decided to excavate a 20-meter-long, 2-meter-wide and 1.5 – 2.4-meter-deep trench (9L-D). In addition, on the eastern side of it, a 4-meter-long and 1-meter-wide additional trench (9EF) was excavated (Fig. 2). Furthermore, we excavated three additional test pits of 2 x 2 meters (Pits 10, 15 and 16) and six test pits of 2 x 1 meters (Pits 11, 12, 13, 14, 17 and 18).

Figure 1. Map of a part of the Upper Purus River Basin showing the current area of the known geoglyphs and the Tequinho and Cruzeirinho archaeological sites (grey dots) discussed in the text.

Figure 2. Plan of the Tequinho site showing the location of the test pits and a detailed structure of Trench 9L-F discussed in the text.

In Tequinho, all our test pits were excavated on observable cultural features, knowing that in these kinds of ceremonial sites open ground was regularly cleared and that only rarely can heavy cultural layers with ceramics or other objects be found in an ordinary open place. Nevertheless, in the sites selected for excavations, the depth of cultural layer varied from 100 to 465 cm. The lowest cultural layers were measured in the pits situated on internal and external embankments (Pits 12: 140cm; Pit 14: 100cm). The two embankments in question were accumulated mainly due to cleaning activities as was an embankment situated at the centre of the northern entrance (Pit 15: 220cm). As expected, the deepest cultural layers were found from sites situated over the original ditches (Pit 13: 390cm; Pit 18: 465cm). Most of the macrofossils, nevertheless, were found in the artificial mounds accumulated during serving ceremonies. The most important in this respect was the mound situated below Trench 9. Two smaller mounds below Pits 10 and 11 also had similar characteristics, and contained considerable numbers of macrofossils.

Our comparative study site is the Cruzeirinho geoglyph, built in a floodable area (*varzea*) located about 6 km east of the Boca do Acre city airport, in the Amazonas State (Pärssinen et al., 2009). The site has quite recently been uncovered from under a dense rainforest cover, and contains two quadrangular 210 m (structure 1) and 310 m (structure 2) wide embankments by their side with corresponding ditches, and with cardinally oriented roads. Structure 1 ends at a small lake which is full of water. Structures 1 and 2 are interconnected by a 30–35 m wide and 400 m long road bordered by embankments along both sides. Finally, a third rectangular

structure can be partly seen, but seems to be older and is situated below structure 2 (Fig. 3). Two test pits at Cruzeirinho were excavated in 2014. The first test pit (1 x 1 m) was made near the southern entrance of structure 2, but there were no finds. The second pit (U2, 1 x 1 m) was excavated on the embankment but near the edge of the ditch of structure 1. During this time ceramics, charcoal and macrofossils were found in the 110 cm deep cultural layer.

Figure 3. Plan of the Cruzeirinho site with the three main structures and the test pits mentioned in the text.

Our methods include archaeological excavations, identification of plant macrofossils, and ethnographic study, and analyses of indigenous oral histories and written colonial sources.

During each excavation, directed by the first author together with the fourth author (AR) and the late Denise Schaan, all artefacts and macrofossils were collected by using artificial 10 cm levels, and features were documented taking notes on natural stratigraphy.

Most macrofossils and ceramics were detected *in situ*. Nevertheless, all excavated soil was further systematically sieved by using a 7 mm dry mesh. Considering that all macrofossils and archaeological artefacts were adhered to the surrounding soil, most objects bigger than 5 mm could be found. In total ca. 127 tons of soil passed through sieving. Ordinary soil samples were also taken for future microscopic analysis. Charcoal from secure contexts was collected for radiocarbon dating, and these samples were analysed in the Ångström Laboratory of the University of Uppsala. All calibrations have been made by the OxCal v4.3 programme, using the Southern Hemisphere Atmospheric SHCal13 curve (Bronk Ramsey 2009, 2017). The first author also reviewed historical sources including the two manuscripts of Álvarez Maldonado's report of 1570 conserved in the General Archive of the Indies (Seville, Spain).

The second author has carried out the identification of plant macrofossils using the modern palm fruit collection deposited at the Herbarium of the Federal University of Acre (UFACPZ). Additional information was gathered from scanned images of fruit samples deposited at the New York Botanical Garden's Steere Herbarium (NY). In this paper the flattened, anastomosing and adherent outer endocarp fibre patterns and the position of the fertile pore displaced latitudinally as well as the two infertile pores displaced longitudinally in the endocarp have been used to distinguish *Bactris gasipaes* and its wild relative from all the other *Bactris* (Henderson, 2000). To uncover the fibre patterns typical of the endocarp surface of *Bactris gasipaes* var. *gasipaes* (domesticated peach palm) and *Bactris gasipaes* var. *chichagui*

(wild peach palm) (Ferreira, 1999), it was necessary to humidify their surfaces. The samples of all *Attalea phalerata* (uricuri) endocarps were unmistakable due to their typical shapes and fibre arrangement, both on the surface, where the fibres leave several parallel and longitudinal marks, and within the endocarp wall, where the fibres are arranged in distinct clusters.

The third author has carried out collaborative fieldwork work with the Manchineri (numbering 900 persons) along the Yaco River between 2004–2007 and with the Apurinã (numbering 8,000 persons) along the Purus River from 2013–2017. These Arawak-speaking peoples are the closest indigenous habitants today to the geoglyphs' sites, and their extensive oral histories on their ancient food consumption, environment management, practices, ways of living, as well as myths were discussed with the communities. The ecological knowledge and practices of these two indigenous groups are very important for the interpretation of the archaeological sites and macrofossils, even if the human occupation of Amazonia has changed drastically.

3. Results

3.1. First European accounts of southwestern Amazonian cultivated trees and other plant species

According to the very first European accounts of Amazonian plants from the 16th century, the horticultural plantation of fruit trees appears to be rather common. Gaspar de Carvajal, who documented (1541–1543) the expedition of Francisco de Orellana from the Andes to the Atlantic Ocean, mentions that in an Omagua village, situated between the current Juruá and Purus River confluences, they found “very large amounts of the very good biscuit that the Indians make of corn and yuca [manioc, *Manihot esculenta*]; and all kinds of fruits.” Somewhat later, in the

province that Carvajal called Picotas, Carvajal specifically says that there they observed “in several places planted (*sembrados*) fruit-trees” (de Carvajal, 1992). In southwestern Amazonia, not very far from the Upper Purus, Captain Pedro de Candia and Captain Perañúres [Pedro Anzúrez] tried to penetrate into Chuncho in 1538–1539 with 300 Spaniards and some 8,000 indigenous and blacks. Both of these two successive invasions failed due to the fact that the local inhabitants destroyed their own crops and escaped. Nevertheless, Cieza de León ([1553] 1991) writes that yuca was the principal food in Chuncho, and in a village called Sietelinga the expedition also found corn, peppers, sweet potatoes, and other foods. In some areas they only had the palm hearts that they took from the big palms that the indigenous peoples grew. This statement is confirmed in Álvarez Maldonado’s report (1570), who mentions “royal palms” (*palmas reales*)¹ and Brazil nuts (cultivated in locations the Spaniards called *almendrales*, almond groves) as among the most important edible plants in northern Chuncho (the Madre de Dios River region). In his report many other kinds of edible nuts and the hearts of different palms are also mentioned but without any specification. Furthermore, in his list of cultivated trees one can find species such as guajava (*Psidium guajava*), banana (*Musa* spp.),² cacao (*Theobroma cacao*), pineapple (*Ananas* spp.), abiu (*Pouteria lucuma*) and guanábana (*Annona muricata*). Among other cultivated plants he mentions species such as corn, pepper, sweet potato, “yam” (ñame), “many kinds of beans,” squash, peanuts (*Arachis hypogaea*), arracha (*Arracacia xanthorrhiza*) and “açipa” (probably *Pachyrhizus ahipa*) (Álvarez Maldonado, 1570). We do not have independent confirmation of his list from the same time period, but the cultivation of palms,

¹ The common name “palma real” is used to identify several palms, including species in *Mauritia*, *Attalea* and *Ceroxylon* genera.

² Bananas originated in Asia. According to current knowledge, bananas came to the New World from Western Africa or the Iberian Peninsula/Canary Islands probably not earlier than in the 16th century (e.g., Nayar 2010). If this is true, it is surprising how quickly banana cultivation was adopted in southwestern Amazonia during the same century – before Europeans conquered the region.

Brazil nuts, guajava, banana, pineapple, lucuma and many other species are independently confirmed by 17th century explorers such as Bolivar ([1621] 1906) and Recio de León ([1623] 1906).

3.2. List of Identified Macrofossils in Tequinho and Cruzeirinho

The Tequinho archaeological site is located *ca.* 200 kilometres north of the Madre de Dios River described earlier by Álvarez Maldonado (1570). One of the 18 test pits of Tequinho was excavated into an artificial mound, of *ca.* 2.2 meters height and *ca.* 30 meters diameter, situated on the western side of the main avenue leading to the site. After the initial pit 9A was made in the centre of the mound, we continued excavating in a west-east direction a 24-meter-long trench 9A-L into the mound (Fig. 2). The mound appeared to be some kind of redistribution point where food and beverages were deposited and served during different ceremonies. Some grinding stones, tens of thousands of sherds of high-quality drinking and serving vessels, and more than a hundred macrofossils were found at this particular location. In addition, we noticed that the hard shells of nuts had survived only when their soft stems were in an upward position, allowing the silt of the surrounding soil to penetrate the hard wall of the fruit shell. The silt prevented the total decomposition of the fruits, even though their shell walls were only minimally hardened by sunshine or fire. Despite the fact that only those shells survived whose stems happened to be in the correct position, we were still able to identify more than 100 Brazil nut shells in the Tequinho mound. This means that the mound must have been rich in nuts. Furthermore, taking into account that the recovered fruits were unbroken, this probably means that these Brazil nuts had been stored with their shells in the site, but were not prepared for consumption. In contrast, *Attalea*

phalerata in particular, and to some extent other palm fruits, were associated with archaeological levels that had been subject to heavy fire, and that also generally contained a good amount of broken ceremonial cooking and serving ceramics – all indicating active ceremonial use.

Macrofossils were also recovered from other test pits marked on Figure 2, and listed in Table 1. In addition, the small test pit (U2) excavated on an embankment of structure 1 from the Cruzeirinho site (Fig. 3) produced six identified and dated macrofossils.

Test pit	Species	Amount	Levels	Corresponding C14 date of the pit
Tequinho				
9K	<i>Bertholletia excelsa</i>	6	50 – 120 cm	
9J	<i>Bertholletia excelsa</i>	2	40 – 110 cm	
9I	<i>Attalea phalerata</i>	6	100 – 220 cm	*35 (95.4%) 210AD (150 cm below surface)
	<i>Bactris gasipaes</i> var. <i>chichagui</i>	1	150 – 160 cm	*46 (6.5%) 6BC, or 15 (85.2%) 140AD, or
	<i>Bactris gasipaes</i> var. <i>gasipaes</i>	1	210 – 220 cm	180 (3.8%) 202AD (210 cm b.s.)
	<i>Bertholletia excelsa</i>	1	60 – 70 cm	
9H	<i>Attalea phalerata</i>	4	30 – 210 cm	*46 (6.6%) 6BC, or 15 (83.9) 145AD, or
	<i>Bertholletia excelsa</i>	12	40 – 120 cm	178 (4.9%) 203AD (55 cm b.s.)
	<i>Spondias mombin</i>	1	20 – 30 cm	*123 (76.2%) 259AD, or 276 (19.2%) 340AD (160 cm b.s.)
9G	<i>Attalea phalerata</i>	7	60 – 140 cm	
	<i>Bertholletia excelsa</i>	11	50 – 110 cm	
9A	<i>Attalea phalerata</i>	2	20 – 140 cm	*Three combined C14 dates from levels
	<i>Bactris gasipaes</i> var. <i>gasipaes</i>	1	70 – 80 cm	100, 130 and 185 cm below surface: 25 (94.5%) 129AD
	Family <i>Arecaceae</i>	1	50 – 60 cm	
	<i>Bertholletia excelsa</i>	17	40 – 200 cm	
9B	<i>Bertholletia excelsa</i>	15	40 – 100 cm	
9C	<i>Bactris gasipaes</i> var. <i>chichagui</i>	1	70 – 80 cm	*2864 (16.1%) 2806 BC or 2760 (79.3%) 2481 BC (90 cm)
	<i>Bertholletia excelsa</i>	23	30 – 120 cm	
	Family <i>Lecythidaceae</i>	1	80 – 90 cm	
9D	<i>Bertholletia excelsa</i>	12	40 – 110 cm	*63 BC (95.4%) 124 AD (120cm)
9E	<i>Bertholletia excelsa</i>	9	40 – 110 cm	
9F	<i>Bertholletia excelsa</i>	6	60 – 100 cm	
10	<i>Attalea phalerata</i>	2	70 – 80 cm	
	<i>Bertholletia excelsa</i>	23	20 – 80 cm	

11	<i>Astrocaryum</i> sp.	1	40 – 50 cm	
	<i>Attalea phalerata</i>	1	40 – 50 cm	
	<i>Bactris gasipaes</i> var. <i>gasipaes</i>	1	50 – 60 cm	
	<i>Bertholletia excelsa</i>	7	40 – 90 cm	
	<i>Hevea brasiliensis</i>	1	60 – 70 cm	
	<i>Oenacarpus mapora</i>	1	50 – 60 cm	
12	<i>Bertholletia excelsa</i>	8	50 – 80 cm	
14	<i>Bertholletia excelsa</i>	1	60 – 70 cm	
15	<i>Bertholletia excelsa</i>	1	50 cm	
16	<i>Bertholletia excelsa</i>	1	40 cm	
18	<i>Gustavia</i> sp.	1	60 – 70 cm	*572 (94.8%) 666 AD (145 cm)
Cruzeirinho				
U2	<i>Attalea maripa</i>	1	20 – 30 cm	*Four samples dated between 119 – 518 AD (20-105 cm)
	<i>Attalea phalerata</i>	2	40 – 60 cm	
	<i>Bactris concinna</i>	1	30 – 40 cm	
	<i>Bactris gasipaes</i> var. <i>chichagui</i>	2	30 – 70 cm	

Table 1. Identified macrofossils excavated in Tequinho and Cruzeirinho. When more than one example is found, only the minimum and maximum levels are indicated. The amount of sieved soil derived from each pit is the following: Pit 9K: 8800 litres; Pit 9J: 8200 litres; Pit 9I: 9100 litres; Pit 9H: 9200 litres; Pit 9G: 6900 litres; 9A: 8800 litres; 9B: 8000 litres; 9C: 7200 litres; 9D: 6000 litres; 9E: 3000 litres; 9F: 3500 litres; 10: 8800 litres; 11: 2700 litres; 12: 2200 litres; 14: 2200 litres; 15: 4850 litres; 16: 5200 litres; 18: 6900 litres; U2: 1000 litres.

It is important to note that from the 151 fruits of *Bertholletia excelsa* collected from the Tequinho site, it was possible to measure the diameter of only 69. The results indicated an average diameter of 5.7 cm for the fruits (minimum and maximum diameters of 3.9 cm and 6.6 cm; standard deviation=5.1 and coefficient of variation=8.88%). Today, Brazil nut fruits measure from *ca.* 11 to 15 cm in diameter (Shepard and Ramirez, 2011) (Fig. 4). One explanation for this

may be that both wild and incipiently domesticated fruits were collected, but only the larger fruits were opened and consumed, while the smaller, wild examples were left unbroken at the site (as only unbroken fruits were found). This would have meant a secondary selection process realised in ceremonial sites. Another alternative and most probable explanation for the bigger Brazil nut fruits found today is the continued selection made by the ancient indigenous people in order to save Brazil nut trees bearing bigger fruits, and, in general, use bigger fruits for planting and cultivation while unwanted trees may have been cut down for log wood use. This supported the idea of the species being mainly dispersed by humans during the past two thousand years (Shepard and Ramirez, 2011; Thomas et al., 2015) and the suggestion that today Amazonian Brazil nut trees are incipient domesticated species (Clement, 1999). However, this would mean that the macrofossils of *Bertholletia excelsa* found are more likely of the wild species (diameters from 3.9 to 6.6 cm) and the actual process of domestication of Brazil nut trees toward current incipiently domesticated species (diameter of ca. 11 to 15 cm) was not initiated in Acre before the Current Era. The heavily carbonized fruits of peach palm (*Bactris gasipaes*) in Tequinho were clearly from both domesticated and wild species. Just like cultivated and wild peach palm found throughout the Amazon today, where the fruits and endocarps are clearly size distinct (see Figure 2 in Clement et al., 2009; Clement et al., 1999), the endocarp remains found in the Tequinho pits are also clearly size distinct (Figure 5). Endocarp size of the domesticated peach found are up to 2.4 cm long and 1.9 cm wide, well within the sizes of 1-4 cm length and 1-2 cm width reported for modern samples by Mora-Urpí et al. (1997). The wild peach palm endocarps recovered from the sites are 1.5 cm long and 1.3 cm in width, slightly bigger than today's endocarps from wild peach palm found around the city of Rio Branco, Acre, which are 1.3 cm long and 1.3 cm in width.

The remains of both domesticated and wild peach palm were unmistakable on account of their latitudinally displaced fertile pore and longitudinally displaced infertile pores (Figure 5). A careful observation of the endocarp surface showed, in both taxa, the typical flattened, anastomosing, and adherent endocarp fibres. In order to see the fibre patterns in the endocarp remains surface, it was necessary to wet the surface to remove the clay that covered them, a procedure that usually leads to the mischaracterization of the endocarp fibre patterns after a few minutes of being wet, making it difficult to take photographs. Furthermore, it is important to highlight that different studies (Ferreira, 1999; Clemente et al., 2017) indicate that the southwestern Amazon region, which encompasses the Tequinho and Cruzeiro sites, was the area of peach palm domestication.

Uricuri (*Attalea phalerata*) endocarps from the pits measure 4–6 cm long and 1.4-1.7 cm in width (Fig. 6). Compared to modern endocarps (up to 8.2 cm long and 3.2-4.3 cm wide), the ancient uricuri endocarps recovered from the pits are clearly smaller than those from samples collected in a secondary forest located around Rio Branco, Acre (Fig. 7). The endocarp size evolution of the uricuri palm indicates that a continuous selection of bigger fruits has been made over time by indigenous people in the region, among them the earthwork constructors and visitors.

Figure 4. Dessicated remains of *Bertholletia excelsa* fruit (left) excavated from test pit 10 (level 60–70 cm) at Tequinho, and a modern Brazil nut fruit (right).

Figure 5. Charred remains of *Bactris gasipaes* var. *gasipaes* (left) recovered from test pit 11 (level 50 – 60 cm), and *Bactris gasipaes* var. *chichagui* (right) recovered from test pit 9C (level 70 – 80 cm), at Tequinho. FP: fertile pore displaced latitudinally.

Figure 6. Charred remains of *Attalea phalerata* recovered from test pit 9G (level 70 – 80 cm) at Tequinho. LMF: parallel and longitudinal fibre mark on outer endocarp.

Figure 7. Size comparison of modern endocarp of *Attalea phalerata* (A) found in a present-day secondary forest around Rio Branco, Acre, and ancient samples (B) recovered from test pit 11 (level 40-50 cm) at Tequinho.

3.3. Radiocarbon dates

Twelve samples from trench 9 at Tequinho were radiocarbon dated (Table 2). The oldest point was from an earlier small mound (Fig. 8), which yielded the date 2864 (16.1%) 2806 cal BC, or 2760 (79.3%) 2481 cal BC (Ua-48320), indicating a much older occupational period at the site. Much later, however, a depression was made over this older mound that contained Brazil nut shells. The oldest archaeological stratum (9D, level 120 cm below the surface) of the newer mound yielded a date of 63 cal BC (95.4%) 124 cal AD (Ua-48319). After this date, the mound had been extended towards the west. From there, the latest date derives from pit 9H (160 cm below the surface), with a date of 123 (76.2%) 259 cal AD, or 276 (19.2%) 340 cal AD (Ua-48324).

Figure 8. Stratigraphy of Pits 9A, 9B, 9C, 9D, 9E and 9F. At the bottom of the profile there is a six-meter-wide older mound, with a later depression containing especially macrofossils of Brazil

nuts. The original mound gave the date 2864-2481 cal BC. At the turn of the Common Era, the soil started to accumulate toward the west with periodical burning events that left thousands of shards, burnt clay, charcoal and macrofossils of uricuri palms (*Attalea phalerata*) and other fruits on the stratigraphy of the present mound.

Interestingly, even though some 2.20 meters of soil were accumulated on the central part of the mound, no significant time differences existed between the bottom and top of the mound. For example, almost the same dates were recorded from 210 cm below the surface of pit 9I [46 (6.5%) 6 cal BC, or 15 (85.2%) 140 cal AD, or 180 (3.8%) 202 cal AD] as from 55 cm below the surface of the next pit 9H [46 (6.6%) 6 cal BC, or 15 (83.9%) 145 cal AD, or 178 (4.9%) 203 cal AD]. Nevertheless, the soil was not mixed, but instead showed a clear stratigraphy. All these indicate that the mound was accumulated quite rapidly over the span of a few generations. As a result, we decided to combine three similar vertically sampled dates from the centre of the mound (pit 9A 100, 130 and 185 cm below surface; samples Ua-48323, Ua-48322 and Ua-48321 respectively seen in Fig. 7). Using the “combine” function of the OxCal v4.3 program, the three samples yielded dates of 62 – 115 cal AD with a probability of one sigma (68.25%); and 25 - 129 cal AD (94.5%) and 188 – 193 cal AD (0.9%) with a probability of two sigma (95.4%) (X2-Test: df=2 T=0.0 [5% 6.0]). Hence, by using all calibrated dates, we may safely state that the second mound was accumulated due to human activity between 63 cal BC – 340 cal AD, and most likely between ca. 63 cal BC – 175 cal AD.

From Tequinho, we have one other date derived from test pit 18, made on a 4.8-meter-deep ditch that was filled with soil cleaned from the central plaza of the main geoglyph. The

sample was taken from a level 145 cm below the surface, and yielded a calibrated date of 553 (0.6%) 556 cal AD, or 572 (94.8%) 666 cal AD (Ua-50108).

From the Cruzeirinho site, four samples were dated, all from the U2 test pit, made on an embankment of the westernmost geometric structure 1. The stratigraphy was mixed due to the fact that the soil of the embankment was accumulated by making a ditch inside of the geoglyph. As can be seen in a Google Satellite image (S 08 50' 38'', W 67 15' 11''), the actual geoglyph was constructed above an earlier geometric earthwork, which explains why the oldest date is derived from a sample situated only 20-30 cm below the surface (Ua-48333), while the most recent date derives from a sample situated 60 cm below the surface (Ua-48332). The two other samples, from 80 (Ua-48331) and 105 cm below the surface (Ua-48330), fell between these two extremes. The oldest sample gave the date 119 (95.4%) 340 cal AD, and the most recent the date 249 (16.5%) 308, or 320 (77.6%) 496, or 509 (1.2%) 518. Thus, all the Cruzeirinho macrofossil samples can be dated to between 119 – 518 cal AD.

Unit	Level	Material	14C age BP	Lab. number	$\delta^{13}\text{C}$ ‰	Cal. 2 sigma
Tequinho 9D	120 cm	charcoal	2011 $\pm$ 43	Ua-48319	-27.2	63BC – 124AD
Tequinho 9C	90 cm	charcoal	4120 $\pm$ 42	Ua-48320	-24.7	2864 – 2481BC
Tequinho 9A	185 cm	charcoal	1964 $\pm$ 40	Ua-48321	-28.0	46BC – 204AD
Tequinho 9A	160 cm	charcoal	1956 $\pm$ 34	Ua-48329	-26.8	39BC – 204AD
Tequinho 9A	130 cm	charcoal	1963 $\pm$ 39	Ua-48322	-27.8	46BC – 204AD
Tequinho 9A	100 cm	charcoal	1879 $\pm$ 39	Ua-48323	-26.5	71 – 321AD
Tequinho 9H	160 cm	charcoal	1841 $\pm$ 34	Ua-48324	-28.3	123 – 340AD
Tequinho 9H	110 cm	charcoal	1874 $\pm$ 33	Ua-48325	-26.1	80 – 249AD
Tequinho 9H	55 cm	charcoal	1966 $\pm$ 35	Ua-48326	-27.3	46BC – 203AD

Tequinho 9I	210 cm	charcoal	1968 ± 33	Ua-48327	-26.1	46BC – 202AD
Tequinho 9I	150 cm	charcoal	1935 ± 33	Ua-48328	-25.5	35 – 210AD
Tequinho 9L	70 – 80 cm	charcoal	1910 ± 32	Ua-50107	-24.4	66 – 226AD
Tequinho 18	145 cm	charcoal	1476 ± 34	Ua-50108	-27.2	553 – 666AD
Cruzeirinho						
Pit U2	105 cm	charcoal	1782±34	Ua-48330	-28.3	224 – 383AD
Pit U2	80 cm	charcoal	1813±40	Ua-48331	-30.0	135 – 365AD
Pit U2	60 cm	charcoal	1705±42	Ua-48332	-26.1	249 – 518AD
Pit U2	20 – 30 cm	charcoal	1846±40	Ua-48333	-29.1	119 – 340AD

Table 2. Radiocarbon dates from Tequinho and Cruzeirinho.

4. Discussion

Our findings regarding the Tequinho site support the idea of prehistoric activities of domestication seemingly related to landscape modification. The process included selection, planting, and care of seeds extracted from those trees bearing the biggest fruits. It is possible that small Brazil nut fruits found at our research sites were not broken or consumed due to secondary selection. This may have affected the general aspects of our archaeological Brazil nut fruit collection. Nevertheless, the fact is that no bigger macrofossil than 6.6 cm in diameter was found. This can be contrasted with the current Brazil nut fruits considered to be incipiently domesticated, which are much bigger (ca. 11 to 15 cm in diameter) than at the beginning of the Current Era. This also supports the idea of the species being spread by humans, since the dispersal of *Bertholletia excelsa* through the agency of certain rodents (agoutis and acouchis) is considered to be too slow a process to explain the species' rapid expansion ca. two thousand

years ago (Shepard and Ramirez, 2011). It is supposed that the rapid distribution of *Bertholletia excelsa* is related to the movements of Arawak and/or Tupi-Guarani groups. The cultivation of *Bertholletia excelsa* may have spread from central to southwestern Amazonia (Shepard and Ramirez, 2011) or most likely the other way round, from southwestern to central Amazonia (Thomas et al., 2015). According to our indirect evidence, the size of Brazil nut tree fruits started to grow considerably during this multifaceted process. Today, Brazil nut trees 1080 ± 40 years old (Vieira et al., 2005), can be found less than 100 km from the Tequinho archaeological site at the Fazenda Experimental Catuaba (10°04'S; 67°37'W. Alt.: 241 m) and nearby all known geoglyphs of Acre – together with uricuri and peach palms. When they were young, all of them needed open space for rapid growth, and this was offered by the geoglyph builders. It is important to note that this particular Brazil nut tree has bigger nut fruits than two thousand years ago, and that it was growing already at the time when Álvarez Maldonado (1570) described *almendrales*, indigenous almond groves (Brazil nut gardens) in the nearby Madre de Dios river region.

Many of the species identified in Amazonian pre-colonial geoglyph sites appear in narrations of ancient diets (Smith, 2015), as well as being actors in the social relations of current indigenous peoples. According to the Apurinã and Manchineri, these uricuri, peach palm, and Brazil nut trees were a fundamental part of their ancestors' diet, as well as those of tucumã, bacaba, and many others. Furthermore, uricuri's soft leaves were used to make a nutritive soup since the ancestors' time. According to Apurinã and Manchineri oral histories and current practices, *Oenocarpus mapora* offers edible fruits and heart of palms, and its rich oil and its wood are also used. The fruits of *Astrocaryum* are very nutritional, even a bit more than those of

Spondias mombin, which are somewhat acid. *Hevea brasiliensis* has been used for balls used in games.

Today the fruits of the wild peach palm, var. *chichagui*, are also eaten, but the palm is always spiny and its fruits are much smaller (da Silva Batista and Clement, 2005) and do not have a good taste; hence it was probably mostly exploited for its palm heart. Thus, it is generally accepted that the only fully domesticated pre-colonial palm in the Americas was the peach palm, *Bactris gasipaes* var. *gasipaes*, the difference in fruit weight between domesticated populations and its wild relative being in the order of up to 2000% (Clement, 1988; Clements et al., 2010; Piperno, 2011). Manchineri oral myths about the origin of the world mention the cultivation of these palm trees. Palm leaves are also good for building material and for weaving baskets, and peach palm especially yields materials to produce bows and arrow heads.

For the Manchineri, the wild peach palm and *Attalea phalerata* also have a crucial role at a cognitive level as they are associated with the powerful master spirits of the forest (Virtanen, 2011). Hence, they are treated as “persons” associated with respect and their extraction is done with special care, and these are the leading principles of indigenous plant management practices in the region. Similarly, the Apurinã consider *Bertholletia excelsa*, which is mentioned in some versions of Apurinã’s creation myth, to have a powerful spirit agency that enables a shaman to do healing work. Generally, this tree person is treated with respect. Connections between other Amazonian indigenous peoples’ myths and other cultivated species have also been documented (e.g. Smith, 2015). For the Manchineri and Apurinã, both today and as narrated about in the past, festivities are often organised during the palm fruit seasons, and palm fruit is used for ceremonial drinks. Not only vital ceremonial substances made of palms, but also foods, instruments, and costumes made of diverse palm materials offer means to communicate with the ancestors and the

non-human world. The activities related to palms, thus, differ, but ceremonial use and locations offer evidence of ecological practices.

Theoretically, it would be possible to agree on measurable criteria in order to distinguish wild, incidentally co-evolved, incipient domesticated, or semi- and fully domesticated species of palms as proposed by Clement (1999). According to our study, other modern species than the peach palm would likely also fulfil the criteria for domestication or semi-domestication if we could archaeologically identify and study their wild progenitors better (see, Zeder et al., 2006) or compare late Pleistocene species with the later Holocene species consumed by humans.

Nevertheless, in some cases we can also probably speak about hybridization processes (see, Zeder et al., 2006), and with different management practices and systems of cultivation that affected the distribution and density of certain palms as well as fruits, beans, roots and other harvested species (see, Levis et al., 2012; Levis et al., 2017; Levis et al., 2018). In every case, the choices made by humans were crucial in the domestication process, and in spite of the fact that local indigenous peoples seem to have managed and protected also wild tree species pointing to the complexity of domestication in the Amazonian context, it is obvious that human and botanical interaction has also led to clear and observable differences in Brazil nuts and some palm trees compared to their ancestors.

5. Conclusion

Our study of tree engagement shows that during the first and second century of the Common Era (0-200AD) visitors at the Acrean earthworks consumed a large amount of Brazil nuts, diverse palm fruits, and possibly palm kernels, especially from the uricuri palm (*Attalea phalerata*), but

also from the domesticated peach palm (*Bactris gasipaes* var. *gasipaes*) and its variant, which is considered to be a wild form of *Bactris gasipaes*, var. *chichagui*. Fruits of the bacaba (*Oenocarpus mapora*) and *Astrocaryum* species were also identified, and the findings also include carbonized fruits of the rubber tree (*Hevea brasiliensis*), hog plum *Spondias mombin*, and *Gustavia* sp., of the same *Lecythidaceae* botanical family as the Brazil nut, all indicating some sort of use of these trees in pre-colonial times. Unfortunately, one or two measured individuals of these species are not enough to define wild and cultivated populations.

Furthermore, taking into account that the carbonized fruit of the *Gustavia* species was found in a ditch that was dated to 533-666 cal AD (145 cm below the surface), and that our *Gustavia* sample was recovered ca. 80 cm above the dated level (60–70 cm below the surface), it probably belongs to the period of the second half of the first millennium of our era. *Oenocarpus mapora*, *Astrocaryum*, *Spondias mombin* and *Hevea brasiliensis* samples are also found in prehistoric contexts, but no absolute dates are available for them. Furthermore, our test pit in Cruzeirinho shows that – along with *Attalea phalerata* and *Bactris gasipaes* var. *chichagui* – the palm fruits of the marajá (*Bactris concinna*) and najá (*Attalea maripa*) species were also used between 119 – 518 cal AD.

The results show a diversity of subsistence practices, as well as an indigenous understanding of domestication and tree management. In previous studies, the concept of domestication refers to a long but measurable process of human management and selection (Pickersgill, 2007), but our study shows that the palm and Brazil nut species identified in geometric earthwork sites underwent different types of processes of domestication and engagement, and possibly hybridization. Ferreira (1999) using cladistic analysis of morphological traits has indicated that the southern Amazon region, which comprises eastern

Acre, was a place where the peach palm was domesticated, thus justifying the presence of both domesticated and wild relatives in the same region. Clement et al. (2017) also suggest the same region as the place of domestication of peach palm, but indicates the sympatric occurrence of two wild peach palm relatives (chichagui 1 and 3), with the second showing signs of incipient domestication, but with an ability to become a feral trait, easily surviving on little-disturbed ecosystems. Therefore, we argue that in the Amazonian indigenous context, domestication should be understood as a part of a cultural phenomenon related to the human management of protecting, caring, respecting, supporting, and planting activities, apart from a well-planned process of measurable domestication. In this complex process, not only domesticated but also wild species were actively harvested.

Even Lévi-Strauss, who introduced the dichotomy between the raw and the cooked and nature and culture into structural anthropology (Lévi-Strauss, 1963), once noted that in the South American tropics it is difficult to distinguish between wild and cultivated plants, “for there are many intermediate stages between the utilization of plants in their wild state and their true cultivation” (Lévi-Strauss, 1952; cited also in Smith, 2015). We must also remember that in Amazonian indigenous thinking this kind of dichotomy between ‘natural’ and ‘cultural’ spaces and products is practically irrelevant (Fausto and Neves 2018; Virtanen and Saunaluoma, 2017).

Historical accounts indicate that *Bertholletia excelsa* and diverse palm species were under cultivation before the European conquest (Álvarez Maldonado, 1570; de Carvajal, [1541-1543] 1992; Cieza de León, [1553] 1991), but we cannot know how far their journey towards full domestication was at that time. Some species may have been simultaneously incipiently domesticated, such as the Brazil nut and cupuaçu (*Theobroma grandiflorum*) (Clement, 1999), some semi-domesticated, as in the case of cacao in the Amazon region (Clement, 1999), and

some fully domesticated, such as the peach palm (*Bactris gasipaes* var. *gasipaes*) (Clement, 1988), pineapple, inga (*Inga edulis*) and guaraná (*Paullinia cupana*) (Clement et al., 2010). Furthermore, a natural wild species' transformation should be examined in the context of the human clearance and planting actions realised over a long period of time. In any case, this article gives further support for the idea of Amazonian anthropogenic forests (Balée, 1989; Erickson and Balée, 2006) that facilitated the rise of complex Amazonian earthworking societies more than two thousand years ago. As demonstrated by both Balée et al. (2014) and Watling et al. (2017, 2018), legacies of these societies can still be seen in the forest composition of the region where ancient geoglyphs can be found.

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