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Accepted Version

Watling, J., Mayle, F. E. ORCID: https://orcid.org/0000-0001-9208-0519 and Schaan, D. (2018) Historical ecology, human niche construction and landscape in pre-Columbian Amazonia: a case study of the geoglyph builders of Acre, Brazil. Journal of Anthropological Archaeology, 50. pp. 128-139. ISSN 0278-4165 doi: 10.1016/j.jaa.2018.05.001 Available at https://centaur.reading.ac.uk/77826/

To link to this article DOI: http://dx.doi.org/10.1016/j.jaa.2018.05.001

Publisher: Elsevier

Historical ecology, human niche construction and landscape in pre-Columbian Amazonia: a case study of the geoglyph builders of Acre, Brazil.

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ABSTRACT

This paper applies concepts from the fields of historical ecology and human niche construction theory to interpret archaeological and palaeoecological data from the Brazilian state of Acre, southwest Amazonia, where modern deforestation has revealed hundreds of pre-Columbian monumental earthworks called 'geoglyphs', largely built between ca. 2000–650 cal. BP (calibrated years before present). Our main objective was to move away from the debate which currently dominates Amazonian archaeology over large- vs. small-scale pre-Columbian environmental impacts, and instead offer a more nuanced interpretation of human-environment interactions in our specific study area. Despite the difficulties presented by working with an incomplete regional archaeological dataset, interpreting our findings in light of these theoretical frameworks allowed us to re-think landscape history and ask new questions about a possible relationship between anthropogenic forests, symbolic capital and monument building in our particular study area.

KEYWORDS

Earthworks, landscape, historical ecology, human niche construction

HIGHLIGHTS

- First time human niche construction (HNC) applied to Amazonian archaeology
- Novel questions emerged applying HNC and historical ecology to geoglyph landscape
- New relationship hypothesised between anthropogenic forests and monument building

1. INTRODUCTION

Mapping the nature, scale and legacies of past global human impacts on the environment is now considered to be essential for the conservation of ecosystems around the world (Crumley 2015; Hayashida 2005; Roberts et al. 2017). Over the last thirty years, studies grounded in historical ecology have overturned the notion, rooted in the natural sciences, that the Amazon rainforest was not able to support complex, sedentary societies because of its low natural protein abundance and its infertile soils that limit agricultural production (Gross 1975; Meggers 1971, 1954). Instead, pre-Columbian societies are now seen as having been important agents in transforming their environment to make it more productive; for instance, by practicing agroforestry, creating fertile soilscapes (Amazonian Dark Earths), and building raised fields (e.g., Clement 1999; Denevan 2006; Dickau et al. 2016; Iriarte et al. 2010; Rostain 2013; Smith 1980; Woods et al. 2009)

In the eastern portion of the Brazilian state of Acre, neighbouring parts of Rondônia and Amazonas states, and northern Bolivia, deforestation across large swathes of upland *terra firme* forest has revealed over 450 pre-Columbian geometric earthworks known as 'geoglyphs' (Pärssinen et al. 2009; Saunaluoma 2012; Saunaluoma and Schaan 2012; Schaan 2012; Schaan et al. 2012; Schaan et al. 2009) which, since their discovery, have been the subject of much speculation–both in terms of their function, and the environmental impact that was caused by their construction and use. To respond to the environmental question, between 2011–2014, we conducted palaeoecological research (phytolith, charcoal and stable carbon isotope analysis) in the region of two excavated and dated geoglyph sites–Jaco Sá (JS) and Fazenda Colorada (FC)– to reconstruct vegetation and fire histories from before, during and after earthwork construction. Among our key discoveries, reached through comparing palaeoecological phytolith assemblages with those from different modern vegetation formations (Watling et al. 2017a, 2016), were: 1) the geoglyph region, unlike neighbouring Bolivia at the same time (Carson et al. 2014), was dominated by bamboo forest before the geoglyphs were built; 2) the continued dominance of closed-canopy vegetation and low charcoal counts throughout the profile sequences suggested that large-scale deforestation, such as that practiced today, was not commonplace in the past; and 3) both the JS and FC geoglyphs, and potentially many more, were constructed within palm-abundant forests formed by previous human activities over millennia.

The publication of these results (Watling et al. 2017a) and follow-up debate (Piperno et al. 2017a; Watling et al. 2017b) detailed these environmental impacts and their implications for the debate surrounding small vs. widespread human footprints in interfluvial Amazonia. In the current paper, we attempt to re-interpret the same data but from a theoretical perspective that also draws upon anthropology, ethnography and landscape archaeology, and which explicitly tries to incorporate the research frameworks of historical ecology and human niche construction theory to understand landscape history. The aim of this approach is to provide a more holistic understanding of the geoglyph landscape than that offered previously.

Historical ecology and human niche construction theory have, at their core, a preoccupation for the role of human agency in shaping environments–the first from an historical perspective, the second from an evolutionary one. Both being frameworks, they do not constitute disciplines in themselves but rather *ways of thinking* about certain problems. Arroyo-Kalin (2016) has proposed that historical ecological studies in Amazonia–of which many exist–be incorporated into niche construction perspectives, implying that a complementary relationship can be established between these two frameworks to understand Amazonian landscapes. We believe this complementarity comes from their different emphases on specific, non-exclusive, aspects of human-environment interactions: historical ecology emphasizes the historic and ecological mechanisms by which the landscape is formed, and the human niche constructed, and emphasizes the conservation of those landscapes; while human niche construction focusses on the mechanisms of transmission and inheritance of specific cultural behaviours, ecologies and material culture as evolutionary processes which affect natural selection.

We start by introducing the theoretical and archaeological background to the study, including a description of our original methods (found in more detail in the *Supplementary Information* of Watling et al. 2017a), followed by our interpretations, and, finally, a reflection on the successes and challenges of incorporating historical ecology and niche construction theory to the geoglyph region.

2. THEORETICAL BACKGROUND

Historical ecology is defined as “the study of dialectic interactions between *people and environment* to understand the formation of *culture and landscape*” (Balée 2006, p. 76). As a conceptual tool, it was developed in the 1980s by anthropologists and ethnobotanists studying indigenous Amazonian subsistence practices. In their seminal publication, Posey and Balée (1989) showed how various indigenous societies do not just *adapt to*, but *transform* their surroundings through a host of cultural practices that include relocating, attracting, protecting, planting, semi-domesticating, domesticating and using resources (Balée 1989). Their findings estimated that 11.8% of Brazilian *terra firme* forest was of pre-Columbian cultural origin (Balée

1989), which was essential in overturning “the notion of the pristine primitive” (Balée 2006, p. 76), as well as environmentally deterministic archaeologies that dominated in Amazonia at the time (e.g. Meggers, 1971).

The “unit of analysis” of historical ecology is the landscape, since it contains the physical evidence of human-environment interactions (Crumley 2007). As such, a range of different disciplines have been employed to pick apart historical ecological trajectories, such as ecology, biology, archaeology, anthropology, history, geography and ethnobiology (Armstrong et al. 2017; Crumley 2015), with the key goal of understanding the totality of human-environment interactions that formed the present-day landscape. In a critique of the ambitiousness of such a goal, Whitehead (1998, p. 31) wrote that, in order to reach a true historical ecological understanding of landscape, one would need to map “the interplay of *all structures* of human activity”, including polity, economy-ecology, society and culture, a task which archaeologists are rarely–if ever–able to fulfil. On the other hand, the optimistic nature of historical ecology is arguably one of its strengths, since it uniquely encourages conversation and collaboration between the social and natural sciences.

In Amazonia, as elsewhere (Armstrong et al. 2017), historical ecological studies have focussed on combining archaeological and ecological data, most notably within the earthwork-rich landscapes of the Llanos de Mojos, in lowland Bolivia (Erickson, 2010; Erickson and Balée, 2006), French Guiana (McKey et al. 2010; Rostain 2013) and the Upper Xingu (Heckenberger et al. 2003). These authors, among others (e.g. Clement 1999; Clement et al. 2015; Levis et al. 2017; Lins et al. 2015), emphasize ‘landscape domestication’ as a key mechanism for shaping Amazonian landscapes, particularly plant species distributions. In this paper, we adopt Clement’s (1999, p. 190) definition of landscape domestication as: *“a conscious process by which human manipulation of the landscape results in changes in landscape ecology and in the demographics of its plant and animal populations, resulting in a landscape more productive and congenial for humans”,* though we also recognise other authors’ preference to integrate the concept of *domus* within this process (e.g. Erickson 2006).

Recording and predicting the ‘landscape legacies’ of pre-Columbian impacts such as earthworks, anthropogenic forests and dark earths, and the intentionality behind them, has also dominated historical ecological studies (Arroyo-Kalin 2016, 2010; Balée 1989; Balée and Erickson 2006; Levis et al. 2017; McMichael et al. 2014a, 2017; Piperno et al. 2015; Watling et al. 2017a), in part because of the implications for conservation and policy making (Barlow et al. 2012; Bush and Silman 2007; Junqueira et al. 2010; Posey and Balick 2006; Roberts et al. 2017). Indeed, the creation of *“historically grounded and socially just”* (Armstrong et al.

2017, p. 2) conservation programs is a key concern within the historical ecology framework (Balée 1998; Crumley 2015; Szabó and Hédl 2011).

A relatively recent branch of evolutionary theory, human niche construction theory shares the central concern of historical ecology through its emphasis on the dialectic relationship between humans and their environment. Conceived as a reaction against passive 'adaptation' as the process guiding evolutionary change in Darwinian theory, niche construction models the way in which organisms co-direct their own evolution through modification of their own, and each other´s, niches (Laland and O'Brien 2011; Odling-Smee et al. 2003). As "*an alternative means of thinking about evolutionary problems*" (Laland and O'Brien 2010, p. 303), its primary concern is to map how genetic, ontogenetic and cultural information is selected and inherited (culturally, ecologically, and genetically) over time to create the human niche– i.e. the "chain of events" that drives natural selection (Odling-Smee et al. 2003, p. 195).

It has been argued that niche construction theory is well-suited to archaeology due to its biologically- and culturally-based conceptual framework and its shared emphasis on human agency (Laland and O'Brien 2010), however its use within the discipline has, until now, been largely focussed on plant and animal domestication and the origins of agriculture (e.g. Laland and O'Brien 2010; Rowley-Conwy and Layton 2011; Smith 2016; Zeder 2009; but also see Piperno et al. 2017). These themes lend themselves ideally to niche construction theory due to the explicit and direct impact that humans have on other species during the domestication process, as well as the vast body of archaeological, palaeoenvironmental and genetic data which can be drawn upon through years of accrued research. Applying human niche construction to other themes within archaeology requires new exploration. A landmark study by Shennan (2011) showed how the accumulation of wealth and power are, in some instances, forms of niche construction, since these processes can affect the reproductive success of certain groups or individuals.

With the exception of a discussion about its potential use (Arroyo-Kalin 2016), to date, we are not aware of any previous attempts to apply human niche construction to Amazonian archaeology. One recent study, however, emphasized the scale and antiquity of human niche construction upon global tropical forests and environments in general (Boivin et al. 2016) concluding, as do historical ecologists (Balée 1998), the absence of truly "pristine" landscapes anywhere in the world.

Furthermore, few studies have applied human niche construction theory to understanding specific landscape trajectories. Instead, there has been a strong tendency for scholars to tackle much broader evolutionary processes over multiple spatial and temporal scales, such as hominid evolution or the transition to agriculture. A notable exception is the study of Kluiving

(2015) who reviewed geoarchaeological and landscape archaeological data from four different European locations within a niche construction perspective. By reconstructing these different environments, he was able to distinguish between the \`inceptive\` (i.e. instigative) and \`counteractive\` (i.e. responsive) human impacts that formed these landscapes, and highlight the role of landscape *gradients* as a selective pressure (see section 5.2). In the current study, we also aim to use archaeological and palaeoenvironmental data to interpret human impacts at a landscape-specific scale (Mayle and Iriarte 2014).

3. THE GEOGLYPHS

Geoglyphs are contiguous ditch and bank structures (averaging around 11 m wide and 3 m deep) that enclose typically circular and quadrangular-shaped areas of between 3–10 hectares in size (Pärssinen et al. 2009; Saunaluoma and Schaan 2012). Excavation and dating evidence has shown that the majority were built between 2000–900 cal. BP, however two sites have yielded dates between 3000–3500 cal. BP, suggesting that some may have been built earlier (Saunaluoma 2012). The areas enclosed by the earthworks typically contain sparse cultural remains, and the presence of ritualised deposits within the ditches of some sites suggests that they were used sporadically by pre-Columbian groups as gathering places to practice ceremonies (Saunaluoma and Schaan 2012; Schaan et al. 2012). These sites were first investigated over thirty years ago (Dias and Carvalho 1988), however it was only as a result of large-scale deforestation linked to the Amazonian Colonization Program at the end of the 1980s that their true geographical extent was revealed, and systematic mapping and excavations of these sites commenced (Ranzi, 2003). The structure of these forests consisted mainly of bamboo-dominated (*Guadua* sp.) forest with patches of palm and dense humid evergreen forest towards the border with Bolivia (Daly and Silveira 2008).

Today, over 450 geoglyph sites have been discovered in a region measuring roughly 13,000 km^2 of Acre state, Brazil, and the grand majority are situated in upland interfluvial areas far away from major river floodplains (Fig. 1). This is significant since the extent to which Amazonian *terra firme* landscapes were impacted by pre-Columbian activities is still debated by archaeologists, geographers and ecologists today (Clement et al. 2015; Denevan 2014; McMichael et al. 2012; Piperno et al. 2015; Stahl 2015). The acidic ultisols that dominate the geoglyph region are of low agricultural potential (Quesada et al., 2011), although an archaeobotanical study confirmed that maize (*Zea mays*) and squash (*Cucurbita* sp.) were cultivated and consumed by the geoglyph builders, alongside palm fruits (Watling et al., 2015).

Despite the large number and density of geoglyph sites discovered, exactly where the earthwork builders lived is unknown. Furthermore, Anthropogenic Dark Earths, black, fertile soils that attest to large and sedentary populations along the Amazon and its tributaries during the late Holocene (Neves et al. 2003; Petersen et al. 2001; Smith 1980) are absent from the region's archaeology. This lack of evidence for large, sedentary villages may signify that they have simply not been discovered yet or, instead, that a decentralized socio-political organization existed consisting of multiple autonomous groups, as proposed by Saunaluoma and Virtanen (2015).

APPROX. LOCATION OF FIGURE 1

Fig. 1 Location map showing the distribution of the geoglyphs in eastern Acre state. Note that the majority are found away from large rivers.

4. CASE STUDY METHODS

4.1. Study sites

The Fazenda Colorada site (9°52'35" S, 67°32'4" W) consists of three earthworks: a circle, a square and double U-shape, the latter of which encloses several mounds and is attached to a trapezoidal enclosure. Radiocarbon dates place its construction and use between 1925–1608 cal. BP and 1275–1081 cal. BP (Table 1), with a later occupation dated to 706–572 cal. BP This later date, retrieved from a mound within the U-shaped enclosure, is coincidentally the most recent date so far obtained from any geoglyph site (Pärssinen et al. 2003; Schaan et al. 2012). The spread of radiocarbon dates suggests a concentrated period of geoglyph use following its initial construction, between 1925–1608 to 1806–1556 cal. BP; but the exact frequency with which the site was visited during this period, and afterwards, is unknown (Schaan et al. 2012).

The Jaco Sá site (9°57'38" S, 67°29'51" W) also consists of multiple earthworks: a square, a circle within a square, and a rectangular embankment between the two. Cultural material from the base of ditch structures belonging to the first two earthworks were dated to 1174–985 and 1220–988 cal. BP, respectively, while a third date of 1405–1300 cal. BP, also obtained from carbonised ceramic residue, perhaps attests to an earlier, pre-earthwork phase of cultural activity (Schaan et al., 2012). Sparse archaeological remains recovered during excavation point towards sporadic use of this site, but the exact frequency of visitation is again unknown. A full list of radiocarbon dates retrieved from JS and FC are available in Table 1.

Table 1: List of radiocarbon dates previously retrieved from the Fazenda Colorada (FC). Jaco Sá (JS), Severino Calazans (SC) and Ramal do Capatará (RC) geoglyph sites. SC and RC are sites from which the oldest dates have been retrieved.

Site	Provenience	Lab code	C14 age years BP (+/-2σ error)	Calibrated age BP.	Reference
FC	Mound, 25 cm	Hela-616	750 +/- 35	706 - 572	a
FC	Unit 10, 67 cm	Ua-37255	1275 +/- 30	1275 - 1081	b
FC	Unit 10, 70-80 cm	Ua-37236	1340 +/- 35	1297 - 1177	b
FC	Unit 9, 218 cm	Ua-37567	1775 +/- 35	1806 - 1556	b
FC	Unit 12, 90 cm	Ua-37256	1820 +/- 30	1819 - 1624	b
FC	Unit 7, 150-160 cm	Ua-37235	1865 +/- 65	1925 - 1608	b
JS	Unit 1, 47 cm	Ua-37257	1195 +/- 30	1174 - 984	b
JS	Unit 8, 80-90 cm	Ua-37258	1205 +/- 30	1220 - 988	b
JS	Unit IVB, 10-20 cm	Ua-37259	1485 +/- 35	1405 - 1300	b
SC	Unit 3, 20-30 cm	Ua-37264	2050 +/- 35	2109 - 1893	b
SC	Unit 6B, 50-60 cm	Ua-37265	2275 +/- 35	2121 - 1975	b
SC	Unit 5, 45 cm	Ua-37238	2915 +/- 35	3161 - 2892	b
SC	Unit 3, 50 cm	Ua-37237	3900 +/- 40	4527 - 4295	b
RC	130-140 cm	Beta-288232	1850 +/- 40	1860 - 1573	c
RC	170 cm	Beta-288233	1990 +/- 30	1989 - 1816	c
RC	70 cm	Beta-288234	3310 +/- 40	3581 - 3380	c

References for table: a) Pärssinen et al. 2003, b) Schaan et al. 2012, c) Saunaluoma and Schaan 2012

4.2. Sampling methods

A total of six 1.5 m-deep profiles were excavated and sampled every 5 cm for phytoliths and charcoal. One profile was located in the centre of the circular earthwork at Jaco Sá (JS1) and an additional four positioned at incrementally greater distances along a transect – 0.5 km (JS2), 1.5 km (JS3), 3.5 km (JS4) and 7.5 km (JS5) – that headed west from the Jaco Sá site into an area containing no known archaeological sites (Fig. 2). This sampling strategy was applied in order to capture scenarios of both small- and large-scale impact associated with geoglyph construction. The sixth profile was placed within the square earthwork at Fazenda

Colorada (FC1) to compare the environmental context of geoglyph construction at two distinct geoglyph sites.

Samples were initially analysed for phytoliths and charcoal at coarse stratigraphic resolution (every 10 cm) before sending charcoal for AMS dating. Once the horizons relating to geoglyph construction were ascertained through the dating of clear charcoal peaks in the proxy record (above 50-55 cm at FC1 and 30–35 cm at JS1), sampling resolution was then doubled from these horizons to the surface.

APPROX. LOCATION OF FIGURE 2

Fig. 2. Image showing soil profile locations in relation to the Fazenda Colorada and Jaco Sá geoglyph sites and current vegetation. Aerial photographs of the geoglyphs have black arrows marking the locations of the FC1 and JS1 profiles (after Watling et al. 2017a; photographs courtesy of S. Saunaluoma).

4.3. Laboratory methods

Phytolith extraction followed standard wet oxidation protocols (Piperno, 2006) and taxonomic identifications were made using a range of published work from the Neotropics (Chandler-Ezell et al. 2006; Dickau et al. 2013; Iriarte and Paz 2009; Piperno 2006, 1988; Piperno and Pearsall 1998; Watling and Iriarte 2013), and by consultation of the University of Exeter phytolith reference collection of modern plants. To be able to assign phytolith assemblages from the soil profiles to specific vegetation types, modern analogues were retrieved from the surface soil phytolith assemblages of monitored forest plots pertaining to different vegetation types in the Acre region (bamboo forest, palm forest, dense humid evergreen forest, dense humid evergreen forest with abundant palms, fluvial forest) (Watling et al. 2016), and a patch of standing forest 500 m from the Jaco Sá geoglyph.

Macroscopic charcoal pertaining to two classes (0.125–0.25 mm and > 0.25 mm) was counted in order to distinguish between *in situ* and local burning events (Whitlock and Larsen 2001). Particles were separated by wet-sieving 3 cm^3 of soil from each horizon and transferred into a gridded petri dish, from which they were counted under a binocular loupe microscope.

Bulk sediment stable carbon isotope analysis was conducted on the JS1 and JS3 profiles to provide an indicator of the relative openness of the vegetation over time at these locations. Sampling was at every 10 cm at JS1 and at every 10 cm, then every 20 cm below 0.4 m below surface (BS) at JS3, and average $\delta^{13}C$ values calculated from three runs of the same sample.

Analysis was conducted using standard procedures (Metcalfe et al. 2014), and care was taken to avoid the inclusion of rootlets and similar non-representative material.

4.4. Profile dating

AMS radiocarbon dates were performed on a total of 19 charcoal samples and calibrated using the IntCal13 calibration curve (Reimer et al. 2013). Dating efforts were focussed on specific events recorded in the proxy data, and charcoal dated *in bulk* from each horizon to minimise problems with dating singular fragments that may have translocated in the profiles.

Basal dates for the profiles (all but JS1) were obtained by ^{14}C dating of soil humin, due to the lack of charcoal present in these lower strata. Soil humin is considered the most stable component of soil organic matter and provides date ranges more similar to those of charcoal than bulk organic matter (Pessenda et al. 2001). In the FC1 profile, an initial charcoal date (8084–6186 cal. BP) from the 50–55 cm horizon (the beginning of a peak expected to be related to geoglyph construction) was older than expected for its stratigraphic position. An additional soil humin date was therefore obtained for the 45–50 cm horizon (the charcoal peak maxima), which yielded an age (2333–2158 cal. BP) in rough agreement with the archaeological date of geoglyph construction. More detailed descriptions of all the methodologies used can be found in the *Supplementary Information* of Watling et al. (2017).

All dates obtained from the soil profiles are listed in Table 2. When referring to them in section 4, we use the midpoint 2σ calibrated age.

Table 2: List of radiocarbon dates obtained in the study (Watling et al. 2017, Table S1)

Profile	**Depth (cm)**	**Lab no.**	**Material**	**C14 age years BP (+/-2σ error)**	**Cal. age BP**
FC1	20-25	Beta-377101	Charcoal	5760 +/- 30	6651–6485
FC1	45-50	CENA-959	Humin	2240+/-20	2333–2158
FC1	50-55	Beta-377102	Charcoal	5300 +/- 30	8084–6186
FC1	100-105	Beta-377103	Charcoal	3390 +/- 30	3701–3569
FC1	140-145	CENA-960	Humin	4800+/-20	5594–5476
JS1	20-25	OxA-29507	Charcoal	2432 +/- 25	2698–2375
JS1	30-35	Beta-355557	Charcoal	1560 +/- 30	1530–1385
JS1	80-85	Beta-355558	Charcoal	3690 +/- 30	4146–3927
JS1	140-145	OxA-29506	Charcoal	5230 +/- 29	6174–5918
JS2	10-15	OxA-29510	Charcoal	605 +/- 23	652–546
JS2	50-55	OxA-29509	Charcoal	3728 +/- 27	4152–3986

JS2	80-85	OxA-29508	Charcoal	6984 +/- 33	9334–7720
JS2	140-145	CENA-961	Humin	5780 +/-20	6650–6501
JS3	10-15	OxA-29512	Charcoal	AD 1958	Modern
JS3	30-35	OxA-29511	Charcoal	2694 +/- 26	2850–2756
JS3	60-65	OxA-29694	Charcoal	2344 +/- 30	2460–2319
JS3	115-120	CENA-962	Humin	3940+/-20	4500–4295
JS4	10-15	OxA-29466	Charcoal	708 +/- 25	688–569
JS4	20-25	OxA-296465	Charcoal	2901 +/- 28	3157–2955
JS4	50-55	OxA-29513	Charcoal	2487 +/- 25	2722–2471
JS4	140-145	CENA-963	Humin	4090+/-20	4800–4455
JS5	20-25	OxA-29469	Charcoal	1783 +/- 25	1812–1618
JS5	60-65	OxA-29468	Charcoal	4350 +/- 50	5212–4836
JS5	100-105	OxA-29467	Charcoal	5731 +/- 32	6635–6446
JS5	140-145	CENA-964	Humin	5700+/-30	6599–6406

5. RESULTS AND DISCUSSION

APPROX. LOCATION OF FIGURE 3

Fig. 3: Graphs showing percentage phytolith frequencies, charcoal concentrations**,** $\delta^{13}C$ values (per mille) and midrange ^{14}C dates (in cal. yr BP, to 2σ accuracy) by depth in the six soil profiles. Shaded yellow bars delimit levels that can be considered as roughly pertaining to geoglyph use where this can be postulated based on the ^{14}C dates. Source: Watling et al. (2017a)

5.1. People take advantage of bamboo forest

In our soil profile samples, we documented >15% frequency of bamboo short cell phytoliths since the beginning of the records (ca. 6000 cal. BP, Fig. 3), showing that bamboo forest has dominated the region since at least the mid-Holocene (Watling et al. 2016). This contrasts with areas of southern Amazonia that are closer to forest-savanna ecotones which supported savanna-like environments during this period of lower rainfall (Burbridge et al. 2004; Carson et al. 2014; de Freitas et al. 2001; Mayle et al. 2000; Pessenda et al. 1998), and may indicate a certain resilience of this vegetation type to drought conditions. The antiquity of bamboo forest attested to in the soil profiles, as well as the discovery of a pre-Holocene *Guadua* fossil close to the Madre de Dios river, Peru, suggests that bamboo forest was already present in Acre before any significant human land use (McMichael et al. 2014b).

The earliest radiocarbon date obtained for human activity in eastern Acre is from a pre-geoglyph cultural level at Severino Calazans, less than 10 km south of Jaco Sá, dating to 4527 - 4295 cal. BP (Schaan et al. 2012, Table 1). The first visible signs of human manipulation of bamboo forest occur shortly after this period in the soil profiles, in the form of large charcoal `peaks` directly dated to ca. 3600 cal. BP (JS1) and 4000 cal. BP (FC1). After these initial peaks of anthropogenic burning, charcoal from local fires becomes generally more common (Fig. 3), despite wetter conditions that prevailed in southwest Amazonia during this time (Mayle et al. 2000; Pessenda et al. 1998).

We interpret ~4000 cal. BP (the beginning of the late Holocene) to be the rough start date of widespread landscape domestication and a form of inceptive human niche construction actioned by predecessors of the first geoglyph builders in the region.

Our understanding of the social landscape during this period is limited by a lack of archaeological data: on the one hand, increasing fire activity could represent the process of colonization of this region by new groups, or "*relocation*" (Odling-Smee et al. 2003); on the other hand, it may have been the result of a socio-economic shift towards more intense landscape use by populations already living in the region, or *"perturbation"* (Odling-Smee et al. 2003). Arguably, the presence of considerable Early Holocene human occupations in neighbouring Rondônia (Miller et al. 1992) and the Bolivian Llanos de Mojos (Lombardo et al. 2013) makes it unlikely that Acre remained unpopulated until this point; however, this question cannot be resolved without more archaeological evidence.

In Acre, the process of niche construction was likely helped by the specific landscape ecology of bamboo itself. *Guadua* sp. undergoes periodic mass die-off events every 27–28 years over populations of up to 330 km^2 (de Carvalho et al. 2013), making it much easier to burn large areas during the dry season if one gets the timing right (McMichael et al. 2014b) Moreover, bamboo forests are naturally more `open` because of the aggressive nature of bamboo, which can kill and restrict the growth of larger trees (Griscom and Ashton 2006), meaning less tree felling would have been required using stone axes (Carneiro 1979). It seems reasonable to suggest that people may have taken advantage of areas particularly dense in bamboo – in other words, pre-existing landscape gradients – to create clearings. The bamboo itself may have also been a valued resource, as much as for construction and tool-making material as for its property of retaining drinkable water during the dry season.

5.2. The long history of human niche construction

Just after the fire events dated to ca. 4000 and 3600 cal. BP, the phytolith data attest to a clear and very gradual increase in palms in the future locations of the FC and JS geoglyphs. This increase is also detected 500 m away from the JS geoglyph (profile JS2) beginning ca. 4000 cal. BP, while at JS4, 5.5. km away, a smaller palm increase follows an increase in charcoal dated ca. 2600 cal. BP.

By the time that the geoglyphs were constructed, some two thousand years later, palms were up to 30% more abundant than in pre-4000 cal. BP levels at FC1, JS1 and JS2. We can hypothesize that a wetter-than-previous climate at this time would, if anything, have discouraged the appearance of palm forest by favouring a denser forest canopy (Salm et al. 2005), and that this phenomenon thus had its roots in coupled human-environment interactions (Watling et al. 2017a). The increases in palms (which accompany overall increases in charcoal in the same locations) may have occurred through the re-visitation and re-utilization of these places in the landscape by successive generations of people, who were attracted to the useful plants concentrated – intentionally or unintentionally – by previous people, and who in turn contributed further to their concentration.

In light of niche construction theory, we might interpret the first charcoal peaks at JS and FC as representing a first, inceptive landscape change that created new landscape gradients (Kluiving 2015) between areas containing more- or less-abundant resources. These landscape gradients, however, had a fundamental and irreversible impact on the environment, as they became preferentially selected by people and progressively altered (*sensu* Kluiving 2015, p. 558), creating a feedback loop. In other words, *“information-guided niche construction generate[d] modified natural selection pressures and, in the process, accrue[d] further information that guide[d] additional niche construction”* (Odling-Smee et al. 2003, p. 195).

Grasping the timescale and continuity of both historical ecological and evolutionary processes reflected in these findings is not a simple task, since the data suggest that this process of landscape domestication took place over millennial timescales. Furthermore, since we still know relatively little about the societies that built the geoglyphs, where they lived and their way of life, inferring about the “*amplifying effects*” of transforming the landscape to be essentially easier to live in (in terms of population growth, sedentism and social complexity) (Arroyo-Kalin 2016, p. 10), is a speculative exercise. Regional population growth could be argued for the 1st millennium AD (like in other areas of the Amazon basin, e.g. Heckenberger 2005; Morães and Neves 2012) when there is a sudden explosion of geoglyph construction, however the lack of occupation evidence means this cannot be confirmed.

On the other hand, we’d be safe to predict, based on ethnographic analogy (e.g. Politis 2007) that an increase in palms at the locations of JS1, JS2, JS4 and FC1 would have led to an increased abundance of game, attracted by the concentration of edible fruits. This in turn may have made them particularly favourable hunting spots during fruiting season (November to March).

Furthermore, at an ideological level, human niche construction is in direct, dialectical relationship with the process of 'human landscaping'. Differing from the term `landscape domestication` (*sensu* Clement 1999), which is the conscious act of making a landscape more productive, `human landscaping` also refers to the acts of cognizing and memorialising material settings (Arroyo-Kalin 2016). In indigenous Amazonian societies, who do not see a separation between 'nature' and 'culture', landscapes are experienced as animated or 'sacred' entities, *"imbued with culture and history"* (Schaan 2012, p. 188; see also, e.g. Descola 1994; Santos-Granero 2004; Viveiros de Castro 1996; Zucchi 2002). As mosaics of anthropogenic forest became ever more abundant in the geoglyph landscape over time, how people cognized these locations would have ultimately changed. We return to this point in the next section.

5.3 Continuity and discontinuity in geoglyph construction

The Jaco Sá soil profiles show that geoglyph building within this palm-rich anthropogenic forest involved only short-term vegetation clearance. A charcoal peak in the JS1 profile (1385–1530 cal. BP) was consistent with an archaeological date from the JS geoglyph thought to fall shortly before geoglyph construction (1450–1300 cal. BP). However, early successional herbs (grasses and *Heliconia*) in these strata remain at levels below 10%, while $\delta^{13}C$ values continue to attest to a closed-canopy environment, and palms continue to be as abundant, indicating that the geoglyph was not kept completely clear of vegetation after its construction. Furthermore, the lack of a corresponding charcoal peak 500 m away in the JS2 profile suggests that initial vegetation clearance was confined to site-level only. At Fazenda Colorada, a charcoal peak occurs in a level pre-dating the earliest archaeological date by roughly 200 years (2333–2158 cal. BP), but which we interpret as most parsimoniously representing geoglyph construction (Watling et al. 2017a); however, like at JS1, the phytolith data suggest that a completely open area devoid of tree cover was not maintained and that palms continued to increase at the expense of arboreal species as an effect of human niche construction.

The acts and consequences of 'landscape engineering' (*sensu* Arroyo-Kalin 2016; Erickson 2006) through geoglyph building at FC and JS would have fundamentally and irreversibly altered the social landscape in these locations. Schaan (2009) suggests that earthwork construction was an act of symbolic – perhaps competitive – communication by local groups, which both broadcasted and reaffirmed identities and territorial claims, contributing to the idea that the geoglyph builders were organised into numerous autonomous social units (Saunaluoma and Virtanen 2015).

The specificity of the symbols carved out in the ground (combinations of circles and squares, many perfectly geometrical), as well as the sheer size of the earthworks and the nature of the archaeological deposits encountered (Saunaluoma and Schaan 2012), show that such identities and land claims were profoundly tied to religious beliefs (Schaan 2012). In a recent study, Virtanen and Saunaluoma make a direct link between the geoglyphs and encounters between human and non-human entities, drawing upon ethnographic practices showing *"how geometric designs are actors enabling and affecting the production of relations with specific nonhumans"* (Virtanen and Saunaluoma 2017, p. 627). With the construction and use of the JS and FC earthworks, people´s movements and experiences of these locations would have profoundly altered (Schaan 2012; Virtanen and Saunaluoma 2017). In addition, the re-use and re-interpretation of these spaces over time would have both transformed and re-produced group and individual identities (e.g. Knapp and Ashmore 1999).

To borrow from niche construction theory, such identities and modes of social interaction, deeply embedded in the earthworks, would have become part of the *ecological inheritance* of the geoglyph builders and have been transmitted through generations of geoglyph use. Without more archaeological evidence, we can only speculate upon the possible effects of geoglyph building on the production and reproduction of power and inequality – processes which, if demonstrably linked to increases in reproductive success of certain sections of society, could be defined as another element of human niche construction (*sensu* Shennan 2011).

The spread of radiocarbon dates from the Acre geoglyphs (Saunaluoma and Schaan 2012; Table 1) show that FC and JS were built during a boom period in earthwork construction in the 1st millennium AD; however, in order to place these specific sites within an historical ecological context, they should be considered part of an already-established tradition of landscape engineering in the region that perhaps started as early as 3000 cal. BP (see exceptionally early dates from the Ramal do Capatará [3581–3380 cal. BP] and Severino Calazans [3161–2892 cal. BP] sites in Table 1). While the cultural meanings of the *specific* locations of JS1 and FC1 changed with geoglyph construction, they were also part of a larger *continuum* of landscape transformations. Thinking about this continuity from an evolutionary perspective, one becomes impressed at the timescale over which the knowledge, behaviours and ideology behind the geoglyphs were transmitted and propagated, which perhaps amounted to 1500–2000 years, or 60–80 human generations.

This point leads us to return to the palm-rich forests that were present at the JS and FC locales before geoglyph construction, since ethnographic studies demonstrate how some western Amazonian groups link palm trees to their ancestors. The Huaorani of Ecuador see palm fruits as the results of activities and lives of past generations, and palm groves are places of celebration and commemoration where people walk recalling names of deceased family members (Rival 1993). The Manchineri of Acre, whose presence in southwestern Amazonia is thought to date back to pre-Columbian times (Gow 2003), associate palm trees within secondary forests with their ancestors, which are both respected and feared (Virtanen 2011). Palm spirits, who are individually associated with specific (and highly economically important) palm species, also offer resources and well-being for the Manchineri, as well as punishment if those resources are abused (Virtanen 2011). During ayahuasca visions, these palm spirits appear as geometric shapes – largely squares and circles – and can be channelled through the shape of one of their ancestor spirits (Virtanen 2011). Perhaps the geoglyph cultures, too, would have recognised palm-rich forests as bearing the legacy (or the literal `fruits`) of their ancestors, thus imbuing these places with not only economic, but also symbolic, capital through time. If territorialised or manipulated (e.g. by geoglyph construction), such capital would have had the potential to increase the power of certain groups and/or individuals (Schaan 2012).

Although there are inherent problems in projecting the Manchineri´s beliefs onto the geoglyph builders, suggesting a possible link between the geometric forms of palm and ancestor spirits and the geoglyphs is tempting (Schaan 2012; Virtanen, 2009, Virtanen and Saunaluoma 2017), particularly if one considers the new palaeoecological data from our study. That the JS and FC geoglyphs were seemingly built in the same locations where palm trees had been favoured through generations of landscape domestication and other human niche construction processes might not be a coincidence, and is supported by other circumstantial data that include: 1) a 30 cm-deep soil profile located in the geoglyph site of JK which revealed a complete dominance of palm phytoliths in all horizons (Watling et al. 2017a, *Supp. Info.*); 2) phytoliths evidence from a hearth feature at the Tequinho geoglyph, and ceramic residues from other archaeological sites in the region which attested to heavy consumption of palm products in these spaces (Watling et al. 2015); and 3) forest growing atop the Três Vertentes geoglyph which was found to be particularly rich in palm species (Balée et al. 2014).

5.4. Landscape legacies

The reasons why the geoglyphs were eventually abandoned remains unresolved. The date of 706–572 cal. BP, obtained from the U-shaped structure at the Fazenda Colorada geoglyph (Pärssinen et al. 2003), represents the last known geoglyph activity so far recorded, and is believed to pertain to a later re-use of the site around 600 years after the main period of human activity (Saunaluoma and Schaan 2012).

Near the top of the soil profiles, a decline in palm taxa occurs in those locations where they were initially encouraged. Dating of charcoal associated with this event at JS2 and JS4 gave overlapping dates that are in accordance with the last date at Fazenda Colorada (652–546 and 688–569 cal. BP, respectively). We suggest that once humans stopped using and managing these locations within the landscape, the selective pressures acting upon these forests changed, this time favouring slower-growing, canopy-filling species. In southwest Amazonia, palms are favoured during an 'intermediate succession stage' following forest clearance, occurring after grasses and lianas and before eventually being out-competed by larger trees (Salm et al. 2005). We might postulate that the geoglyph builders artificially maintained this succession stage and favoured the palm niche, which then became disfavoured once people abandoned this trajectory.

The forest did not return to a pre-human, \`natural\` state, however. The idea that people merely disturb natural processes is rejected by historical ecological thinking (Crumley 2007), and the concept of succession as the self-organization of ecosystems towards a \`single end state\` is also questioned in many scientific branches (Phillips 1999). If succession is an example of *convergence* in self-organizational processes, models that favour *divergence* hold that ecosystem perturbations persist and grow and do not have a single end point (Phillips 1999).

As part of a phytolith study of different modern vegetation formations, we sampled surface soils, and conducted small botanical surveys of, the residual forest patches surrounding the JS2 and JS4 profile locations (9°57'39'' S, 67°30'07'' W and 9°57'56'' S, 67°31'52'' W, respectively). Species data for the JS2 forest immediately stood out because nine of its ten most abundant species are economically useful, compared with five out of ten in the JS4 forest patch (Table 3). Although many of the useful species at JS2 do not produce diagnostic phytoliths (e.g. *Bertholettia excelsa* [Brazil nut]), when the phytolith assemblages from the modern soils were statistically compared with those from the JS2 profiles samples (via Principal Components Analysis), the phytolith assemblages from the modern forest plotted closely to those present at the time of the geoglyph builders, suggesting that present-day species composition is close to what it was at the time of the geoglyphs (Watling et al. 2017a).

If we compare the JS2 species data to a more thorough, one-hectare forest inventory carried out at the Três Vertentes geoglyph by Balée et al. (2014), there is some overlap in terms of which species are represented. Two economic species (*Euterpe precatoria*, *Bertholetthia excelsa*) and two genera (*Astrocaryum* and *Cedrela*) that were among the 10 most abundant tree species at JS2 (Table 3) were among the 30 most abundant species in the Três Vertentes forest (Balée et al. 2014, Table 3), while *Acacia polyphylla, Cecropia* sp., *Pouteria* sp., *Apuleia* sp. present in Balée et al.´s inventory were also recorded at JS2, but in smaller percentages.

We also noted, like Balée et al., an unusually high abundance (/community) of the herb species *Phenakospermum guianensis* (Strelitziaceae)–a result of a relatively open forest canopy that may be linked to the secondary, anthropic nature of these forest formations (Balée et al. 2014).

Table 3: Table showing 10 most abundant tree species and families in the JS2 and JS4 forest patches.

Plot name	**Most common tree species %**		**Most common tree families %**	
Jaco Sá 2	*Tetragastris altissima* (Burseraceae)*	COMM	Burseraceae	COMM
	Bertholettia excelsa (Lecythidaceae)*	15.2	Arecaceae	28.6
	Euterpe precatoria (Arecaceae)*	11.2	Fabaceae	12.7
	Jacaranda copaia (Bignoniaceae)	7.9	Lecythidaceae	10.0
	Astrocaryum murumuru (Arecaceae)*	5.6	Bignoniaceae	9.1
	Astrocaryum tucuma (Arecaceae)*	5.6	Moraceae	7.7
	Bellucia sp. (Melastomataceae)	3.9	Melastomataceae	4.1
	Maclura tinctora (Moraceae)*	3.9	Euphorbiaceae	3.2
	Cedrela odorata (Meliaceae)*	3.9	Meliaceae	3.2
	Bactris coccinea (Areaceae)*	3.2	Urticaceae	3.2
	Total:	57.3	Total:	78.6
Jaco Sá 4	*Bactris maraja* (Arecaceae)*	COMM	Arecaceae	COMM
	Sida rhombifolia (Malvaceae)*	COMM	Malvaceae	COMM
	Cecropia polystachys (Urticaceae)	9.1	Fabaceae	23.6
	Tapirira guianensis (Anacardiaceae)*	7.7	Anacardiaceae	15.7
	Inga minuta (Fabaceae)	6.4	Urticaceae	15.2
	Virola multinervia (Myristicaceae)	6.4	Myristicaceae	5.6
	Attalea phalerata (Arecaceae)*	6.4	Euphorbiaceae	5.1
	Acacia polyphylla (Fabaceae)	4.1	Myrtaceae	3.9
	Eugenia sp. (Myrtaceae)	3.6	Bignoniaceae	2.8
	Hura crepitans (Euphorbiaceae)*	3.2	Verbenaceae	2.8
	Total:	46.8	Total:	74.7

COMM = Community; * = useful species (Daly and Silveira 2008)

These results strongly suggest that modern forest composition at JS2 is a result of pre-Columbian impact which, accumulated over many centuries, resulted in cultural forests at this location. Along with the earthworks themselves, these forests, where they remain, are part of the landscape legacies left by the geoglyph builders.

Since the abandonment of the geoglyphs, eastern Acre has been subject to a series of new social and economic pressures. While European Contact in the 16th–17th centuries may have had considerable `knock-on effects` on the native population in Acre, large-scale exploration of the region only began during the Amazonian Rubber Boom (Schaan 2012). From 1877 onwards, thousands of European, Brazilian and indigenous workers migrated to the region to exploit *Hevea brasilensis* trees to sell to international markets – an endeavour which was swiftly abandoned in the 1910s due to the emergence of more competitive Asian markets (Schaan 2012). The low temporal resolution of our soil profile data does not allow us to expand upon the ecological effects of this relatively brief historic period in the FC and JS landscapes.

Our profile data do show clearly, however, the impacts of further migrations to the region from the 1970s onwards, as part of the Amazonian Colonization Programme, and the relative impacts of cattle rearing– an economic activity that requires large areas of deforested land.

Both Jaco Sá and Fazenda Colorada are today situated in cattle farms, and highly elevated grass phytolith frequencies, charcoal concentrations and stable carbon isotope values observed in the top soil profile levels (0–5 cm) leave little doubt that modern forest depletion has been more complete and long-lasting in these locations than at any point in the past.

The modern industrialised era signals a different, exploitative relationship with the environment than that observed during the time of the geoglyph builders. The non-destructive land-use strategies of the latter are demonstrated in the fact that these societies once thrived in eastern Acre, and that today the alpha diversity of Acre's forests is higher than roughly half of similar inventories throughout Amazonia (Silveira et al. 2008). Drawing upon historical ecological studies, our data suggest that such land-use strategies included those used by many indigenous groups today (managing fallow forests and promoting agrobiodiversity), which have long been promoted as 'sustainable' alternatives to modern practises (Eden 1990; Posey and Balée 1989; Posey and Balick 2006).

6. CONCLUSION

In this paper we have attempted, where possible, to apply concepts of historical ecology and human niche construction to the discussion of archaeological, palaeoecological, anthropological and ethnographic data from the geoglyph region in Acre. By moving away from debates over the scale of human impact on the environment (Piperno et al. 2017b; Watling et al. 2017a, 2017b), we show how a locally-sensitive approach that combines archaeological and palaeoecological proxies (Mayle and Iriarte 2014) can provide a baseline for more nuanced studies about the historical ecological trajectories of specific landscapes.

There are still many gaps in our knowledge about the geoglyph builders that hinder finer-grained interpretations of regional historical ecological and human niche construction processes. Some of these may still be filled by continuing archaeological work in the region (e.g. location of settlements and social structure of the geoglyph builders), while others (e.g. specific religious beliefs, individual choices) will inevitably remain a matter of speculation. We must also point out the small spatial scale of our palaeoecological analyses which came from just six soil profiles within a region of earthworks covering 13,000 km^2 (similar approaches have been likened to *"digging with spoons"* (Stahl 2015)), and highlight the taxonomic limitations of phytolith data, whereby several useful species found growing today in the JS2 forest patch were silent in the phytolith record.

However, while problems of incomplete datasets limited the interpretive capacity of these frameworks for the periods before and after the influence of the geoglyph builders, they have helped us think about some of our data in new ways. We can propose, for instance, that predecessors of the geoglyph builders were responsible for an intensification of landscape domestication around 4000 cal. BP and the beginning of a new type of inceptive niche construction in the region. We can also propose that the effects of such niche construction practices created landscape gradients in terms of areas with more- or less-concentrated resources (particularly palms), and began a trajectory towards greater resource concentration in these areas through repeated human visitation (i.e. at JS1, JS2 and FC1).

While historical ecologists, at this point, might be tempted to focus upon the intentional vs. unintentional nature of anthropogenic forest formation in the geoglyph region–something which is very difficult to do (Arroyo-Kalin 2016)–human niche construction theory has opened alternative avenues in how this phenomenon may be considered. Firstly, by emphasizing the micro-processes behind long-term change–in this case, the increasing \`anthropization\` of the JS1, JS2 and FC forests–we can appreciate, regardless of intentionality, the considerable persistence of cultural processes that had to exist for such long-term niche construction to take place. In a similar way, we can see the building of the JS and FC geoglyphs as products of the transmission of specific knowledge, behaviours and religious values which lasted for dozens generations. Perhaps more importantly, by situating human niche construction as a *cause* of evolutionary change (Laland and O'Brien 2011), it made us consider what would have been the cumulative effects of geoglyph building and palm proliferation (i.e. the ecological inheritance) upon human landscaping. Drawing upon examples in the ethnographic literature of how certain western Amazonian groups–including the Manchineri of Acre–imbue special meaning to anthropic forests, in particular palm groves, a new question has emerged: could it be that the building of the geoglyphs at JS and FC, and potentially elsewhere, marked the moment when the economic and symbolic capital of these forests became monumentalised and territorialised by specific groups or individual political actors?

While the answer is probably more complex than this, an interesting avenue for further research would be to analyse soil profiles from within the Severino Calazans and Ramal do Capatará geoglyphs to see if the landscape trajectories of these earliest sites are similar to those at JS and FC. A separate, although not unrelated, question would be: did a more secure resource base acquired though a mixture of crop cultivation and forest management feed the explosion of geoglyph sites during the 1st millennium AD?

Finally, we can see that at least some of Acre's remaining forests, like those adjacent to the JS2 profile and the Três Vertentes geoglyph (Balée et al. 2014) are landscape legacies of the geoglyph builders, and reach an important historical ecological observation about the conservation of Acre´s biodiversity: If we are to try and preserve Amazonian forests, we need to learn from past indigenous land management practices which were able to sustain large populations without depleting the forest.

We conclude this paper by reiterating Arroyo-Kalin´s (2016) argument that historical ecologists could benefit by including human niche construction as a theoretical approach within Amazonian studies. In particular, niche construction theory´s emphasis upon the cultural transmission of ecological inheritance can shed new light on persistent phenomena such as landscape domestication and, in some cases, earthwork building.

ACKNOWLEDGMENTS

Funding for this research was granted by the United Kingdom Arts and Humanities Research Council (AH/J500173/1) (to J.W.), NERC/OxCal Radiocarbon Fund (2013/2/8) (to J.W), National Geographic Society and Exploration Europe (GEFNE14-11) (to F.E.M) and the Conselho Nacional de Desenvolvimento Científico e Tecnológico (301366/2013-6) (to D.S.). We thank Jonas Gregorio for making Figs. 1 and 2 and Manuel Arroyo-Kalin, Sanna Saunaluoma and the two anonymous reviewers for providing valuable insights on the manuscript before submission. We (J.W. and F.M.) dedicate this paper to the memory of our co-author Denise Schaan, whose tireless work in Acre will be one of her many legacies within Amazonian archaeology.

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FIGURE 1:

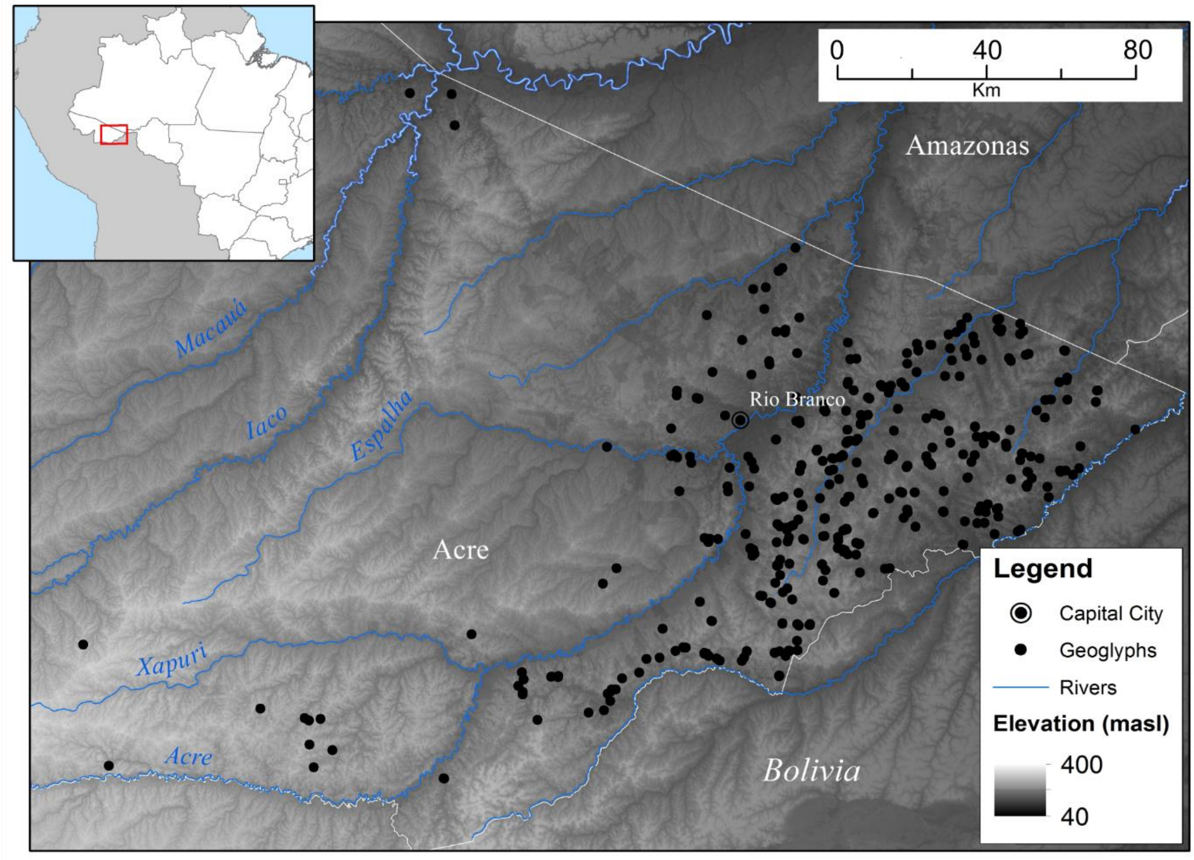
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FIGURE 2

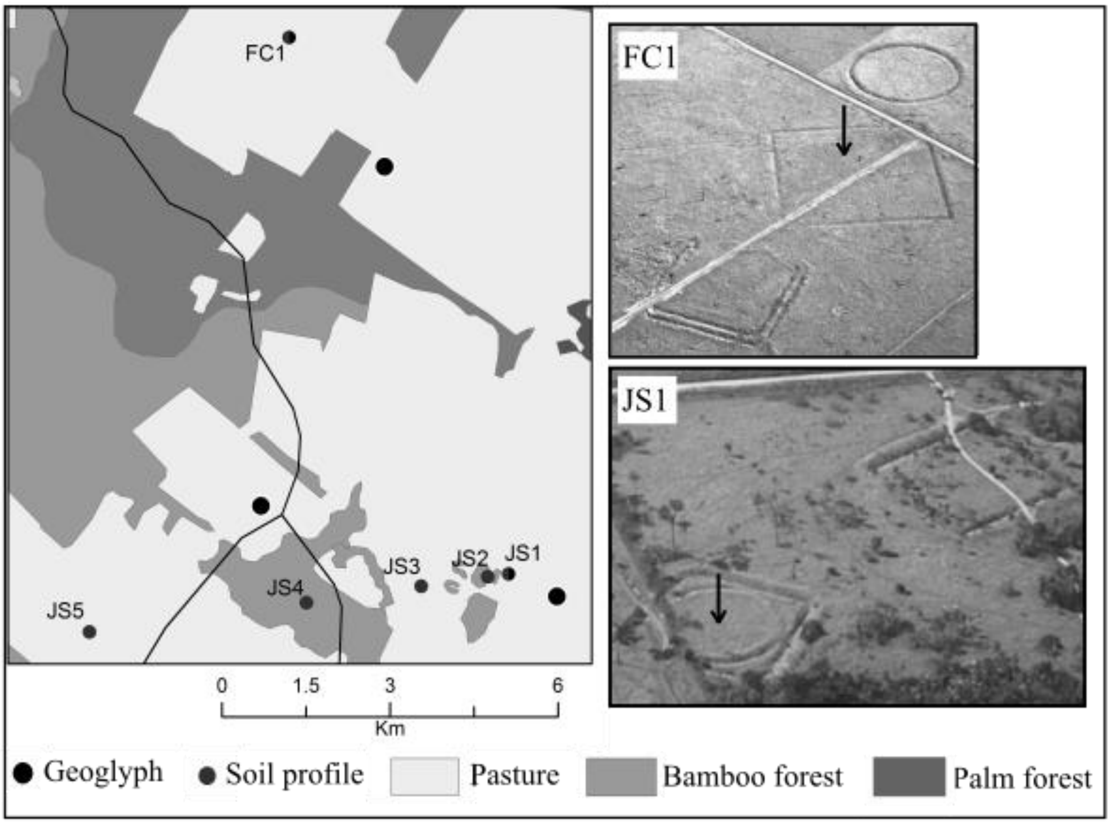

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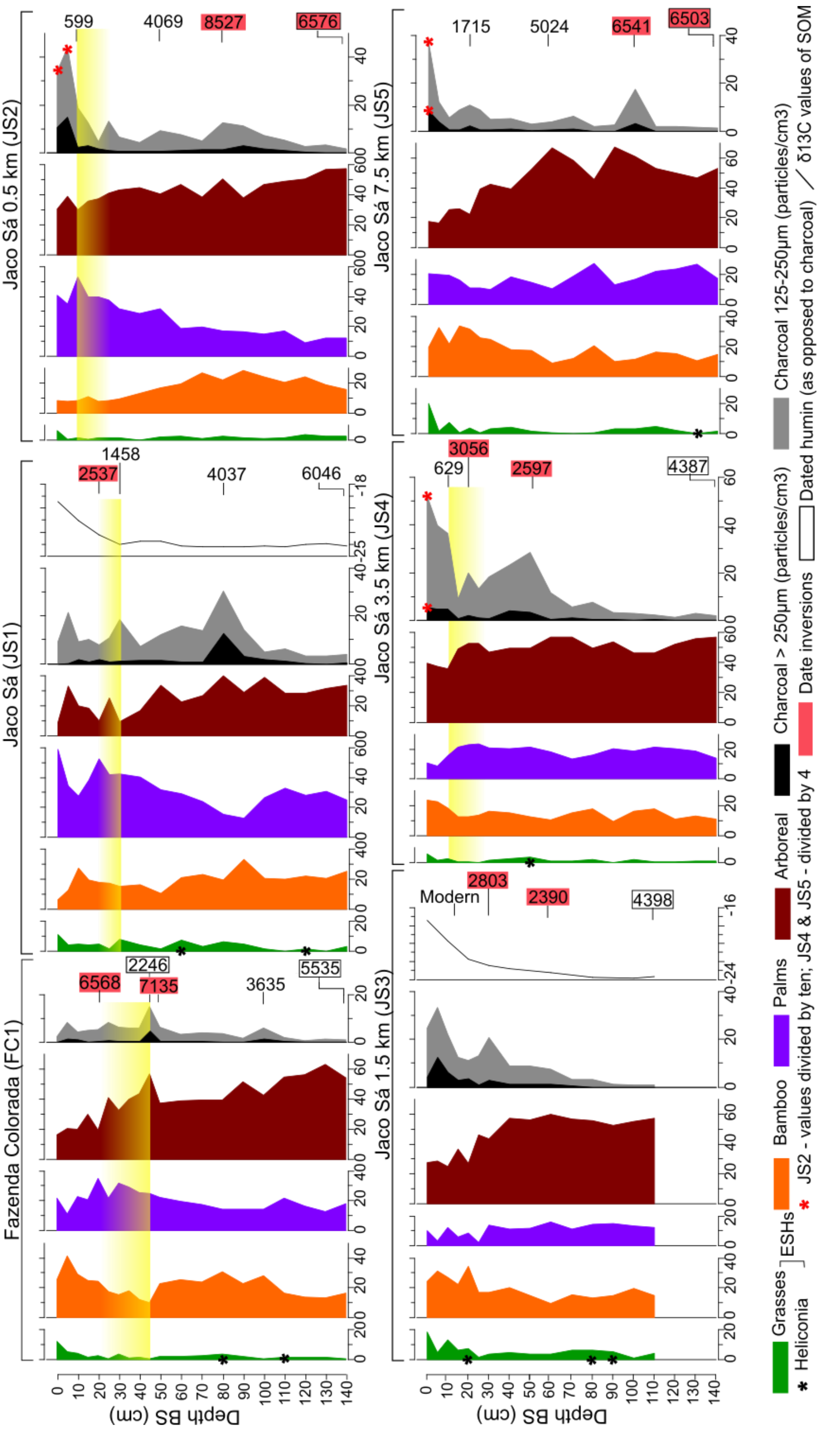
FIGURE 3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