

Pre-Columbian land use in the ring-ditch region of the Bolivian Amazon

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Pre-Columbian land use in the ring-ditch region of the Bolivian Amazon.

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Abstract

The nature and extent of pre-Columbian (pre-1492 AD) human impact in Amazonia is a contentious issue. The Bolivian Amazon has yielded some of the most impressive evidence for large and complex pre-Columbian societies in the Amazon basin, yet there remains relatively little data concerning the land use of these societies over time. Palaeoecology, when integrated with archaeological data, has the potential to fill these gaps in our knowledge. We present a 6,000-year record of anthropogenic burning, agriculture and vegetation change, from an oxbow lake located adjacent to a pre-Columbian ring-ditch in north-east Bolivia (13°15'44" S, 63°42'37" W). Human occupation around the lake site is inferred from pollen and phytoliths of maize (*Zea mays* L.) and macroscopic charcoal evidence of anthropogenic burning. First occupation around the lake was radiocarbon dated to ~2500 years BP. The persistence of maize in the record from ~1850 BP suggests that it was an important crop grown in the ring-ditch region in pre-Columbian times, and abundant macroscopic charcoal suggests that pre-Columbian land management entailed more extensive burning of the landscape than the slash-and-burn agriculture practised around the site today. The site was occupied continuously until near-modern times, although there is evidence for a decline in agricultural intensity or change in land use strategy, and possible population decline, from ~600-500 BP. The long and continuous occupation, which predates the establishment of rainforest in the region, suggests that pre-Columbian land use may have had a significant influence on ecosystem development at this site over the last ~2000 years.

Keywords

Tropical palaeoecology, pollen, phytoliths, Amazonian archaeology, human-environment interactions, Anthropocene

Introduction

In recent decades there has been a paradigm shift in ideas over the size and complexity of pre-Columbian (pre-AD 1492) Amazonian societies. Rather than being limited to small, semi-nomadic, hunter-gatherer groups and shifting horticulturalists (Meggers, 1992), there is abundant archaeological evidence, in the form of settlement remains, artificial earthworks and Amazonian dark earth (*terra preta*) soils (Woods et al., 2009), for sedentary groups with relatively large populations, in many different parts of the Amazon basin. Some of the major archaeological sites occur in the *Llanos de Moxos*, Bolivia, (Erickson, 2000; Lombardo and Prümers, 2010; Lombardo et al., 2010; Saunaluoma, 2010; Walker, 2009), eastern Acre state (Pärssinen et al., 2009; Schaan et al., 2012), the Upper Xingu (Heckenberger, 2003), the central Amazon (Glaser, 2007; Heckenberger and Neves, 2009), Marajó Island (Roosevelt, 1991; Schaan, 2012) and Amapá state (Saldanha and Cabral, 2010), Brazil, and coastal French Guiana (Iriarte et al., 2012). Denevan (2014) has estimated a pre-Contact population of at least 5-6 million in Greater Amazonia (with the caveat that population density was not even across the basin, but concentrated in certain “more productive” environments). It has been suggested that these pre-Columbian populations had a much more extensive impact on Amazonian environments than previously assumed and played an intrinsic part in the development of its ecosystems, through altering the floristic composition, soils, hydrology, and topography of the landscape (Clement and Junqueira, 2010; Denevan, 1992; Erickson, 2008; Heckenberger et al., 2007; Levis et al., 2012; Lombardo et al., 2010; Saldanha and Cabral, 2010). However, there is still considerable debate over the type of land use, the scale of environmental impact, and the chronology of these societies.

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9 The *Llanos de Moxos*, located in the Bolivian department of the Beni
10 (Figure I) in south-west Amazonia, has some of the most diverse and extensive
11 examples of pre-Columbian earthworks in the Amazon Basin (Denevan, 1966;
12 Walker, 2008). These include raised agricultural fields (Rodrigues et al., 2014;
13 Walker, 2004), monumental habitation mounds (Lombardo and Prümers, 2010),
14 canals, causeways, and ring-ditch structures (Erickson, 2000; Prümers and
15 Betancourt, 2014b; Prümers, 2014a, 2014b), which together are indicative of
16 large and socially complex, sedentary populations. The north-east province of
17 Iténez is a unique archaeological sub-region within the Beni. It is characterised
18 by extensive ring-ditch earthworks alongside causeways, ditched agricultural
19 fields, and fish weirs (Denevan, 1966; Erickson, 2000; Lombardo et al., 2013). It
20 is also home to the Iténez Forest Reserve, which was established in recognition
21 of the unique species diversity of this region. However, to date, research in this
22 important historical and natural landscape has been limited. Detailed
23 archaeological investigations have been published from only one site, Bella
24 Vista Village (BVV) (Dickau et al., 2012; Prümers, 2009; Prümers et al., 2006),
25 and limited palaeoecological work has been carried out (Carson et al., 2014).
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37 Remote sensing and ground-based surveys are beginning to map the
38 spatial extent of earthworks in Iténez (Erickson, 2010; Prümers, 2012a, 2012b),
39 which have been estimated to cover an area of 12,000 km² across the whole
40 province (Erickson, 2010). The large number of earthworks below what is now
41 closed-canopy rainforest in this region is suggestive of significant pre-
42 Columbian environmental impact. However, as argued in Carson et al. (2014),
43 one cannot make such inferences based solely upon the spatial extent of
44 earthworks within the modern landscape, but must also know the
45 palaeoenvironmental context of their construction. This is because the spatial
46 extent of forest versus savannah/grassland may have changed through time.
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9 Palaeo data can also inform us about important aspects of the nature of land
10 use; for example, whether it involved extensive burning, clearance or
11 suppression of forest growth. Improving our knowledge in this area will inform
12 wider debates over the resilience of Amazonian ecosystems to long-term
13 anthropogenic impacts and the extent to which parts of Amazonia can be
14 considered a pristine vs. anthropogenic landscape (Barlow et al., 2012;
15 Heckenberger, 2003; Meggers, 2003; Peres et al., 2010). It has been suggested
16 that pre-Columbian land use had a significant impact on Holocene biomass
17 levels and carbon emissions, through deforestation and burning (Dull et al.,
18 2010; Nevle et al., 2011). Testing the validity of this Early Anthropocene
19 hypothesis in Amazonia requires a better understanding of the scale and nature
20 of pre-Columbian impact.
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28 Archaeological excavations in Iténez are also documenting the material
29 culture of the earthwork-building societies, and have provided dating from
30 occupation layers within excavated ring ditches (Prümers and Betancourt,
31 2014a; Prümers, 2014a, 2014b; Prümers et al., 2006). Archaeobotanical
32 analyses from one of these excavations have uncovered aspects of palaeo diet
33 (Dickau et al., 2012), suggesting that maize may have been an important crop
34 grown in the region. Historical ecological studies (which are informed by modern
35 ethnographic data) of the vegetation surrounding earthwork sites have
36 attempted to reconstruct the legacy of pre-Columbian land management within
37 extant forest in lowland Bolivia (Erickson and Balée, 2006; Erickson, 2010).
38 However, these studies often lack the temporal depth/continuity to be able to
39 discern changes in land use, agriculture, and legacy of environmental impact,
40 over Holocene timescales. Palaeoecological data can provide a deeper
41 temporal perspective on pre-Columbian human-environment interactions and,
42 subsequently, their legacy in the modern landscape. Furthermore, by dating
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9 activities such as burning, agriculture and clearance, it may be possible to
10 recognise periods of occupation at a site that are not visible in the
11 archaeological record, because of poor preservation. Gaining a sound
12 chronology of occupation is vital for informing debates over the antiquity and
13 decline of indigenous Amazonian societies. There is strong historical and
14 archaeological evidence for a widespread, post-contact, native population
15 collapse driven by epidemic crises across the Americas (Denevan, 1992, 2014;
16 Dobyns, 1966). However, the decline of human activity at some Bolivian sites
17 appears to predate European Contact (Whitney et al., 2014), and may reflect
18 site abandonment due to internal social, political or environmental/climatic
19 factors.
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27 In order to best exploit the complementary aspects of palaeoecological
28 and archaeological data, Mayle and Iriarte (2014) proposed an integrative
29 approach, combining local-scale palaeoecological records from small lakes with
30 archaeological/archaeobotanical data from nearby archaeological sites.
31 Although such an approach has long been used in other parts of the world (e.g.
32 Europe), it has only recently been adopted in Amazonia (Iriarte et al., 2012;
33 Whitney et al., 2013, 2014). The regular and continuous nature of sediment
34 accumulation in lakes, and our ability to isolate and identify cultigens through
35 pollen and phytoliths, allows for a continuous chronology of human
36 settlement/land use. Pollen and phytoliths have been shown to be
37 complementary proxies when reconstructing tropical environments from
38 lake/bog sediments (Iriarte et al., 2012; Whitney et al., 2013), with pollen
39 providing higher taxonomic resolution for arboreal taxa, and phytoliths for grass
40 and herb taxa (Piperno, 2006). By combining palaeoecological and
41 archaeological data, over comparable spatial scales, we gain insights into the
42 land-use strategies of pre-Columbian peoples, the spatial extent of past
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Aims

In this paper we apply an integrative approach to investigate pre-Columbian human-environment interactions at the Bella Vista (BVV) archaeological site, in north-east Bolivia. This is achieved by analysing pollen, phytoliths, and macroscopic charcoal from Laguna Granja (LG), an oxbow lake located within BVV and adjacent to the Granja del Padre (GDP) ring-ditch feature. The pollen and charcoal records from LG were previously discussed in Carson et al. (2014) in comparison with a regional-scale lake record, to determine the palaeoenvironmental context of pre-Columbian geometric earthwork construction in the region. Here, these pollen data are combined with new phytolith data from LG, and archaeological data from previous excavations (Dickau et al., 2012; Prümers et al., 2006), to better define the occupation history of the BVV site, and discuss the land use practices and potential environmental impacts of its pre-Columbian inhabitants. Specifically, we expand upon the findings of Carson et al. (2014) by addressing the following questions:

1. What was the period of occupation on the site and did abandonment coincide with the arrival of Europeans ~500 years BP?
2. What was the subsistence strategy? What were the staple crops? Maize, manioc and/or sweet potato? Did this change over time?
3. What was the nature of pre-Columbian land management (i.e. did it involve extensive burning, clearance or manipulation of economically useful forest resources) and what was its spatial extent?
4. What legacy, if any, has pre-Columbian land use left in the modern vegetation?

Study site, physical setting, and archaeological context

Northern Iténez

The modern village of Bella Vista is located in the north of Iténez, the easternmost province of the Beni department, Bolivia. The village lies on the north side of the San Martín River (Figure 1), which marks the geo-ecological divide between two Amazonian landscapes. To the north of the river, the *terra firme* (non-flooded) Pre-Cambrian Shield (PCS) supports dense-canopy, evergreen rainforest, which forms part of the Madeira-Tapajós rainforest ecoregion that extends from south of the Amazon river down to the Brazilian-Bolivian border (Olson et al., 2010). To the south and west is the *Llanos de Moxos (LDM)*, a vast, low lying sedimentary basin which, due to the impermeability of its clay sediments (Clapperton, 1993), becomes largely flooded during the annual wet season from November-March. As a result of this annual flooding, the landscape comprises a wetland savannah, interspersed by small outcrops of the PCS (Clapperton, 1993), which support *terra firme* rainforest, and are commonly called “forest islands”. Extensive ring-ditch earthworks, ranging from discreet circular ditches hundreds of metres in diameter to kilometre-long, curvilinear ditches, are distributed across the *terra firme* landscape of both the main PCS in the north and the forest islands of the *LDM* to the south. In the savannah of the *LDM*, there are also ditched agricultural fields and linear causeway structures which run between the forest islands, and in the far south-east of the province, zigzagged “fish weir” structures (Erickson, 2000; Lombardo et al., 2013).

[Insert Figure 1]

Archaeology of Bella Vista Village

Surveys over an area of ~200 km² around BVV have documented numerous pre-Columbian ditched earthworks, enclosing areas of up to 200 ha (Prümers, 2012a, 2012b). Two of the circular ditches, Granja del Padre (GDP;) and BV-3, were excavated by Prümers et al. (2006). The two ring ditches are located 1 km apart and are connected by a long, semi-circular ditch, which surrounds an area of 150 ha. The GDP ring ditch (figure 2) has a 2 m deep trench and measures 150 m in diameter. A total area of 600 m² of GDP was excavated, uncovering 16 urn burials and a single thin cultural layer, which was radiocarbon dated from soot on ceramic sherds to between ~650-750 calibrated years before present (cal yr BP). BV-3 also had a single, shallow occupation layer, which was radiocarbon dated from charcoal on ceramic sherds to ~550-570 cal yr BP (Prümers et al., 2006). Excavations were also conducted at a location in the centre of the modern town (BV-1) where ceramics had been uncovered by construction work. Radiocarbon dates from the BV-1 site dated the occupation layer between ~700-640 cal yr BP. The dates, with 95% confidence interval age ranges, are summarised in figure 3.

[Insert figure 2]

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20 The function of the ring ditches in this region remains unknown. Historical
21 accounts from early European travellers in the Iténez region describe
22 settlements with a defensive ring ditch (Nordenskiöld, 1910), which was
23 enhanced by a palisade (Altamirano, 1891; Block, 1994). The design of the ring
24 ditches around BVV led Prümers et al. (2006) to conclude that they were
25 probably defensive features. However, the excavations at BVV and around
26 Baures in the south (Prümers and Betancourt, 2014a) found no evidence of
27 wooden remains or post holes that would indicate the construction of a
28 palisade. Some ring ditches, such as GDP, also functioned as burial sites.
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35 The subsistence strategy of ring-ditch builders and other pre-Columbian
36 groups in lowland Bolivia involved agriculture (Dickau et al., 2012; Whitney et
37 al., 2013, 2014). It has been hypothesised that Amazonian farmers became
38 increasingly dependent upon intensive food-production systems through the late
39 Holocene, due to increasing population density (de Paula Moraes and Neves,
40 2012; Rebellato et al., 2009), but there is a long-standing debate over whether
41 the predominant staple crop that supported these increasingly complex
42 societies was manioc (*Manihot esculenta* Crantz) (Arroyo-Kalin, 2010;
43 Heckenberger, 1998; Lathrap, 1970; Oliver, 2001; Piperno and Pearsall, 1998a)
44 or instead maize (*Zea mays* L.) (Roosevelt, 1993). Manioc is the staple crop
45 grown in the Iténez region today. However, in an analysis of the phytoliths and
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8 starch grain residues left on stone tools excavated from the BVV site, Dickau et
9 al. (2012) found maize to be the main identifiable cultigen. Starch grains from
10 manioc were also recorded on two handstone tools, but maize starch grains
11 were by far the most common type found. This led the authors to tentatively
12 conclude that maize was an important crop grown on site. A more confident
13 conclusion was not possible because of the small sample size available.
14 Further, independent proxy analysis is needed from the site to test these
15 conclusions.
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24 *L. Granja*

25 In order to investigate elements of land use on the BVV site, a local-scale
26 palaeoecological record was required, which could be integrated with the
27 existing archaeological data. The pollen catchment area of a lake is proportional
28 to the lake surface area (Sugita, 1994), therefore we selected a small lake for
29 coring, which would represent vegetation on a local scale around the
30 archaeological site. The lake cored for this study, LG (13°15'44" S, 63°42'37"
31 W), is a small (0.2 km²) oxbow lake, located 100 m from the GDP ring ditch
32 (Figures 1 & 2) and 1 km north of the modern BVV. The water depth of the lake
33 is 2 m at its deepest point (measured during the dry season, July 2011). The
34 majority of the lake margins are dominated by riparian forest which, according
35 to local inhabitants, becomes flooded up to a height of 2 m every year during
36 the annual wet season. In exceptional flood years the lake becomes temporarily
37 reconnected to the San Martín River. On the east side of the lake, a small area
38 of land (~0.3 km²) has been cleared for cattle grazing.
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Materials and methods

Sample acquisition

Fieldwork was carried out in June-July 2011. Samples were taken from a stable floating platform in the central, deepest part of the lake, using a modified drop-hammer Livingston piston corer (Colinvaux et al., 1999). Surface sediments were taken using a 5-cm diameter Perspex® tube and piston to capture the uppermost unconsolidated sediments. Softer sediments from the surface core were sub-sampled in the field at 0.5-cm intervals and stored in watertight plastic tubes. Firmer sediments were extruded in the field as intact cores and shipped back to the UK in robust, watertight packaging. Livingstone core sections were transported in their aluminium core tubes and extruded in the lab in the UK. In the lab, the sediment cores were split lengthways into equal core halves, one of which was used for destructive sampling while the other was retained as an archive core. All samples were kept in cold storage at 4° C.

Chronology

An age-depth model for the sediment core was derived from five AMS ¹⁴C dates obtained from organic lake sediments. All the dates were from non-calcareous bulk sediments, because the core lacked plant macrofossils and macroscopic charcoal particles large enough for radiocarbon dating. Dates were calibrated to 95% (2σ) confidence intervals using the IntCal13 calibration curve in the OxCal program version 4.1 (Reimer et al., 2013) (Table I). Given the small total number of dates, the best representation in an age model was achieved using simple linear interpolations between data points (Bennett, 1994; Telford et al., 2004a) (Figure 4). Single age estimates for each date were calculated using the weighted means of the probability distribution of the calibrated ages (Telford et

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9 al. 2004), as this was the best method for representing those calibrated age
10 ranges which have multimodal distributions.
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12 13 Modern vegetation survey

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15 During fieldwork a rapid assessment botanical survey of the vegetation around
16 LG was made by JDS to aid pollen and phytolith identification, and estimation of
17 the spatial representation of the microfossil record. All species encountered
18 along 4, 100 x 5 m transects (orientated north, south, east and west around the
19 lake) were identified and voucher specimens collected for the herbarium of the
20 Museum of Natural History 'Noel Kempff Mercado', in Santa Cruz, Bolivia
21 (Table 2).
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27 28 Pollen analysis

29 The core was sampled initially at coarse resolution (20-cm intervals) to create a
30 framework pollen profile, after which sample resolution was increased, focusing
31 on depths where significant pollen assemblage changes occurred. From 0-110
32 cm depth, sampling resolution was increased to 5-cm intervals, and from 110
33 cm to the base at 150 cm, resolution was increased to 10-cm intervals.
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37 A 1 cm³ sub-sample of sediment was prepped from each horizon using a
38 modified sieving protocol designed for optimal recovery of large cultigen pollen
39 (Whitney et al., 2012). All other stages followed the standard pollen preparation
40 protocol (Faegri and Iversen, 1989). Samples were spiked with a known
41 concentration of *Lycopodium* marker spores for calculation of pollen
42 concentration values, and to confirm that observed changes in pollen
43 percentage abundance were not the result of changes within a closed sum. The
44 pollen in the fine fractions (material <53 µm) was counted to the standard 300
45 grains. The coarse fractions (>53 µm) were scanned for large cultigen pollen
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grains up to a standardised equivalent count of 2000 *Lycopodium* spores, representing ~0.4 cm³ of the original 1 cm³ of sediment processed. Fossil pollen was identified with reference to the collection of over 1000 tropical pollen specimens (housed at the University of Reading), and from atlases of Neotropical pollen (Bush and Weng, 2007; Colinvaux et al., 1999). Maize grains were distinguished from other wild grasses according to the morphological criteria described in Holst et al. (2007). Where possible, members of the Moraceae family were identified to genus using morphological descriptions from Burn & Mayle (2008). Where genus level identification was not possible, grains were assigned to the Moraceae/Urticaceae undifferentiated category. Cyperaceae and *Alternanthera* were identified in the modern botanical survey as common aquatic/semi-aquatic types within the modern lake. They were therefore counted, but excluded from the terrestrial pollen sum of 300 grains, and presented as part of the aquatic flora.

Interpretations of the fossil pollen assemblages are also based upon extensive modern pollen rain studies conducted across different lowland Amazonian ecosystem types in north-eastern Bolivia (Burn et al., 2010; Gosling et al., 2005, 2009; Jones et al., 2011).

Phytolith Analysis

Sediments were sub-sampled for phytolith analysis at 10-cm resolution throughout the core, with an additional three samples at 22, 35, and 45 cm depth. Phytolith extraction followed standard procedures established by Piperno (2006). Samples were pre-treated to remove clays through deflocculation and gravity sedimentation using a centrifuge, carbonates were removed using 36% HCl, and organics were removed by heating the sample in a solution of 70%

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HNO₃. Phytoliths were extracted by heavy liquid flotation in ZnBr₂ (specific gravity 2.3g/cm³) and mounted with Entellan® mounting agent to allow for rotation under the microscope for 3D viewing. Due to the small volumes of sediment available (because of our multiproxy analyses), phytoliths were not separated into size fractions (Piperno, 2006). However, despite these small sediment volumes (minimum 3cm²), all samples yielded abundant quantities of phytoliths. A minimum of 200 phytoliths was counted per slide and the whole slide was scanned for diagnostic crop phytoliths. Phytoliths were identified by comparison with a phytolith reference collection of over 750 Neotropical plant taxa held at University of Exeter (Watling and Iriarte, 2013). Identification of Poaceae short cell phytoliths followed a system first proposed by Twiss et al. (1969) and later expanded to include other aspects of 3-dimensional morphology (Brown, 1984; Pearsall, 2000; Piperno and Pearsall, 1998b). As with the pollen data, Cyperaceae phytoliths are presented separately from the terrestrial sum.

Our interpretations of the fossil phytolith assemblages were also informed by soil-surface phytolith studies, conducted in permanent botanical plots from different lowland Amazonian ecosystems in Noel Kempff Mercado National Park, north-east Bolivia (Dickau et al., 2013).

Charcoal Analysis

Macroscopic charcoal analysis was carried out on the core from 0-150 cm. Samples were initially analysed at 10-cm intervals. Where this process identified significant vegetation changes and/or burning, the sampling resolution for charcoal analysis was increased. From 0-110 cm, sampling resolution was increased to 0.5-cm intervals, while at the base of the core, between 110-150 cm, sampling resolution was increased to 5-cm intervals. Sub-samples of 1 cm³

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9 were taken from each horizon and heated in 5% sodium pyrophosphate to
10 disaggregate clay sediments. The samples were then sieved at 250 μm and 125
11 μm , and charcoal particles counted in water under 40x magnification. All
12 stratigraphic figures were drawn using the program C2 (Juggins, 2007).
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Results and Interpretation

Core stratigraphy and chronology

Sediments from LG were cored to a depth of 240 cm, and compiled into a single composite core by cross-correlation of overlapping Livingstone core sequences and a 58-cm surface core. The overlapping cores were correlated using high-resolution charcoal curves. The sediment throughout was a light to medium brown clay, with some fine sands. Pollen preservation between 150-170 cm was poor, and therefore, palaeoecological analysis and radiocarbon dating of sediments were focused above 150 cm depth.

A total of five AMS ^{14}C dates were obtained to build a chronology for the LG record (Table I). No reversals were observed in the chronology (Figure 4).

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[Insert Table I]

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11 Modern vegetation and surface-sediment microfossils

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13 The results of the modern vegetation survey are presented in Table 2. The
14 vegetation survey yielded 62 species, mostly representing the
15 inundated/riparian forest zone around the lake. The most common terrestrial
16 tree types were *Vochysia mapirensis* (Vochysiaceae) and *Buchenavia*
17 *oxycarpa* (Combretaceae). The dominant aquatic species were the fern
18 *Marsilea polycarpa* (Marsileaceae) and the water hyacinth *Eichhornia azurea*
19 (Pontederiaceae).
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9 [Insert table 2]

10 The surface-sediment pollen assemblage from LG has roughly equal
11 proportions of arboreal (48%) and herb (43%) types. The most abundant
12 arboreal taxa are *Cecropia* (13%), *Brosimum* (8%), Moraceae/Urticaceae (8%),
13 *Alchornea* (4%), Arecaceae (palms) (4%), *Trema* (4%) and *Ampelocera* (2%).
14 Poaceae (grasses) accounts for 35% of the surface pollen assemblage, while
15 other common herb types include the weedy taxa Asteraceae (4%) and *Borreria*
16 sp. (4%). Aquatic grasses were not found to be abundant around the modern
17 lake shore, and therefore it is assumed that the majority of grass pollen and
18 phytoliths in the lake record derive from a terrestrial source. Of the aquatic
19 types documented in the botanical survey, *Eichhornia* (<1%) is
20 underrepresented relative to its abundance on the land/water surface, while
21 Cyperaceae (23%) is overrepresented.
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30 The surface pollen assemblage contrasts markedly with the phytolith
31 assemblage, which is dominated by herb taxa (75%) over arboreal types (26%).
32 Grasses (62%) are the most abundant herb, comprising mostly Panicoideae
33 types (bilobates (29%), crosses (22%)), followed by rondels (10%), which are a
34 general Poaceae indicator with a cosmopolitan distribution (Pearsall, 2010), and
35 a very small proportion of Chloridoideae, represented by saddle-shaped
36 phytoliths (1%). *Heliconia* sp. (5%) and bamboos (4%) are present in low
37 abundance. Arboreal types (26%) are represented primarily by globular
38 granulates (20%) and palms (6%). The main aquatic phytolith taxon is
39 Cyperaceae (3%).
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47 Given that trees and grasses produce both abundant pollen and
48 phytoliths (Aleman et al., 2014; Piperno, 2006), it is unlikely that this
49 discrepancy is due to differences in microfossil production. A more likely
50 explanation is that differences in the transport of these two microfossils means
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9 that they represent the landscape around the basin at different spatial scales.
10 Phytoliths, which are silica bodies derived from plant materials, are commonly
11 released by in-situ decomposition of plant organic matter (Piperno, 1988, 2006).
12 Although long distance transport of phytoliths is possible via rivers or advection
13 from large fires, in lakes where fluvial input is low and/or there is a buffer
14 created by surrounding forest vegetation on the shoreline, extra-local and
15 regional phytolith deposition may be limited (Piperno, 2001, 2006). Phytoliths in
16 lacustrine sediment records may therefore represent predominantly local
17 vegetation, as demonstrated at other lake sites in the Bolivian Amazon (Whitney
18 et al., 2013). In contrast, pollen has potential for longer distance transport,
19 especially from anemophilous species such as members of the Moraceae family
20 (Bush and Rivera, 1998; Bush, 1995; Gosling et al., 2005). We therefore infer
21 that the pollen record at LG represents extra-local vegetation around the lake,
22 while the phytoliths represent a more localized catchment area, including the
23 shoreline vegetation.
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33 We can test these ideas by comparing the surface pollen and phytolith
34 assemblages with the modern plant inventory (Table 2). Species which occur in
35 both the plant inventory and the surface pollen assemblage include members of
36 the genera *Cecropia*, *Alchornea*, *Pourouma* and *Uncaria*. In pollen trap and lake
37 core studies from other *terra firme* sites in eastern lowland Bolivia, *Cecropia*
38 and *Alchornea* were shown to be common members of humid evergreen
39 riparian forest (Burn et al., 2010). *Brosimum* is found in the surface pollen
40 assemblage from LG, but was not identified in the plant inventory. We therefore
41 infer that it and other anemophilous, *terra firme* taxa found in the pollen record,
42 such as *Pseudolmedia* (Burn et al. 2010), represent an extra-local signal, which
43 derives from the *terra firme* evergreen rainforest, outside the riparian zone
44 around the lake. The modern vegetation around LG includes a cleared area of
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9 farm land (~0.3 km²) on its eastern shore. This and other cleared patches
10 visible immediately around the lake, are likely the source of abundant grass
11 phytoliths found in the lake surface sediment, but also contribute to the grass
12 pollen signal.
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15 16 LG-1 6000-2500 yrs BP

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18 From 0-150 cm in the sediment core, pollen and phytolith preservation were
19 good. Pollen and charcoal results are presented in figure 5 and phytolith results
20 in figure 6. In Zone LG-1 (comprising 11 pollen and 5 phytolith samples), the
21 pollen assemblages are dominated by Poaceae (40-77% abundance),
22 indicating that the wider *terra firme* landscape around the lake was covered by
23 savannah during this period. Pollen assemblages with Poaceae proportions of
24 >40% typically represent savannah (Gosling et al., 2009; Jones et al., 2011).
25 The very high proportion of Poaceae pollen (≥50%) compared to arboreal types
26 (18-38%) in this zone, suggests that the *terra firme* environment from 6000 to
27 2500 yrs BP was an open savannah with low tree density, rather than a more
28 densely forested woodland savannah or seasonally-dry tropical forest (Gosling
29 et al., 2009; Jones et al., 2011). Of the arboreal taxa present, common types
30 are *Cecropia* sp. (5-17%), Moraceae/Urticaceae (3-10%), *Alchornea* (0-6%) and
31 *Pseudolmedia* sp. (0-3%). The taxon Asteraceae (2-10%), which can occur as
32 herbs, shrubs or lianas, is present throughout the zone.
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43 The phytolith record in this zone is dominated by arboreal globular
44 granulate type phytoliths (32-75%), with low Poaceae levels (7-16%), low level
45 of palms (4-21%) and abundant Asteraceae (5-41%), suggesting seasonally
46 inundated semi-deciduous dry forest (Dickau et al. 2012). The small contribution
47 of Poaceae phytoliths indicates that the high Poaceae pollen levels in this zone
48 derive from the *terra firme* landscape, beyond the lake margins. In the pollen
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9 record the presence of *Anadenanthera* ($\leq 2\%$), a tree which is common in
10 seasonally-dry tropical forest, but may also grow in seasonally flooded forest
11 (Pennington et al., 2006), may support this interpretation of seasonally-flooded
12 forest around the lake margins.
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15 The appearance and high abundance in the pollen record of the semi-
16 aquatic genus *Alternanthera* sp. (1-8%) in this zone (presented outside the
17 terrestrial sum) is also indicative of swampy conditions around the lake, possibly
18 related to a low stand in the lake's history, which exposed more of the shoreline
19 for colonization by *Alternanthera*. Charcoal levels throughout this zone are low.
20 This is likely due to the presence of semi-inundated riparian forest around the
21 lake at this time, which 1) unlike the savannah in the wider landscape, would
22 not have been susceptible to frequent burning and 2) may have acted as a
23 barrier to the deposition of charcoal from extra-local/regional sources (Aleman
24 et al., 2013).
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32 LG-2 2500-500 yrs BP

33 In zone LG-2 (14 pollen and 10 phytolith samples), there is a sharp increase in
34 charcoal abundance at ~2500 yrs BP, likely indicating an increase in both the
35 frequency and extent of burning around the lake. This increase in charcoal at
36 LG contrasts with the pattern of decreasing burning seen at this time in the
37 regional-scale records from Lagunas Orícore (LO) (Carson et al., 2014), Bella
38 Vista (LBV) and Chaplin (LCH) (Burbridge et al., 2004; Mayle et al., 2000). The
39 regional-scale decrease in burning observed across S-W Amazonia has been
40 linked to increasing late-Holocene precipitation, and reduced natural fire
41 potential. This suggests that burning around LG was localised and
42 anthropogenic in origin.
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The first maize pollen of the record is found at ~1850 yrs BP, and maize pollen was recovered throughout the rest of the zone. The high Poaceae levels (50-77%) and low total arboreal pollen (15-30%) indicate that the PCS landscape around LG continued to be open savannah throughout this period. However, there is evidence for a shift in floristic composition toward more evergreen rainforest species such as *Brosimum* (1-6%) and *Pseudolmedia* (1-4%) (Burn et al., 2010; Gosling et al., 2009) in response to increased precipitation. Between ~1600 and 700 yrs BP, charcoal levels decline and in the pollen record there is a moderate reduction in Poaceae (50%) in favour of the weedy taxa Asteraceae (2-10%), Chenopodiaceae/*Amaranthus* (1-6%) and *Borreria* (0-2%).

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At ~700 yrs BP there is another sudden spike in charcoal, indicating a second intensive burning period between ~700 and 500 yrs BP, with peak Poaceae levels (78%) occurring at ~680 yrs BP. The disappearance of *Alchornea* and *Celtis* and reduction of *Cecropia* (1-3%) from ~750 to 600 yrs BP, suggest opening of the gallery forest. The charcoal peak begins to decline ~600 yrs BP.

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The phytolith record in zone LG-2 shows an expansion of grasses (35-75%) and decrease in woody dicots (18-64%), signalling the opening of the landscape around the lake margins. Bamboos (1-8%) appear in the phytolith record in this zone, and may reflect a floristic transformation toward evergreen forest (Dickau et al., 2013), but may also be the result of human disturbance. Bamboos are a common component of disturbed forest and form constituent flora of evergreen *terra firme* rainforest (Dickau et al., 2013). This zone also sees the first appearance of maize phytoliths alongside maize pollen in the record at ~1000 yrs BP and throughout the rest of zone LG-2.

LG-3 500 yrs BP-present

Charcoal declines to near modern levels at the zonal boundary (500 yrs BP) between LG-2 and LG-3 (7 pollen and 5 phytolith samples). The fall in charcoal concentrations is complemented by a decrease in Poaceae pollen (34-44%) and increase in arboreal pollen types (35-58%), most notably *terra firme* taxa such as *Brosimum* (7-10%) and *Pseudolmedia* (0-6%). These changes signal reduced frequency/intensity of burning and an expansion of evergreen forest into the *terra firme* areas of the site (Burn et al., 2010). Both the pollen and phytolith records also appear to show expansion of the gallery forest, with woody phytoliths (25-45%) increasing, and the reappearance of *Cecropia* (3-12%), *Celtis* (1-6%) and *Alchornea* (2-9%) in the pollen record. However, grasses remain the dominant component of the phytolith assemblage (48-62%), suggesting that there is still open ground around the lake margins. Maize is found in the pollen and phytolith records until close to modern times (~50-100 yrs BP).

[insert figure 5]

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Discussion

Timing of occupation at Laguna Granja

Archaeological excavations of the two ring ditches, GDP and BV-3, identified a single, thin occupation zone. At GDP this layer was dated to between ~750-650 yrs BP and at BV-3 to between 570-550 yrs BP (Prümers et al., 2006). The construction/occupation of the ring ditches is broadly contemporaneous with a period of intense burning and degradation of the riparian forest seen in the LG record, suggesting that this activity was linked with use of the earthworks. Our palaeoecological analyses however, have revealed a much earlier start to human occupation around LG, with anthropogenic burning evident from ~2500 yrs BP. This is perhaps not surprising given that, so far, excavations and radiocarbon dating at BVV have been limited to the ring ditch sites. Excavations close to ring ditch earthworks around Baures in the south of Iténez province (Prümers and Betancourt, 2014b), and in Riberalta, in northern Bolivia (Saunaluoma, 2010), have produced evidence of early, possibly pre-ring ditch occupations, dated to ~1650-1450 BP and ~2100 BP respectively. Our dating of first occupation of the BVV site from the palaeoecological record is therefore consistent with the wider chronology of occupation in the south-west Amazon. It is unclear whether this early activity around LG represents a culture that was superseded by ring-ditch builders, or whether some of the numerous, undated earthworks on the BVV site were constructed during this early period. Answering this question will require further excavations and dating from terrestrial contexts.

The palaeoecological record from LG also shows that the dating of this cultural layer in the GDP and BV-3 earthworks does not mark the end of occupation on the site. There is a probable decline in population and activity

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9 between ~600-500 cal yr BP, when burning declines and afforestation begins.
10 However, maize agriculture was evidently still practised on the site after this
11 date. This could have been the result of cultivation by a relatively small
12 population later in the site's history, unlike the once extensive populations that
13 likely built the ring ditch structures. Maize microfossils are found almost
14 continuously through the upper part of the lake record and until near to modern
15 day (~50-100 years BP), suggesting that part of this maize signal derives from
16 cultivation by colonial/20th century populations. There is an interval between
17 ~200-250 BP in which no maize pollen or phytoliths were identified. This may
18 represent a transitional period between the final abandonment of the site by
19 native population and its settling by a modern population, although this is
20 speculative, given the limitations in temporal resolution of our record.
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28 The timing of this settlement decline or change in land use strategy
29 (~600-500 BP) as recorded in the LG record is intriguing, as it approximately
30 coincides with the arrival of Europeans in the Americas in AD 1492. Historical
31 records tell us that the Spanish did not begin to formally colonize the Iténez
32 region until the 18th century (Alcina Franch and Sáinz Ollero, 1989; Altamirano,
33 1891; Barnadas, 1985; Block, 1994), and that some Bolivian ring ditch sites
34 were still inhabited in this late period (Eder, 1985). However, the hypothesis of
35 post-Contact Native American demographic collapse proposes that Old World
36 diseases could have been spread rapidly via extensive native trade routes
37 (Denevan, 1976, 1992; Dobyns, 1963), without the need for direct contact with
38 Europeans. Site abandonment/decline at other southern Amazonian sites, such
39 as the ring-ditch villages in the Upper Xingu, occurred in the century after
40 European arrival, and is ascribed to disease-driven demographic collapse
41 (Heckenberger, 2003).
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In the first instance, the timing of site decline at LG would appear to support a population collapse linked with European contact. However, closer inspection of the record reveals that burning began to decline from ~600 BP and was lagged by forest expansion, which was complete by ~500 BP. This suggests that site decline around LG began before first European contact. We must treat the dating of this record cautiously, as the age model in this upper section of the core has a wide error range (see Figure 4). When we take into account the interpolated 95% error range of the dates, this places the forest expansion around LG somewhere between 400-620 yrs BP, meaning that afforestation of the site could have occurred up to a century before or after European contact. However, given that the dating of this horizon is bounded by two radiocarbon dates, the narrow confidence interval on the lower constraining date GR45 (95% age range of 680-760 cal BP), and the linear sedimentation rate throughout the top 100 cm of the core, as indicated by our age model (Figure 4), accepting the interpolated age of forest expansion ~500 BP seems reasonable. We also note that the dating of the charcoal decline at LG, when the interpolated 95% confidence range is taken into account, is between 550-690 cal BP. This still places the beginning of the burning decline before 1492 AD.

Other recently published records of pre-Columbian occupation at earthwork sites contemporary with that of LG, located in the central *Llanos de Moxos* (Whitney et al., 2013, 2014), have dated site decline/land use change to shortly before the arrival of Europeans. Decline at these sites was evidently caused by factors other than Old World disease. It is also worth noting that the youngest radiocarbon dates obtained so far from ring ditch (geoglyph) earthworks in Acre State, Brazil, are ~700 BP (Schaan et al., 2012), and the majority of the younger dates obtained from ring ditch sites in Riberalta are also

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8 pre-1492 AD (Saunaluoma, 2010). Our palaeoecological record, coupled with
9 the dating of archaeological layers at BVV by Prümers et al. (2006), all of which
10 are older than 500 BP (see Figure 3), suggest that a pre-European decline on
11 this site is more likely.
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15 Although a definite causal link between European contact in 1492 AD
16 and the decline in anthropogenic activity observed at LG is not supported from
17 our data, exchanges between Europeans and native Amazonians nevertheless
18 likely contributed to changes in land use strategy on sites like BVV in the
19 centuries following contact through, for example, the introduction of metal tools
20 (Denevan, 2001). These new tools made slash-and-burn agriculture a
21 possibility, by reducing the labour and time required to fell a tree, and as such
22 may have fundamentally changed the way native Amazonians impacted the
23 forest landscape.
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31 Agricultural and land-use strategy

32 In our pollen analyses, coarse fractions were scanned for common cultigen
33 types, including squash (*Cucurbita* sp.), sweet potato (*Ipomoea batatas* L.),
34 manioc (*Manihot esculenta* Crantz), and maize (*Zea mays* L.), all of which have
35 large pollen grains and are readily isolated by sieving (Whitney et al., 2012).
36 These species also have diagnostic phytoliths, as do arrowroot (*Maranta*
37 *arundinacea* Lindl.) and léren (*Calathea allouia* L.). In both the pollen and
38 phytolith records, *Z. mays* was the only cultigen recovered. An analysis of
39 phytoliths and starch grains from stone tool and pottery remains recovered from
40 the GDP ring ditch also found maize to be a ubiquitous cultigen (Dickau et al.
41 2012). Our data confirm that maize was likely an important staple crop of the
42 inhabitants around LG, not only during the GDP occupation, but from as early
43 as 1850 yrs BP. The high charcoal levels associated with the pre-Columbian
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9 occupation suggest that the land use strategy involved heavy burning of the
10 *terra firme* savannah around the site. However, other sources of charcoal are
11 also likely, such as inputs from everyday fire use from hearths. The sources of
12 fuel for this burning would have included savannah trees, trees from the gallery
13 forest around LG and the nearby San Martín River, and after ~2000 yrs BP,
14 trees from the evergreen rainforest that came to surround the BVV site following
15 regional rainforest expansion. Macroscopic charcoal is deposited in a lake basin
16 by various processes, meaning that peaks and troughs in the charcoal record
17 may represent both changes in frequency/intensity of burning around a lake, as
18 well as changes in the proximity of the burning to the lake (Whitlock and Larsen,
19 2001).
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27 Maize phytoliths appear for the first time in the record alongside maize
28 pollen at ~1000 cal yr BP. Again, this discrepancy between the two proxies may
29 represent a difference in catchment area between phytoliths and pollen, and
30 indicate closer proximity of maize cultivation to the lake after ~1000 yrs BP e.g.
31 because of the adoption of a flood-recessional agricultural strategy, where
32 crops are planted along exposed lake/river shore lines during the dry season,
33 as is commonly practiced today by rural communities across Amazonia. This
34 conclusion is supported by the apparent clearance of gallery forest during the
35 later occupation phase of LG-2, suggesting that cleared land around the lake
36 may have been used for agriculture, possibly associated with the construction
37 and use of the nearby GDP ring ditch. Another possibility is that maize was
38 being processed closer to the lake shore after 1000 yrs BP, resulting in the
39 deposition of phytoliths.
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49 It is interesting that maize is not found before 1850 yrs BP in the
50 microfossil record, despite evidence for prescribed burning around LG from
51 2500 yrs BP. Two possible explanations for the absence of maize before 1850
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9 yrs BP are that: 1) subsistence before this point did not include maize
10 agriculture, or 2) maize was grown on the site, but not in great abundance or in
11 close enough proximity to the lake to be detected in the fossil record. Although
12 maize pollen may be transported further than phytoliths, maize pollen grains are
13 nevertheless large and relatively poorly transported, and therefore reflect
14 cultivation locally around the site of pollen deposition (Lane et al., 2010).
15 Another lake core study by Carson (2014), from a forest island located <15km
16 away from LG, similarly demonstrated absence of maize pollen before ~2000
17 yrs BP. Subsistence at LG during first occupation at 2500 yrs BP, before the
18 appearance of maize in the record, may therefore have been based on a
19 different, unidentified staple, or relied more heavily on non-agrarian resource
20 gathering, such as managing savannah for game hunting. It is also possible that
21 land use on the site at this time was ephemeral, rather than sedentary and
22 agricultural.
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32 The importance of maize, which was grown around LG from ~1850 yrs
33 BP, is interesting. Today the staple crop grown as part of subsistence
34 agriculture in this region is manioc, which is generally considered to be a
35 hardier crop, more suitable for cultivation on nutrient poor, interfluvial, tropical
36 soils (Edwards et al., 1976). Southern Amazonia was likely the centre of ancient
37 manioc domestication (Mühlen et al., 2013; Olsen and Schaal, 1999; Rival and
38 McKey, 2008) and the basis for the development of large, sedentary,
39 agricultural societies in the Upper Xingu ring-village region (Heckenberger,
40 1998). From our palaeoecological record, however, it is evident that maize was
41 an important crop being grown on the PCS around LG before European contact,
42 and that the soils of the PCS were sufficiently fertile to support maize
43 agriculture. Evidence of maize agriculture has also been found at sites in the
44 central and southern *Llanos de Moxos* (Dickau et al., 2012; Whitney et al.,
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9 2013, 2014), which, together with the data presented here, highlight the
10 importance of maize as a cultigen across the Bolivian Amazon region during
11 pre-Columbian times.
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14 A comparison of the pollen assemblage from the surface sediments of
15 LG with the pollen- and phytolith-based record of vegetation cover over the last
16 ~2500 years gives an interesting insight into the scale and intensity of pre-
17 Columbian land management on this site, relative to modern land use. Despite
18 plentiful field evidence for modern disturbance of the riparian forest around the
19 lake, macroscopic charcoal levels in the surface sediments of LG are very low
20 when compared to the much higher charcoal levels recorded from pre-
21 Columbian sediments. From this comparison, we must conclude that the pre-
22 Columbian subsistence strategy involved more intensive and extensive burning
23 of the landscape than the small, patch-scale slash-and-burn agriculture that is
24 practised around the lake today. Burning was likely an important tool for
25 maintaining an open landscape and would have been a self-reinforcing strategy,
26 as a maintained grassland would have been more easily combustible than a
27 densely forested landscape. The modern BVV, which is less than one kilometre
28 south-east of LG, covers a non-contiguously cleared area of ~1.5 km². Again,
29 comparing the surface-sediment pollen record with the palaeo record reveals
30 that the open grassland area maintained by pre-Columbian people must have
31 been significantly more extensive than the area of the modern town and/or had
32 a much lower density of trees compared to the patchily degraded landscape
33 that exists today.
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47 The maintenance of an open landscape by BBV's pre-Columbian
48 inhabitants following regional rainforest expansion from ~2000 yrs BP
49 demonstrates that these people were not "forest dwellers", but employed a land-
50 use strategy which necessitated open areas for agriculture and living space.
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9 Open ground may also have been maintained for the construction of ring
10 ditches (Carson et al., 2014), which appear often to have existed as collections
11 of interrelated features (Prümers, 2012b). Inter-visibility between ring ditch sites
12 may also have been desirable, and therefore required the maintenance of an
13 open landscape on a local scale.
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17 Legacy of pre-Columbian land use

18 The legacy of pre-Columbian impacts in extant rainforest is a key controversy
19 (Barlow et al., 2012; Heckenberger et al., 2007; Peres et al., 2010). The LG
20 record gives some insights into the nature, scale and longevity of such impacts
21 around an earthwork site. We found little evidence in either the pollen or
22 phytolith records that the pre-Columbian inhabitants at LG altered the floristic
23 composition of forest around the site to favour economically useful species.
24 Palms, for example, provide many useful resources, including the edible heart
25 of palm and building materials (Posey and Balée, 1989; Smith, 2015).
26 Palaeoecological studies from lake cores at Mayan archaeological sites in the
27 Yucatan have demonstrated that, where Pre-Columbian cultivation of palms
28 was practised, this is clearly visible as an increase in palm pollen abundance in
29 the fossil record (Rushton et al., 2012). At LG we see no such strong evidence
30 for an increase in palms associated with pre-Columbian occupation.
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41 This of course does not rule out the possibility that forest resources were
42 managed at Bella Vista. Increases in economic species may not be seen in the
43 palaeo record because their pollen morphology does not allow them to be
44 distinguished from other, non-cultivated members of the same genus/family.
45 Alternatively, the pollination strategy of some economic taxa may mean that
46 they are underrepresented in the pollen record (Bush and Rivera, 2001) and
47 cannot be captured in a standard 300-500 pollen grain count. Despite this, one
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9 of the most intriguing outcomes of our investigations at LG is the evidence that
10 people predate the arrival of forest on this site, and that there was a long and
11 continuous occupation (spanning ~1500 years). It is therefore highly likely that
12 the forest on this site has never been without some degree of human impact.
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15 The wider site around LG was maintained as an open anthropogenic
16 landscape until ~600-500 yrs BP, after which afforestation took place. We can
17 conclude, therefore, that much of the forest now surrounding the modern village
18 was established in the last 500 years. On a regional scale also, beyond the
19 zone of intensive human land use around the occupation site, the evergreen
20 forest was established relatively recently, expanding from ~2000 yrs BP in
21 response to increasing rainfall (Carson et al., 2014). The pollen record suggests
22 that there was some regeneration of the gallery forest from ~500 yrs BP.
23 However, the phytolith record indicates that this area continued to be exploited
24 following afforestation of the *terra firme* PCS, and into the modern era. The
25 forest now covering these sites is, therefore, neither ancient nor pristine.
26 However, the model of humans maintaining an open landscape around their
27 settlements rather than deforestation, as suggested by the palaeoecological
28 data from LG, does not support suggestions that pre-Columbian earthwork
29 builders in Amazonia contributed strongly to biomass losses and atmospheric
30 carbon increases during the late Holocene (Chave et al., 2008; Dull et al., 2010;
31 Nevele et al., 2011).
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Conclusions

Our approach of integrating pollen and phytolith analyses of lake sediment cores with terrestrial analyses has revealed important aspects of the chronology and nature of pre-Columbian occupation on the Bella Vista village site. The site is shown to have been occupied since ~2500 yrs BP, long before the construction of the two previously dated ring ditches. The results from our study highlight the possibility that other ring ditches that have been mapped around the site, and in the wider Iténez province, were constructed before the Granja del Padre and Bella Vista-3 ditches. However, only further excavation and dating of archaeological contexts can confirm this hypothesis. We have demonstrated that, in small lakes such as Laguna Granja, pollen and phytoliths represent palaeovegetation over both local- and extra-local spatial scales. This is highly useful in discerning the changing spatial and temporal patterns of land use on an archaeological site.

Our study shows that anthropogenic burning and suppression of trees maintained an open area on the Pre-Cambrian Shield around Laguna Granja, greater than that exposed by modern clearance, which was used for maize agriculture and earthwork construction. We confirmed that maize was an important crop grown on the site, although the spatial pattern and intensity of agriculture may have changed over time, with greater exploitation of the gallery forest occurring from ~1000 yrs BP.

Rather than experiencing site abandonment after European contact in AD 1492, the Bella Vista site continued to be occupied through to near the present day. There does, however, appear to have been a decline in human activity, which occurred slightly before European Contact, and allowed expansion of evergreen forest into the *terra firme* areas, and the establishment of the forest that exists around the site today. This demonstrates that, rather

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9 than being ancient (i.e. millennia in age), the forest covering this site today is \leq
10 500 years old. Furthermore, we have shown that occupation of the site
11 preceded the expansion of closed-canopy rainforest into the wider Iténez
12 region. We infer from this that parts of the forest in this region have never been
13 without a degree of human influence. This finding is significant, as it supports
14 the perspective that previously occupied areas of the Amazon rainforest
15 constitute an anthropogenic environment and may retain a strong legacy of that
16 impact (Chave et al., 2008; Erickson, 2008; Heckenberger, 2003). Whilst the
17 Carson et al. (2014) study showed that regional-scale clearance did not take
18 place in northern Iténez, this study has shown that, on a site-specific (i.e.
19 local/extra-local) scale, impacts on ring ditch sites may indeed have been
20 significant, pervasive and long-lasting.
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List of figures

Figure 1. Map of the study region and site locations showing (a) the *Llanos de Moxos* in Bolivia with study area highlighted, (b) northern Iténez, with the position of Laguna Granja on the Pre-Cambrian Shield and relative to Bella Vista Village, which is represented as a small area of cleared land on the Pre-Cambrian Shield, and (c) vegetation cover around Laguna Granja and position of the Granja del Padre ring ditch. (After Carson et al. 2014).

Figure 2. Aerial photograph of Laguna Granja and the adjacent Granja del Padre ring ditch. The cleared area around the ring ditch represents modern forest clearance for cattle ranching. Image taken in summer 2008 by HP.

Figure 3. Radiocarbon dates from archaeological contexts at BV-1 (three dates), BV-3 (two dates) and Granja del Padre (four dates) excavations, at Bella Vista Village. Originally reported in Prümers et al. (2006). Black lines indicate the median age; box indicates 68% confidence interval age range; tails represent the 95% confidence interval age range; all calibrated using IntCal13 (Reimer et al. 2013). The approximate date of European contact (~500 yrs BP) is shown by a dashed line.

Figure 4. Age depth model for Laguna Granja from 2σ calibrated radiocarbon dates. Interpolated 95% error range between dates is shown by grey shading.

Figure 5. Pollen and charcoal from Laguna Granja plotted against calibrated years BP. Pollen of all taxa with >2% abundance are shown. Pollen is presented as percentage abundance of the terrestrial count of 300 grains, with the exception of *Z. mays*, which is presented as no. of grains. Charcoal is presented as particles per cm³. Calibrated radiocarbon ages from LG are displayed on the right (see Table I and Figure 4). The range of radiocarbon dates from archaeological contexts at Bella Vista Village is represented by grey shading (see Figure 3).

Figure 6. Phytoliths from Laguna Granja plotted against calibrated years before present and expressed as percentage abundance of 200 phytolith count. The diagram is divided into the same pollen zones used in Figure 5.

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List of tables

Table 1. Radiocarbon dates from Laguna Granja.

Table 2. Results of modern vegetation survey around Laguna Granja. An * indicates that the family or genus was identified in the surface pollen assemblage. The symbol ‡ indicates that the family or genus was identified in the surface-sediment phytolith assemblage.

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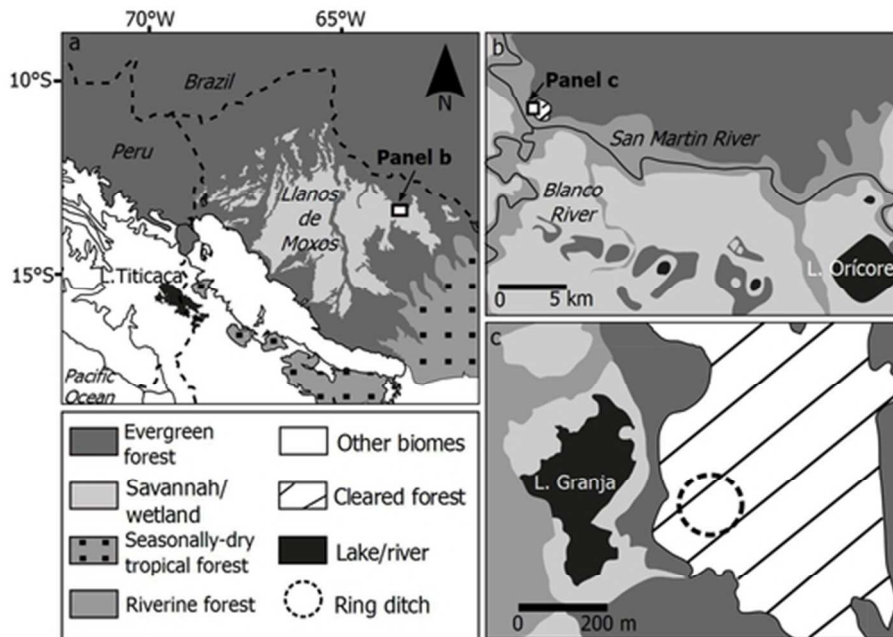


Figure I. Map of the study region and site locations showing (a) the Llanos de Moxos in Bolivia with study area highlighted, (b) northern Iténez, with the position of LG on the PCS and relative to BVV, which is represented as a small area of cleared land on the PCS, and (c) vegetation cover around LG and position of the GDP ring ditch. (After Carson et al. 2014).

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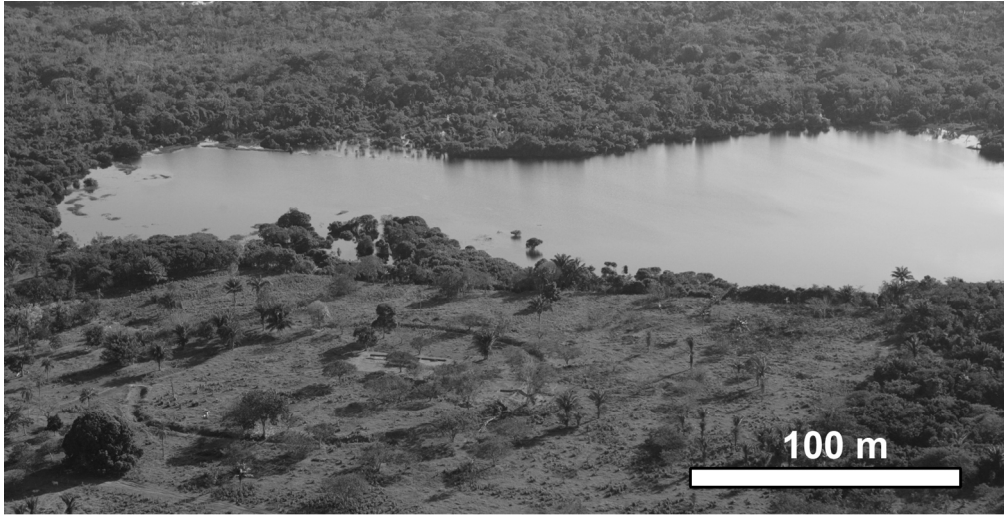


Figure 2. Aerial photograph of Laguna Granja and the adjacent Granja del Padre ring ditch. The cleared area around the ring ditch represents modern forest clearance for cattle ranching. Image taken in summer 2008 by HP.
150x76mm (300 x 300 DPI)

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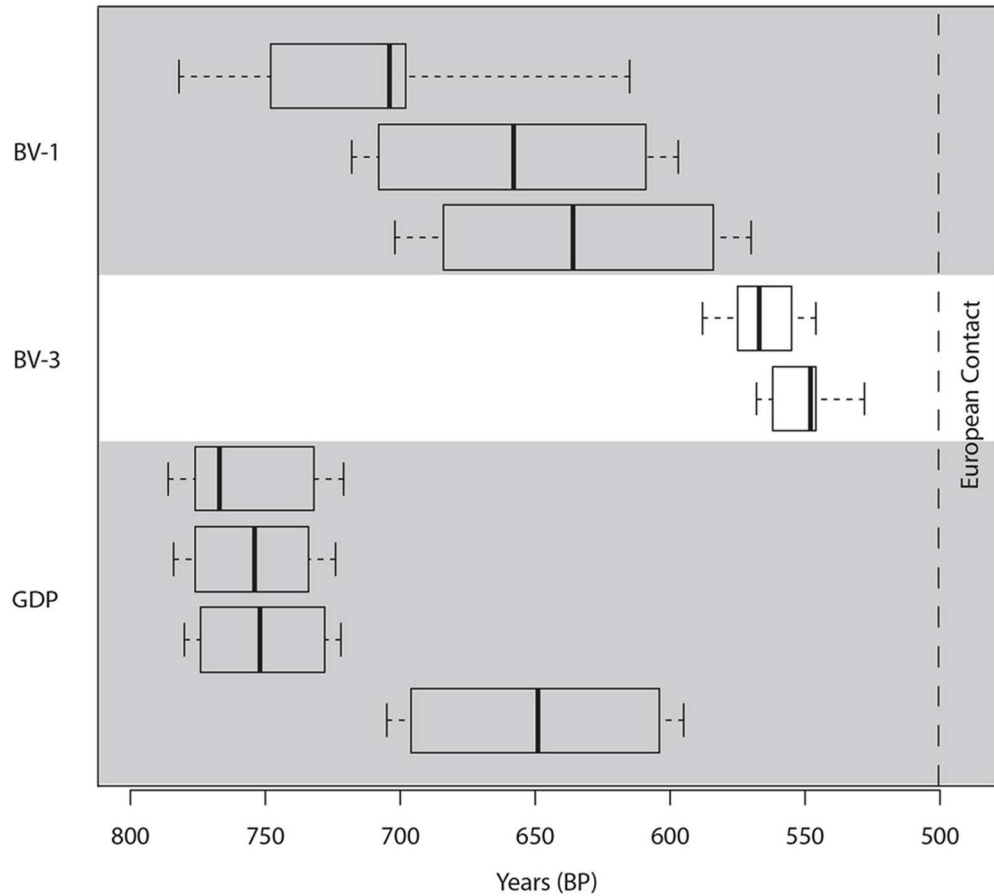


Figure 3. Radiocarbon dates from archaeological contexts at BV-1 (three dates), BV-3 (two dates) and Granja del Padre (four dates) excavations, at Bella Vista Village. Originally reported in Prümers et al. (2006). Black lines indicate the median age; box indicates 68% confidence interval age range; tails represent the 95% confidence interval age range; all calibrated using IntCal13 (Reimer et al. 2013). The approximate date of European contact (~500 yrs BP) is shown by a dashed line.

89x80mm (300 x 300 DPI)



Table I.

Site and sample identifier	Publication code	Depth below sediment-water interface (cm)	Conventional C ¹⁴ age (yr BP±1σ)	Calibrated age range (cal yr BP) ± 2 σ	Area under probability curve	Weighted mean calibration (cal yr BP)	δ ¹³ C _V PDB(‰)
Granja Gr 21.5	Beta - 339227	21.5-22.5	240 ±30	472-444	0.06	290	-26.4
				368-318	0.543		
				262-250	0.014		
				238-197	0.309		
				14-0	0.074		
Granja Gr45	Beta - 339228	45-46	750 ±30	779-713	1	750	-23.1
Granja Gr 91	SUERC-43148	91-92	1782 ±38	1870-1655	1	1760	-22.2
Granja Gr123	Beta-347192	123-124	4070 ±30	4851-	0.125	4630	-23.3
				4812	0.016		
				4792-	0.701		
				4743	0.159		
				4695-			
				4551			
4537-							
4491							
Granja GR 146	Beta - 339229	146-147	5200 ±30	6047-5961	1	6000	-24.2

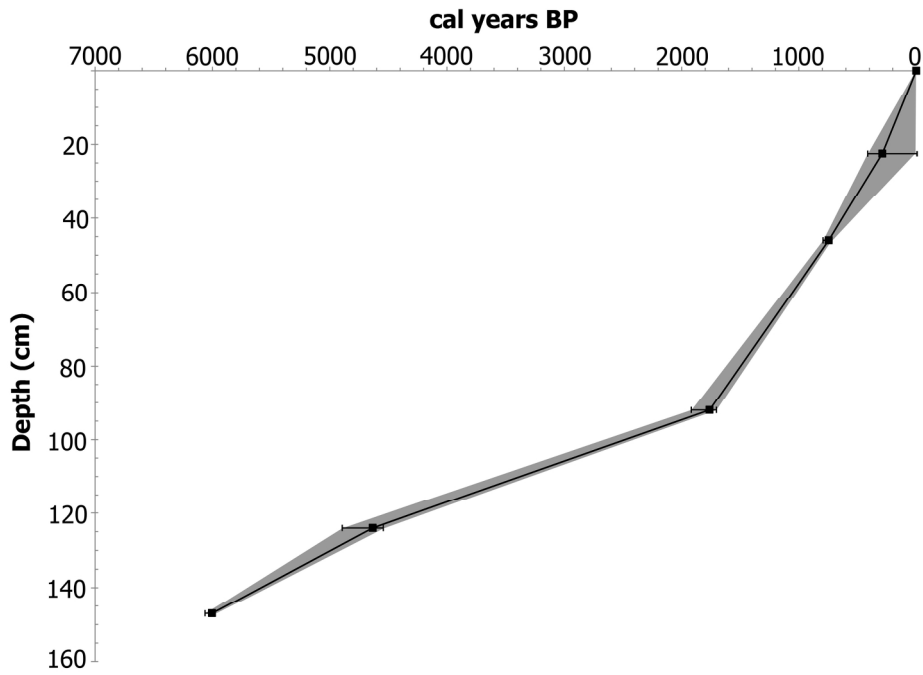


Figure 4. Age depth model for Laguna Granja from 2 σ calibrated radiocarbon dates. Interpolated 95% error range between dates is shown by grey shading.
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Review

Table 2.

Family	Species	Occurrence in modern environment
Acanthaceae	<i>Ruellia</i> cf. <i>nitida</i> (Nees) Wash. & J.R.I. Wood	Gallery forest
Amaranthaceae*	<i>Alternanthera</i> * <i>paronychoides</i>	Semi-inundated
Anacardiaceae*	<i>Tapirira</i> sp.*	Gallery forest
Apocynaceae	<i>Tabernaemontana</i> cf. <i>linkii</i>	Gallery forest
	<i>Tabernaemontana</i> sp.	Gallery forest
Asteraceae*	<i>Eupatorium</i> sp.	Aquatic
	<i>Elephantopus mollis</i> Kunth	Semi-inundated
Chrysobalanaceae	<i>Licania</i> cf. <i>canescens</i> Benoist	Gallery forest
	<i>Licania kunthiana</i> Hookf.	Gallery forest
	<i>Licania</i> sp.	Gallery forest
Clusiaceae	<i>Rheedea brasiliensis</i> (Mart.) Planch & Triana	Gallery forest
	<i>Vismia</i> cf. <i>latifolia</i> (Aubl.) Choisy	Gallery forest
Combretaceae*	<i>Combretum lanceolatum</i> Pohl ex Eichler	Gallery forest
	<i>Buchenavia</i> cf. <i>oxycarpa</i>	Gallery forest
Convolvulaceae	<i>Merremia macrocalyx</i> (Ruiz & Pav.) O'Donell	Gallery forest
Costaceae	<i>Costus scaber</i>	Gallery forest
Cyperaceae**	<i>Scleria</i> cf. <i>melaleuca</i> Reichen. Ex S. & C.	Aquatic
	<i>Cyperus</i> * <i>luzulae</i>	Aquatic
	<i>Cyperus</i> sp.*	Semi-inundated
Erythroxylaceae	<i>Erythroxylon anguifugum</i> Mart.	Gallery forest
Euphorbiaceae*	<i>Mabea fistulifera</i> Mart.	Gallery forest
	<i>Nealchornia</i> sp.	Gallery forest
	<i>Sapium glandulosum</i> (L.) Morong	Gallery forest
	<i>Alchornea</i> sp.*	Semi-inundated
	<i>Dalechampia</i> sp.	Gallery forest
Fabaceae (Caesalpinioideae)	<i>Macrolobium acaciifolium</i> (Benth.) Benth.	Gallery forest
Fabaceae (Caesalpinioideae)	<i>Senna obtusifolia</i> (L.) H.S. Irwin & Barneby	Semi-inundated

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3	Fabaceae	<i>Zygia cauliflora</i> (Willd.) Killip
4	(Mimosoideae)*	
5		<i>Mimosa* pigra</i> L.
6		
7		<i>Albizia subdimiata</i> (Splitg.) Barneby &
8		J.W. Grimes
9	Fabaceae	<i>Indigofera fruticosa</i> J.N. Rose
10	(Papilionoideae)	
11	Loganiaceae	<i>Strychnos cf. darienensis</i> Seem.
12		
13	Malpighiaceae	<i>Byrsonima riparia</i> W.R. Anderson
14		
15		<i>Stigmaphyllon florosum</i> C.E. Anderson
16	Marsileaceae	<i>Marsilea polycarpa</i> Hook. & Grev.
17		
18	Melastomataceae*	<i>Toccoca guianensis</i> Aubl.
19		
20		<i>Mouriri</i> sp.
21		
22	Monimiaceae	<i>Siparuna guianensis</i> Aubl.
23		
24	Myrtaceae*	<i>Eugenia ochrophloea</i> Diels
25		
26		<i>Psidium</i> sp.
27		
28		<i>Eugenia florida</i> DC.
29		
30	Onagraceae*	<i>Ludwigia helminthorrhiza</i> (Mart.) H. Hara
31		
32	Piperaceae	<i>Piper</i> sp.
33		
34	Poaceae**	<i>Sporobolus</i> sp.
35		
36		<i>Panicum laxum</i> Sw.*
37		
38		<i>Guadua paniculata</i> Munro
39	Polygonaceae	<i>Polygonum hispidum</i> (Kunth)
40		
41	Pontederiaceae*	<i>Eichhornia* azurea</i> (Sw.) Kunth
42		
43	Pteridophyta	<i>Adiantum</i> sp.
44		
45	Rubiaceae*	<i>Duroia micrantha</i> (Ladbrook) Zarucchi &
46		J.H. Kirkbr.
47		<i>Genipa spruceana</i> Steyerm.
48		
49		<i>Uncaria* guianensis</i> (Aubl.) J.F. Gmel
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51		<i>Coussarea platyphylla</i> Müll Arg.
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53	Salicaceae	<i>Casearia gossypiosperma</i> Briq.
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55	Sapindaceae*	<i>Talisia cf. hexaphylla</i> Vahl
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57		<i>Matayba macrostylis</i> Radlk.
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Urticaceae*	<i>Pourouma</i> sp.*	Gallery forest
	<i>Cecropia</i> cf. <i>concolor</i>	Gallery forest
	<i>Cecropia</i> sp.*	Gallery forest
Verbenaceae	<i>Vitex pseudolea</i>	Semi-inundated
Vitaceae	<i>Cissus</i> sp.	Gallery forest
Vochysiaceae*	<i>Vochysia</i> * <i>mapirensis</i> Rusby	Gallery forest

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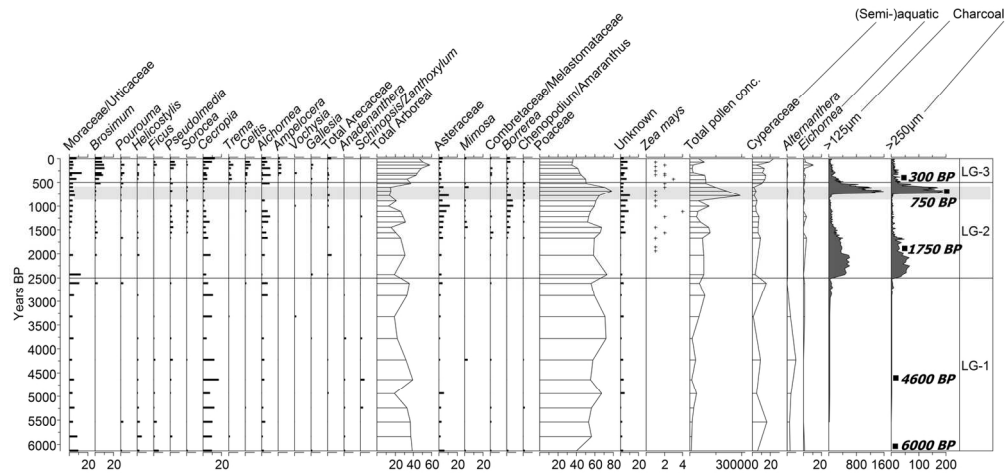


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