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Citation: Carson, John F., Mayle, Francis, Whitney, Bronwen, Iriarte, José and Soto, J. Daniel (2016) Pre-Columbian ring ditch construction and land use on a “chocolate forest island” in the Bolivian Amazon. *Journal of Quaternary Science*, 31 (4). pp. 337-347. ISSN 1099-1417

Published by: Wiley-Blackwell

URL: <http://dx.doi.org/10.1002/jqs.2835> <<http://dx.doi.org/10.1002/jqs.2835>>

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# Pre-Columbian ring ditch construction and land use on a “chocolate forest island” in the Bolivian Amazon.

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## Abstract

We present a palaeoecological investigation of pre-Columbian land use in the savannah “forest island” landscape of north-east Bolivian Amazonia. A 5700 year sediment core from La Luna Lake, located adjacent to the La Luna forest island site, was analysed for fossil pollen and charcoal. We aimed to determine the palaeoenvironmental context of pre-Columbian occupation on the site and assess the environmental impact of land use in the forest island region. Evidence for anthropogenic burning and *Zea mays* L. cultivation began ~2000 cal a BP, at a time when the island was covered by savannah, under drier-than-present climatic conditions. After ~1240 cal a BP burning declined and afforestation occurred. We show that construction of the ring ditch, which encircles the island, did not involve substantial deforestation. Previous estimates of pre-Columbian population size in this region, based upon labour required for forest clearance, should therefore be reconsidered. Despite the high density of economically useful plants, such as *Theobroma cacao*, in the modern forest, no direct pollen evidence for agroforestry was found. However, human occupation is shown to pre-date and span forest expansion on this site, suggesting that here, and in the wider forest island region, there is no truly pre-anthropogenic ‘pristine’ forest.

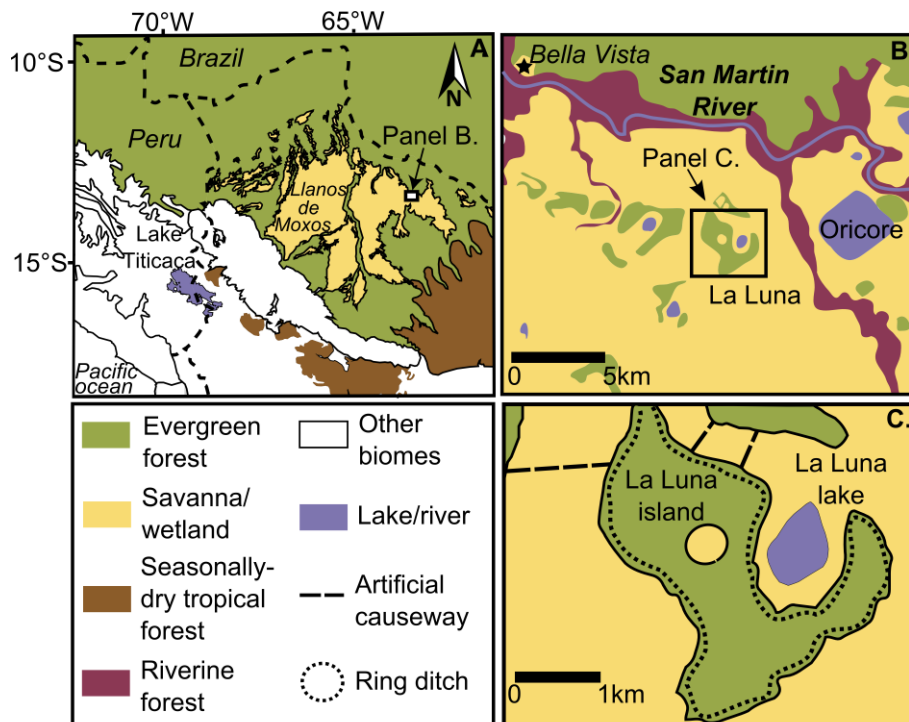
**Keywords:** Palaeoecology, Amazon, Pre-Columbian archaeology, rainforest, human-environment interactions.

## Introduction

In recent decades, the discovery of an ever-increasing number of archaeological sites across the Amazon Basin (Roosevelt, 1991; Heckenberger, 2003; Heckenberger and Neves, 2009; Pärssinen *et al.*, 2009; Iriarte *et al.*, 2012; Schaan, 2012) has challenged the conventional paradigm of pre-Columbian (pre-AD1492) Amazonia as a pristine wilderness, inhabited by small and dispersed hunter-gatherer populations (Meggers, 1992). While it is now widely accepted that large, sedentary and socially-complex groups existed in Amazonia, considerable debate remains regarding the geographical distribution of pre-Columbian populations, and the spatial and temporal scale of their impact on the natural environment (Denevan, 1996; Heckenberger, 2003; Bush and Silman, 2007; McMichael *et al.*, 2012; Carson *et al.*, 2014).

A great part of this debate has focused on the legacy of pre-Columbian land use and its implications for modern ecosystems. It has been suggested that indigenous practices such as agroforestry, burning and earthwork building over the Holocene were integral to the development of plant communities across a wide area and have created anthropogenic “domesticated” landscapes within areas considered by many ecologists to be “pristine” forest (Chave *et al.*, 2008; Erickson, 2008; Clement and Junqueira, 2010). However, some have argued that such legacy effects have been rendered negligible in most locations by the action of natural ecological processes over time (Peres *et al.*, 2010; Barlow *et al.*, 2012). Similarly, while some argue that anthropogenic impacts, such as deforestation, were limited to the immediate area around settlements (Bush *et al.*, 2000; McMichael *et al.*, 2012), others have suggested that such impacts occurred on a large scale (Erickson, 2010). In the most extreme scenario it is even suggested that post-Columbian reforestation and reduction in biomass burning in Amazonia (and the wider Americas) were large enough to have had a significant impact upon global biogeochemical cycles (Nevle and Bird, 2008; Dull *et al.*, 2010), consistent with the early Anthropocene hypothesis (Ruddiman, 2007). Resolving these debates could have profound implications for our understanding of rainforest resilience to disturbance, the nature of plant community development in Amazonian forests and, ultimately, the degree to which indigenous land-use practices should be incorporated into conservation policy (Heckenberger *et al.*, 2007; Clement and Junqueira, 2010; Peres *et al.*, 2010).

The *Llanos de Moxos*, a vast, seasonally-inundated forest-savannah mosaic region in northern Bolivia (Fig. 1A), has provided some of the strongest evidence for large and socially complex pre-Columbian societies, in the form of extensive and structurally diverse earthworks such as raised fields (Lombardo *et al.*, 2010), large habitation mounds (Lombardo and Prümers, 2010), canals and causeways (Denevan, 1966; Lombardo *et al.*, 2013a), ring ditches (Carson *et al.* 2014; Prümers, 2014a) and fish weirs (Erickson, 2000). These different earthworks are geographically distinct across the region (Lombardo *et al.*, 2013a). In the north-east *Llanos de Moxos*, in the province of Iténez, earthworks consist of ring ditches and canals/causeways, estimated to cover a non-contiguous area of ~12,000 km<sup>2</sup> (Erickson, 2010). The *terra firme* forests in this region, which occur on small (1-10 km diameter) outcrops of pre-Cambrian shield protruding above the surrounding seasonally-inundated savannahs, are noted for their high abundance of economically useful plant taxa, such as the cocoa tree *Theobroma cacao*. These cocoa trees are thought to have been planted by pre-Columbian people or the inhabitants of colonial Jesuit missions (Erickson and Balée, 2006; Erickson, 2010). As a result, these outcrops are commonly referred to as “chocolate forest islands” (Erickson 2010). Much of the modern closed-canopy forest on these “islands” is underlain by ring-ditch earthworks, which has led Erickson (2010) to infer extensive pre-Columbian deforestation, by substantial populations, in order to construct the earthworks and surround them with wooden palisades. However, this interpretation is based upon the assumption that, during the construction of the earthworks, the islands were covered with closed-canopy forest, as they are today. A paucity of palaeoecological and chronological data from these forest-island ring-ditch sites has meant that, for the majority, the palaeoenvironmental context of earthwork construction is unknown. Furthermore, little is known about the type of land use practiced by these societies.



**Figure 1. Map of study region, vegetation biomes and sample sites. (A) Position of study site within Bolivia and the Llanos de Moxos. (B) Study region highlighting position of the La Luna site, Bella Vista town and Laguna Orícore. (C) La Luna forest island, La Luna Bog and La Luna Lake. The approximate position of the boundary ring ditch around the island is shown by dotted line and the position of pre-Columbian causeways by a dashed line.**

In a palaeoecological study by Carson *et al.* (2014) at the Bella Vista earthwork site in northern Iténez, an alternative model of land use was proposed. The authors suggested that earthwork-building cultures did not practice large-scale deforestation, but instead built in an open savannah landscape, which existed in the northern Iténez region prior to ~2000 cal a BP (calendar years before present), when climatic conditions were too dry to support rainforest. After ~2000 cal a BP, increased precipitation caused closed-canopy, evergreen rainforest to expand in the south-west Amazon (Mayle *et al.*, 2000; Carson *et al.*, 2014). However, whether this scenario of human-climate-vegetation interaction applies to other ring-ditch sites in Iténez remains to be tested.

Although some in-depth archaeological survey and excavation work has been published from Iténez, (Prümers *et al.*, 2006; Erickson, 2010; Dickau *et al.*, 2012;

Prümers, 2012a, 2014a, 2014b; Prümers and Betancourt, 2014a, 2014b), such studies are rare. A great deal therefore remains unknown about the subsistence strategies/resource management of these forest island cultures and the chronology of settlement in the region. Recent studies have demonstrated how local-scale palaeoecological reconstructions from small lakes, located in close proximity to pre-Columbian sites, can be highly valuable in addressing these types of questions (Iriarte *et al.*, 2012; Carson *et al.*, 2014, 2015; Mayle and Iriarte, 2014; Whitney *et al.*, 2014). In the study by Carson *et al.* (2014), the palaeoecological lake record demonstrated a much earlier start to human occupation on the Bella Vista site (~2500 BP) than had been apparent from previously dated archaeological contexts (~800 BP) (Prümers *et al.*, 2006; Dickau *et al.*, 2012), and revealed important aspects of the inhabitants' subsistence and land-use practices. However, as the Carson *et al.* (2014, 2015) Bella Vista record is the only palaeoecological study published from the northern Iténez region so far, it is unclear whether the environmental history of this site is representative of the broader Iténez region, or instead constitutes a local anomaly.

### *Aims*

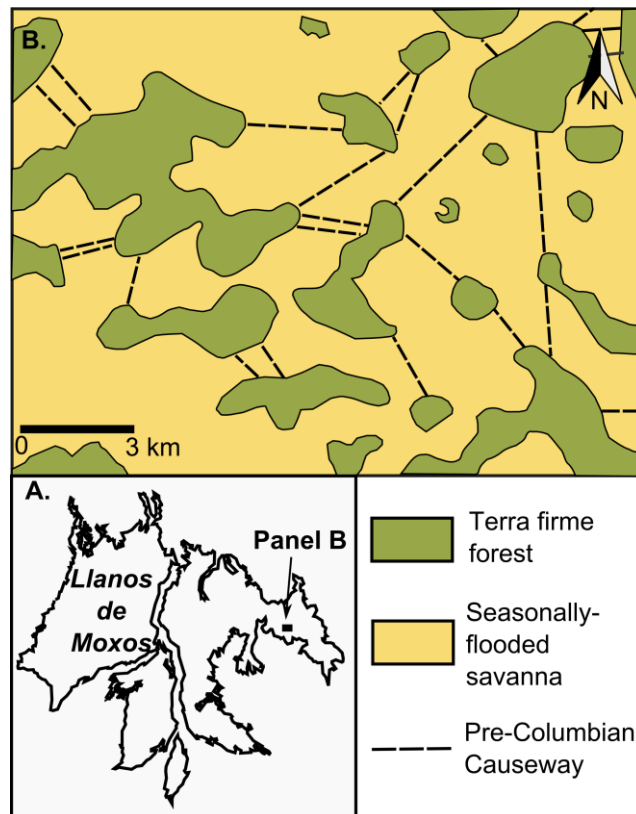
Here, we use a palaeoecological approach to investigate the land-use history associated with a previously unstudied ring-ditch site on 'La Luna forest island' in northern Iténez. Specifically, we aim to:

1. Test the hypothesis (Erickson, 2010) that construction of the ring ditch required deforestation of the forest island,
2. Test the hypothesis (Carson *et al.*, 2014) that the ring ditch was constructed in a naturally open landscape under climatic conditions too dry to support rainforest,
3. Establish a chronology of pre-Columbian land use at the site, and determine whether it was occupied contemporaneously with neighbouring sites at Bella Vista.
4. Investigate the type of agricultural/subsistence strategy practised by pre-Columbian forest island inhabitants.

## Study area

Our study was conducted in Iténez Province, situated in the north-east of the Department of the Beni, Bolivia (Fig. 1). The Beni encompasses a large, low lying, sedimentary basin filled with Quaternary sediments (Clapperton, 1993). Average annual temperature is 25°C, although this can range from 23°C in austral winter up to 40°C in summer. Average annual precipitation is ~2000 mm, with the majority falling during austral summer, from November-March. The flat topography and impermeability of the clay sediments means that, during the annual wet season, the majority of the landscape is flooded, forming the *Llanos de Moxos*, a vast, seasonally-inundated savannah, interspersed with occasional forest on elevated (non-flooded) areas of land (Navarro and Maldonado, 2005). In Iténez, exposed outcrops of the Brazilian Precambrian Shield (PCS) have created most of the *terra firme* 'forest islands' within the savannah (see Figs. 1 and 2), although pre-Columbian earthworks, such as causeways and fish weirs, also support forest growth above the flood level.

The pre-Columbian earthworks in Iténez consist of ring ditches on the *terra firme* forest islands, and linear causeways in the wetland savannah that link many of the forest islands in the province (see Fig. 2) (Denevan, 1966). Ridged fields have also been discovered in the savannahs in the north of the province (Lombardo *et al.*, 2013a), and in the far south-east there are zig-zagged earthworks, which may have functioned as fish weirs (Erickson, 2000). The ring ditch earthworks range from circular forms that are hundreds of metres in diameter, to larger, irregular-shaped boundary ditches, which can be kilometres in length. The ditches typically range from 2-4 m deep and 2-5 m wide, but can be up to 10 m deep (Erickson 2010). Surveys conducted in the south of Iténez documented ring ditches on almost every island > 2 km<sup>2</sup> (Erickson, 2010) and, in the north, earthworks are commonly encountered on field survey, although their full extent is unknown (Prümers *et al.*, 2006; Prümers, 2012b).



**Figure 2. Schematic of numerous pre-Columbian causeways connecting forest islands located ~40km south of La Luna (13°35'03"S, 63°34'38"W).**

The most likely function of the Iténez ring ditches is defence (Prümers *et al.*, 2006). Erickson (2010) has also suggested that these defensive ditches were enhanced by wooden palisades, citing descriptions of palisade villages in the contemporary accounts of early European explorers (Eder, 1985). However, no archaeological evidence for palisades, such as post holes, has yet been found (Prümers, 2012b; Prümers and Betancourt, 2014b). In the Upper Xingu region of Brazil, pre-Columbian settlements were arranged as networks of ring-ditch villages, connected by roadways (Heckenberger *et al.*, 2008). In a similar way, the artificial causeways that run between the forest islands in Iténez may have served to link up the islands during the flood season. Alternatively, they may have been used to control savannah drainage (Lombardo and Prümers, 2010).

The lake cored for this study was Laguna de La Luna (LL), a relatively small (0.48 km<sup>2</sup>) lake, located within the savanna (13°21'20" S, 63°35'2"W; [elevation 130 m a.s.l.](#)) and adjacent to La Luna Island (LI), a forest island approximately 7.4 km<sup>2</sup> in area. The island is almost completely covered by closed-canopy rainforest, except



for a 480 m diameter circular bog near the centre (see Fig. 1C). A brief survey of the island revealed that its entire circumference is bounded by a ditch, approximately 3 m deep and 4 m wide, and which lies 10 m in from the edge of the forest. The La Luna site is also located 15 km south-east of the previously studied Laguna Granja site (Carson *et al.*, 2014, 2015), at the town of Bella Vista, and 5 km west of the much larger lake, Laguna Orícore, which provided a regional-scale reconstruction of forest-savannah ecotonal shifts over the last 6000 years in northern Iténez (Carson *et al.*, 2014).

## Materials and Methods

### *Site selection and fieldwork*

Our aim was to obtain a local-scale reconstruction of palaeoenvironmental change and land use on the LI site. Pollen catchment area is related to lake surface area (Jacobson and Bradshaw, 1981; Sugita, 1994). We therefore selected a relatively small lake, in close proximity to the pre-Columbian site, for coring. In a forest-grassland mosaic landscape, the representation of forest taxa in the lake pollen record is also dependent upon the size of the surrounding forest patches relative to the size of the lake (Bunting *et al.*, 2004). Although LL is larger than previous 'small lakes' used for local-scale reconstructions in the Bolivian Amazon (Carson *et al.*, 2014; Whitney *et al.*, 2014), the close proximity and large size of the adjacent LI relative to LL made us confident that vegetation from the *terra firme* island would contribute a large proportion of the total pollen rain to the lake.

Fieldwork was carried out in June-July 2011. A series of parallel, overlapping sediment cores from the central, deepest part of LL ([2m depth](#)) was retrieved from a stable floating platform using a modified (drop-hammer) Livingston piston corer (Colinvaux *et al.*, 1999). A 5-cm diameter Perspex® tube and piston were used to collect the surface core (uppermost unconsolidated sediments and sediment-water interface). Surface-core sediments which were too soft to extrude as an intact core were divided in the field into 0.5-cm thick increments and stored in watertight plastic tubes. Firmer surface-core sediments were extruded in the field as intact cores and shipped back to the UK in robust, watertight packaging. Livingstone cores 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.

### *Modern vegetation survey*

During fieldwork, a rapid assessment botanical survey was made by JDS of the open wetland vegetation around the lake and the forest on LI. A qualitative assessment of the relative abundance of species was recorded and voucher specimens were collected for the herbarium of the 'Noel Kempff Mercado' Natural History Museum in Santa Cruz, Bolivia. [\(table 2\)](#).

### *Pollen analysis*

The core was sub-sampled for pollen analysis at intervals of 2.5 to 3 cm in the interval spanning 58 to 0 cm below the sediment-water interface, below which point pollen was not preserved. A 1 cm<sup>3</sup> sub-sample of sediment from each horizon was prepared using the standard pollen preparation protocol (Faegri and Iversen, 1989), with the addition of a sieving stage designed for optimal recovery of large cultigen pollen (Whitney *et al.*, 2012). A known concentration of *Lycopodium* marker spores ([batch #483216](#)) was added to each sample for calculation of pollen concentration values (Benninghoff, 1962), and to confirm that observed changes in pollen percentage abundance were not the result of changes within a closed sum. [Samples were mounted in silicon oil.](#) The pollen in the fine fractions (material <53 µm) was counted to the standard terrestrial pollen sum of 300 grains.

The coarse fractions (material >53 µm) were scanned for large cultigen pollen grains up to a standardised equivalent count of 2000 *Lycopodium* spores, representing an average of ca. 0.1 cm<sup>3</sup> of the original 1 cm<sup>3</sup> of sediment processed. Fossil pollen was identified with reference to the collection of over 1500 tropical pollen specimens housed at the University of Reading, and from atlases of Neotropical pollen (Roubik and Moreno, 1991; Colinvaux *et al.*, 1999; Bush and Weng, 2007). Maize grains were distinguished from other wild grasses, [such as \*Tripsicum sp.\*](#), according to the morphological criteria described in Holst *et al.* (2007). [The cultivated form of maize and its wild relative, \*Zea mays ssp. parviglumis\* \(teosinte\), cannot be distinguished using pollen morphology. However, teosinte is not native to southern Amazonia.](#) 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.

### *Charcoal Analysis*

Macroscopic charcoal analysis was carried out at 0.5-cm intervals throughout the core, from 0 – 58 cm depth. Sub-samples of 1 cm<sup>3</sup> were taken from each horizon and heated in 5% sodium pyrophosphate to disaggregate clay sediments. The samples were then sieved at 250 µm and 125 µm and charcoal particles counted in

water, under 40x magnification. All graphs were drawn using the program C2 (Juggins, 2007).

## Results and Interpretation

### *Core stratigraphy and chronology*

A 167 cm sediment sequence was recovered (measured beneath the sediment-water interface). The sediments consisted of fine clay throughout, but changes in colour and the degree of compaction were observed. From the base of the core (167 cm) to 47 cm depth, sediments were light grey, very stiff clay. At 47 cm there was a sharp transition to dark grey, medium-stiff clays up to ~ 25 cm depth. This sharp transition was used to correlate the surface core and Livingstone core lithologies. From 25 to 0 cm depth, the sediments were comprised of very soft, medium-grey clay.

Five AMS  $^{14}\text{C}$  dates were obtained from bulk sediment samples from the LL core (table 1). The absence of carbonate from the area means that there is little likelihood of anomalously old dates due to the hard-water effect. However, two samples, from the softer sediments in the top 25 cm of the surface core, produced near-modern radiocarbon ages. These ages are anomalously young, given the depth of the samples below the surface, suggesting that the soft sediments in the top 25cm of the core have been affected by mixing. It was therefore not possible to produce a reliable age-depth model for the core, but three chronologically sequential dates, not contaminated by modern carbon, were obtained for the base of Zone 1 (5760 cal a BP) and the base and middle of Zone 2 (2090 cal a BP and 1240 cal a BP, respectively). These dates were calibrated using the IntCal13 curve (Reimer *et al.*, 2013). The sharp stratigraphic boundaries at 47 cm and 25 cm depth suggest that there may have been a sedimentary hiatuses between these two zones.

### *Modern vegetation survey and surface pollen*

The results of the botanical survey are presented in table 2. The survey identified 55 plant species in 26 families, across the four habitat types which occur around the lake (see table 2 caption). The most common arboreal taxon encountered was the shrub *Melochia hirsute*, which grew mostly on the small circular mounds found across the savannah landscape. In the transitional, semi-inundated riparian zone around the lake edges, the species *Tabebuia elliptica*, *Hura crepitans*, and *Tabernaemontana* sp. grew as shrubs or small trees, forming mats of vegetation around the lake edge. The aquatic and semi-aquatic ~~herbs~~ **grasses** identified on the lake margins and ~~semi-aquatic grasses~~ in the savannah were exclusively from the family Cyperaceae. However, this was a rapid assessment survey covering a limited area. It is very likely that Poaceae does occur in both of these habitats within the landscape, but was not encountered in the survey. On the *terra firme* forest island, *Theobroma cacao* and the leguminous tree *Inga* spp., many species of which produce edible seeds that are collected by modern indigenous groups (Balée, 1994; Clement, 1999), were notably frequent economically-useful taxa.

The surface pollen assemblage from the LL core (Fig. 3) is dominated by arboreal types (51%). The most abundant arboreal pollen types are from the Moraceae/Urticaceae (36%), of which the commonest are *Pseudolmedia* (9%), Moraceae/Urticaceae undiff. (8%), *Brosimum* (6%) and *Cecropia* (5%). Other well-represented arboreal pollen taxa include *Ampelocera* (5%), *Celtis* (5%), *Helicostylis* (3%), *Alchornea* (3%), *Gallesia* (2%), and Arecaceae (2%). The most abundant herb type was Poaceae (32%) followed by Cyperaceae (6%).

The pollen source of a lake in a forest-savannah mosaic landscape is likely to be complex. The herb pollen in the LL surface sediments likely derives from the seasonally-inundated savannah and some aquatic inputs. The dominant arboreal component of the pollen assemblage is mostly composed of *terra firme* rainforest taxa such as Moraceae, *Ampelocera* and *Celtis* (Gosling *et al.*, 2005, 2009; Burn *et al.*, 2010). The size of the La Luna forest island (7.5 km<sup>2</sup>) relative to the lake surface area (0.48 km<sup>2</sup>) and its proximity to the lake suggests that it constitutes a large part of the pollen source area of the lake (Bunting *et al.*, 2004). Furthermore, a number of

common genera were identified between the surface pollen assemblage and the botanical survey (e.g., *Borreria*, *Hyptis*, *Hura*, *Tabebuia*, and *Zanthoxylum*), suggesting pollen inputs from local vegetation. However, given the size of LL, it is likely that this rainforest pollen assemblage also includes a background component from the *terra firme* forest on the main PCS area to the north of the lake (Sugita, 1994).

Pollen was well-preserved in sediments spanning the interval from 58 to 0 cm. Below this depth pollen was absent. The record has been divided into three zones based upon major changes in pollen assemblages and lithology.

#### *Zone 1 (58-47 cm, <5,670 cal a BP)*

Zone I is the lowermost unit of the record, comprising five pollen samples and has a maximum age of 5760 cal a BP. This zone is dominated by Poaceae pollen (62-75%) with some Cyperaceae (5-10%) and very low abundance of arboreal types ( $\leq$  20%). The most common arboreal types are Moraceae/Urticaceae (8-16%) and Arecaceae (2-4%). Macroscopic charcoal levels in this zone are high in comparison to the modern charcoal levels.

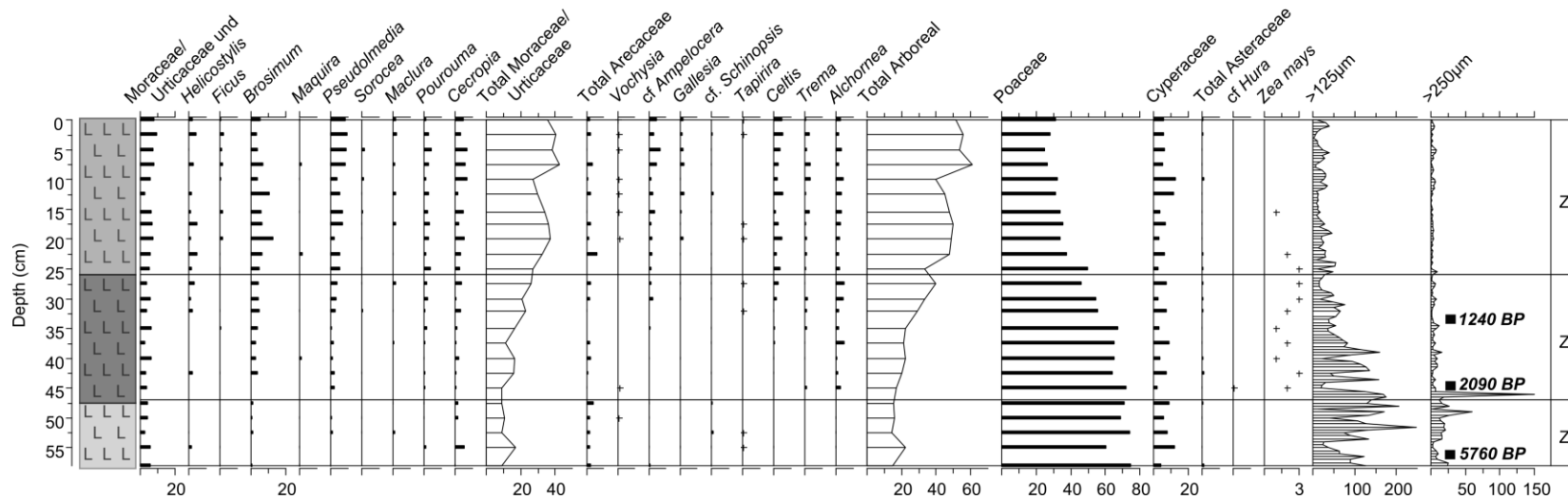
#### *Zone 2 (47-25 cm, <2090 cal a BP)*

The central unit of the lake core record, from which eight pollen samples were analysed, has a maximum age of 2090 cal a BP. The lower portion of the zone, from 47-35 cm depth, dates to > 1240 cal a BP, and is dominated by Poaceae (65-73%) with relatively low arboreal pollen abundance (15-23%). However, from 1240 cal a BP, between 35-25 cm, there is a steady decline in the percentage of Poaceae (46-56%) and an increase in arboreal pollen abundance (30-40%). This arboreal pollen increase is driven mostly by evergreen taxa such as *Brosimum* (4-6%), *Pseudolmedia* (1-6%), *Cecropia* (1-4%), and by *Alchornea* (2-5%), which appears for the first time in the record in this zone. This zone also sees the first appearance of maize (*Zea mays* L.) in the record at 2090 cal a BP, which is present throughout Zone 2. Charcoal abundance in the lower half of the zone is high, with a notable spike in the >250  $\mu$ m fraction at 46 cm depth. In the upper half of the zone, from ~37 cm depth, charcoal in the >125  $\mu$ m fraction begins to decline toward modern levels.

#### *Zone 3 (25-0 cm)*

The upper unit of the surface core comprises 11 pollen samples. Both radiocarbon dates from this unit are modern. Given that the latter may be the product of sediment mixing, it is not possible to discuss changes within the zone, although comparisons can be made between this zone and Zone 2. In Zone 3, the proportion of arboreal taxa (40-61%) to Poaceae (25-38%) reaches levels comparable to those of the modern surface sediment assemblage. The arboreal total is dominated by members of the Moraceae/Urticaceae (27-42%), *Ampelocera* (2-7%), *Celtis* (2-6%), *Alchornea* (2-5%) and some Arecaceae (0-6%). Maize pollen is also present, with the last grain identified at 15 cm depth. *Gallesia* is found for the first time in notable abundance ( $\geq 2\%$ ) in the record in this zone. Charcoal levels are low and consistent with modern abundance throughout the zone.





**Figure 3. Stratigraphic plot of pollen, charcoal and lithology from Laguna de La Luna. Pollen data are presented as percent abundance relative to the terrestrial sum, and charcoal as particles/cm<sup>3</sup>. Z. mays is presented as no. of grains/cm<sup>3</sup>. 'Total Arboreal' is the percentage sum of all arboreal taxa. Rare plant taxa ( $\leq 1\%$ ) which were also identified in the modern botanical survey, are included and represented by + symbol. Results are plotted against depth (cm), with calibrated single age estimates of radiocarbon dates plotted on the right (table 1).**

## Discussion

### *Palaeoenvironmental change and land-use history*

The earliest part of the LL record indicates that LI was not forested from 5670 cal a BP, but was covered mostly by grasses, with low density tree cover. This reflects the wider *terra firme* savannah environment that existed on the PCS in northern Iténez during the middle Holocene (Carson *et al.*, 2014) under drier palaeoclimatic conditions. Multiple palaeoclimate/vegetation records have shown that south-west Amazonia experienced drier conditions during the mid-to-late-Holocene (before ~2000 years BP) (Cross *et al.*, 2000; Baker *et al.*, 2001; May, 2006; Mayle and Power, 2008; Metcalfe *et al.*, 2014). As a result, during this period, the southern boundary of the Amazon rainforest was located further north than the current forest-savannah ecotone (Absy *et al.*, 1991; Mayle *et al.*, 2000; Burbridge *et al.*, 2004). A drier climate prior to 2000 years BP would also have created conditions conducive to increased natural fire frequency. Despite lower above-ground biomass in savannah systems, there is higher charcoal abundance in the LL record during this period, which points to greater burning of the landscape. There is no direct evidence (e.g. archaeological remains) for human occupation in this part of Iténez during the middle Holocene, although there is evidence of human occupation in the central *Llanos de Moxos* since ~10,000 BP (Lombardo *et al.*, 2013b) and in the Amazon since at least 12,000 BP (Roosevelt *et al.*, 1996). Humans may therefore have been active in the Iténez landscape as early as the mid-Holocene, and contributed to the high fire frequency seen in the early part of the LL record.

The earliest direct evidence for human activity on LI is the appearance of maize pollen in the LL record at ~2090 cal a BP. At this point savannah is the dominant vegetation on the island. However, the L. Orícore record shows that, regionally, there was a decline in burning in northern Iténez from ~ 2200 cal a BP, and an expansion of forest, dated to ~2000-1700 cal a BP, in response, most likely to increasing precipitation (Carson *et al.*, 2014). Despite this regional transition from savannah to forest, LI remained an open environment dominated by grasses and with low tree density, which continued to experience higher burning frequency/intensity until ~1240 cal a BP. Subsequently, declining charcoal levels coincided with expansion of arboreal species, and the island's vegetation changed from savannah to closed-canopy forest. This may suggest a similar history of land

use to that practised at the Bella Vista earthwork site, located 15 km north of LI (Carson *et al.*, 2014, 2015), whereby the inhabitants of LI held back the climatically-driven forest expansion through burning and suppression of tree growth.

One of our aims in this investigation was to assess the environmental impact of the construction of the boundary ditch encircling LI. The first hypothesis we tested, posited by Erickson (2010), states that the *terra firme* islands in Iténez were once forested and were subsequently deforested in order to build the ring ditches. However, we reject this hypothesis (at least for this site), as we found no evidence from our data that LI was deforested at any point during its occupation. According to the second hypothesis, based on the findings from the Bella Vista site by Carson *et al.* (2014), ring ditches were built within a naturally more open landscape under climatic conditions too dry to support rainforest. Unfortunately, there are no radiocarbon dates available from terrestrial excavations to date the construction of the LI earthwork and confirm whether it was built before forest expansion at ~1240 cal a BP. However, the data presented here has demonstrated that, as in Carson *et al.* (2014), pre-Columbian occupation of the LI site did begin at a time when vegetation on the island was naturally more open. The nearest dated ring-ditch features are those at the Bella Vista site, which are dated between 800 and 500 cal a BP (Dickau *et al.*, 2012). However, these represent only two of the numerous ring ditches at Bella Vista, most of which are undated. Excavations from similar ring-ditch earthworks, in southern Iténez (Prümers and Betancourt, 2014b), Riberalta, northern Bolivia (Saunaluoma, 2010), and Acre State, northwest Brazil (Schaan *et al.*, 2012), have dated occupations from as early as ~2000 cal a BP. This raises the possibility that hypothesis 2 is true, not just for the Bella Vista sites but for our LI study area too, i.e. the LI earthwork was built at a time when the vegetation on LI was open. A third hypothesis is that the LI boundary ditch was built after forest expansion ~1240 cal a BP, but that, since the earthwork lies at the extreme perimeter of the island, its construction would have required only minimal deforestation, at too small a scale to be detectable in the LL pollen record.

In light of these findings, which do not support Erickson's (2010) hypothesis, previous estimates of population size, based upon the labour required to clear forest islands and build palisades (Erickson, 2010), should be reconsidered. Furthermore, our finding does not support the hypothesis that pre-Columbian land use in

Amazonia had significant impacts on regional-to-global biogeochemical cycling, through extensive biomass removal (Dull *et al.*, 2010; Nevle *et al.*, 2011).

The dating of maize pollen in the LL record demonstrates contemporaneous occupation with the site at Bella Vista (Carson *et al.*, 2014, 2015), which was occupied from ~2500 cal a BP. The two sites may therefore have been part of a wider population/culture, which lived in, and built across, the savannah-*terra firme* island landscape. However, the decline in burning and expansion of forest at LL, dated to ~1240 cal a BP, occurred much earlier than the forest expansion recorded at Bella Vista, which was dated to ~500 cal a BP (Carson *et al.*, 2014, 2015). This may indicate an earlier decline in intensity of land management at LI, in comparison to Bella Vista. The presence of maize pollen informs us that people continued to occupy LI after forest expansion. However, it is conceivable that LI served a different function during the latter stages of its occupation, perhaps being used for low-intensity farming and resource gathering. This possibility is supported by Lombardo and Prümers (2010) and Lombardo *et al.* (2011), who argue that forest islands in the *Moxos* may have served as temporary slash-and-burn agricultural sites, rather than as settlements. Alternatively, land use on La Luna may have switched toward exploitation of economically useful tree species, which are common in the forest on the island today.

#### *Agriculture and resource management*

Maize was the only cultigen pollen type identified at La Luna. At the neighbouring Bella Vista site, a small number of manioc phytoliths were recovered from artefacts (Dickau *et al.*, 2012), but the main cultigen represented in the terrestrial phytolith and the lacustrine pollen/phytolith records was also maize (Carson *et al.*, 2015). This is unlike the other earthwork regions located further west in the central *Llanos de Moxos*, where there is strong evidence for a diversity of cultivars having been grown (Dickau *et al.*, 2012; Whitney *et al.*, 2014). The dating from the LL record, together with other sites (Whitney *et al.*, 2013, 2014; Carson *et al.*, 2014), suggests widespread cultivation of maize in the Bolivian Amazon region, dating from at least 2000 cal a BP.

The apparent importance of maize for these early cultures is significant, as it differs from the subsistence strategies of later and extant indigenous groups. Today in this region the staple crop is manioc (*Manihot esculenta* Crantz) which was

domesticated in the southern Amazon (Olsen and Schaal, 1999, 2001) and can be grown in less fertile tropical soils, using swidden agriculture (Heckenberger, 1998). Maize requires well drained soils (Edwards *et al.*, 1976) and its pollen is poorly transported, meaning it will not travel far from the source plant (Lane *et al.*, 2010). There are no earthworks that might have been used to improve drainage of the savannah soils immediately around LL, suggesting that the *terra firme* island itself is the most likely location for pre-Columbian cultivation. A non-forested LI would have provided abundant, well-drained, open land for cultivation. Furthermore, a number of these islands are used today for shifting swidden agriculture, suggesting that the soils are fertile enough for growing crops. Organically enriched anthropogenic soils have been discovered in *terra firme* areas elsewhere in northern Iténez (Hastik *et al.*, 2013; Lombardo *et al.*, 2013a).

The prevalence of economically useful plant taxa on LI today suggests a history of forest management. However, we found that these economic taxa, such as *Theobroma cacao*, are poorly represented or silent in the palaeoecological record. This was the case even when surface pollen counts were increased to 1000 grains. As such, we are not able to determine whether their introduction/expansion was a pre-Columbian event, or the result of later Jesuit land management. In the case of *Theobroma*, its absence from the pollen record may be the result of a conservative pollen dispersal mechanism (Young, 1994). Cacao has evolved a floral structure that limits access to a few preferred insect pollinators and does not freely release pollen. Also, as *Theobroma* is a small understorey tree with cauliflorous flowers (i.e., grow directly from the trunk), it may be expected that it would be poorly represented in the pollen record, compared with taller, canopy-level and wind-pollinated trees.

It should be noted, however, that pollen of other economic taxa, such as palm, which was identified in the LL fossil record, do not show any increase in abundance associated with human land use at LI either. Previous studies have demonstrated that relatively intensive palm agroforestry can be detected in the pollen record (Rushton *et al.*, 2012). The lack of any substantial changes in palm pollen abundance at LL therefore suggests that, if economically-useful tree taxa were managed on the LI site, this did not involve intensive management of palms in an orchard style planting arrangement.

What our palaeoecological record has demonstrated, however, is that the earliest occupation of the LI site pre-dates the growth of forest on the island. This

finding is intriguing, as it intersects with the concept of a long-lived and intrinsic human influence on Amazonian forest composition, which has been discussed extensively by authors such as Posey and Balée (1989), Chave *et al.* (2008), Erickson (2008) and Clement *et al.* (2015). In the case of the LI site, we have no truly “pre-anthropogenic” base-line forest with which to make comparisons, as there was a human presence on the island throughout the expansion and establishment of closed-canopy rainforest. Therefore, both intentional and unintentional human impacts, such as plant management and alteration of soil conditions through burning, may have fundamentally influenced the development of forest on the site, in terms of its structure and floristic composition.

## Conclusions

This study has presented an informative palaeoecological record from a previously unstudied archaeological site, within an important pre-Columbian landscape. Pre-Columbian occupation of the La Luna site is shown to have begun at a time when vegetation on the island was open savannah, rather than closed-canopy rainforest which exists on the site today. The regional environment transitioned from savannah to rainforest beginning at ~2000 cal a BP (Mayle *et al.*, 2000; Carson *et al.*, 2015), but the LI site remained an open herb-dominated landscape. This may have been as a result of the inhabitants suppressing rainforest expansion through burning and clearing of young trees, as likely happened at the nearby Bella Vista site (Carson *et al.* 2014). From ~1240 cal a BP, burning declined and forest was allowed to grow, establishing closed-canopy rainforest similar to that which exists today. We found no evidence that, following the climate-driven afforestation of LI, there was any subsequent deforestation by pre-Columbian people. This contradicts the hypothesis that earthwork construction on forest islands in this region necessitated extensive deforestation (Erickson, 2010). Population estimates, based upon the labour required to clear the forest islands (Erickson, 2010), should therefore be reconsidered in light of these new data, which imply that populations may have been smaller than previously estimated. Furthermore, our findings do not support the hypothesis that pre-Columbian land use had profound impacts on biogeochemical cycling through biomass removal and post-collapse reforestation (Carson *et al.*, 2014). We do demonstrate, however, that human occupation of the site predates and spans the period of forest expansion, suggesting that human impacts may have been significant in the forest's development. This evidence for a long-lived human influence on the forest has important implications for the field of historical ecology, as it supports the notion that anthropogenic influences may have formed an important driver in the development of ecosystems in parts of Amazonia (Posey and Balée, 1989; Erickson and Balée, 2006; Heckenberger *et al.*, 2007; Clement and Junqueira, 2010; Bush *et al.*, 2015; Clement *et al.*, 2015).

## Acknowledgments:

This research was supported by a Leverhulme Trust research grant (F/00158/Ch) awarded to FM and JI and a NERC Doctoral Training Scheme grant (NE/152830X/1) and funds from the University of Edinburgh's Principal's Career Development Scholarship, awarded to JC. A NERC radiocarbon facility date was granted to FM (1623.0312). Fieldwork support was provided by the 'Noel Kempff Mercado' Natural History Museum, Santa Cruz, Bolivia. We thank Douglas Bruckner of the 'Programa de Conservación de la Paraba Barba Azul', Trinidad, Beni Department, Bolivia and the rangers from the 'Reserva Iténez' WWF station in the town of Bella Vista, Beni Department, Bolivia, for logistical support in the field.

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**Table 1** Bulk sediment AMS  $^{14}\text{C}$  results from Laguna de La Luna. Calibrated ages are presented as weighted mean of the age distributions (Telford *et al.*, 2004). Sample Lu 14 is given as parts modern carbon (pMC) rather than a conventional radiocarbon age.

Sample identifier	Publication code	Depth below sediment-water interface (cm)	Conventional $^{14}\text{C}$ age (yr BP $\pm 1\sigma$ ) *pMC	Calibrated age range (cal a BP) $\pm 2\sigma$	Area under probability curve	Weighted mean calibration (cal a BP)	$\delta^{13}\text{C}_{\text{VPDB}}(\text{‰})$
Lu 14	Beta-355052	14-15	*118.2 +/- 0.3	-	-	-	-27.1
Lu 23	Beta-347193	23-24	90 +/-30	-	-	-	-26.1
Lu 33	Beta-364772	33-34	1310 +/-30	1294-1223 1213-1181	0.713 0.287	1240	-22.7
Lu 45	Beta-355053	45-45.5	2120 +/-30	2322-2345 2050-2206	0.044 0.956	2090	-24.0
Lu 56	Beta-339230	56-57	5010 +/-30	5857-5942 5706-5818	0.358 0.642	5760	-26.3

**Table 2.** Results of the rapid assessment botanical survey. Taxa were assigned to one of four habitat types: *terra firme* forest island, a riparian zone in the margin between the forest island and the lake, the seasonally-inundated savannah, and aquatic habitats on the lake margins. An \* indicates that the family or genus was identified in the Laguna de La Luna surface pollen assemblage.

Family	Genus/Species	Occurrence in modern environment
Alismataceae	<i>Echinodorus bolivianus</i> (Rusby) Holm-Niels	Riparian
	<i>Limnocharis laforestii</i> Griseb.	Riparian
Annonaceae	<i>Guatteria</i> sp.	Forest island
	<i>Unonopsis</i> sp.	Forest island
Apocynaceae	<i>Tabernaemontana siphilitica</i> Leeuwenb.	Riparian
Araliaceae	<i>Hydrocotyle bonariensis</i> Lam.	Riparian
Bignoniaceae	<i>Godmania</i> sp.	Forest island

	* <i>Tabebuia elliptica</i> (A. DC.) Sandwith	Riparian
Bixaceae	<i>Cochlospermum</i> sp.	Forest island
Caryophyllaceae	Indeterminate	Riparian
*Cyperaceae	<i>Cyperus haspan</i> L.	SI-savannah
	<i>Echinodorus tenellus</i> (Mart.) Buchenau	Riparian
	<i>Eleocharis elegans</i> (Kunth) Roem. & Schult.	Aquatic
	<i>Eleocharis minima</i> Kunth	Aquatic
	<i>Eleocharis minima</i> Kunth	Riparian
	<i>Eleocharis mutata</i> (L.) Roem. & Schult.	Aquatic
	<i>Eleocharis</i> sp.	Aquatic
	<i>Rhynchospora</i> sp.	Riparian
	<i>Scleria obtusa</i> Core	Riparian
Euphorbiaceae	<i>Caperonia</i> cf. <i>castaneifolia</i> (L.) A. St.-Hill	SI-Savannah
	<i>Caperonia</i> sp.	Wetland
	* <i>Hura crepitans</i> L.	Riparian
Fabaceae	<i>Aeschynomene</i> cf. <i>denticulata</i> Rudd	Riparian
	<i>Aeschynomene pratensis</i> Small	Riparian
	<i>Aeschynomene</i> sp.	SI-Savannah
	<i>Andira inermis</i> (W. Wright) Kunth ex DC.	Forest island
	* <i>Inga</i> sp.1	Forest island
	<i>Inga</i> sp.2	Forest island
	<i>Poeppigia procera</i> C. Presl	Forest island
	<i>Pterocarpos amazonicus</i> Huber	Forest island
	<i>Schizolobium amazonicum</i> Huber ex Ducke	Forest island

Lamiaceae	* <i>Hyptis lantanifolia</i> Poit.	SI-savannah
Lythraceae	<i>Physocalymma scaberrimum</i> Pohl	Forest island
Malvaceae	<i>Apeiba tibourbou</i> Aubl.	Forest island
	<i>Helicteres</i> sp.	Semi-aquatic
	<i>Luehea grandiflora</i> Mart.	Forest island
	<i>Melochia hirsuta</i> Cav.	SI-savannah
	<i>Ochroma pyramidale</i> (Cav. ex Lam.) Urb.	Forest island
	<i>Pavonia</i> sp.	SI-savannah
	<i>Theobroma cacao</i>	Forest island
Maranthaceae	<i>Thalia geniculata</i> L.	Si-savannah
*Melastomataceae	<i>Mouriri apiranga</i> Spruce ex Triana	Forest island
Meliaceae	<i>Trichilia pallida</i> Sw.	Forest island
Moraceae	* <i>Pseudolmedia laevis</i> (Ruiz & Pav.) J.F. Macber.	Forest island
Myrtaceae	<i>Myrciaria</i> cf. <i>delicatula</i> (DC.) O. Berg	Forest island
*Onagraceae	<i>Ludwigia leptocarpa</i> (Nutt.) H. Hara	Riparian
Polygonaceae	<i>Polygonum acuminatum</i> Kunth	SI-savannah
Rhamnaceae	<i>Rhamnidium elaeocarpum</i> Reissek	Forest island
Rubiaceae	* <i>Borreria scabiosoides</i> var. <i>anderssonii</i> (Standl.) Steyerm.	Riparian
	<i>Diodia kuntzei</i> K. Schum	Riparian
Rutaceae	* <i>Zanthoxylum fagara</i> var. <i>culantrillo</i> Reynel	Forest island
Salicaceae	<i>Casearia</i> cf. <i>javitensis</i> Kunth	Forest island
Sapindaceae	<i>Matayba</i> sp.	Forest island
Sapotaceae	<i>Chrysophyllum gonocarpum</i> (Mart. & Eichler ex Miq.) Engl.	Forest island
	<i>Chrysophyllum venezuelanense</i>	Forest island



	(Pierre) T.D. Penn.	
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