



A late-Holocene vegetation history from the Maya lowlands, Lamanai, Northern Belize

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Abstract

A 3 m core from the New River Lagoon, adjacent to the Maya city of Lamanai, Northern Belize, contains a continuous record of vegetation change between c. 1500 BC and AD 1500. Inferred changes in forest abundance and plant community assemblage builds on previous palaeolimnological analysis of the same core reported by Metcalfe et al. (2009). A near-complete, abundant record of *Zea mays* grains provides a detailed account of field-based agriculture local to Lamanai, in the context of a regional record obtained from a large lake (13.5 km²) with a substantial catchment. Three periods (c. 170 BC–AD 150, c. AD 600–980 and c. AD 1500) of extraction of *Pinus* from pine savannas adjacent to the east of the New River Lagoon, can be distinguished from clearance of seasonal broadleaf forest for agriculture. An increased palm signal is observed during c. 1630–1150 BC and 100 BC–AD 1100 and may be indicative of Maya cultivation. This record shows that during the late Classic period the Maya actively managed the vegetation resources using a combination of field-based agriculture, arboreal resources and perhaps, palm cultivation. There is no evidence from the vegetation history of drying during the late Classic coincident with the Maya ‘collapse’ and this is consistent with the palaeolimnological and archaeological records of continuous occupation of the Maya at Lamanai. Both the increase in *Pinus* extraction c. AD 1500 and the decline in palms c. AD 1400 are consistent with changes in vegetation associated with European arrival, however further analysis of material from the last 1000 years will enable a better understanding of vegetation change pre- and post-European encounter.

Keywords

forest clearance, Maya ‘collapse’, Northern Belize, pine exploitation, pollen analysis, vegetation history

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Introduction

The vegetation history of the Maya lowlands (parts of Belize, Mexico and Guatemala) reflects a complex mixture of both climatic change and anthropogenic disturbance. The balance of these factors during the Classic and early Post-Classic periods (c. AD 300 to AD 1450) is of particular interest. Palaeoclimatic reconstructions from the Yucatán have shown fluctuations in water balance consistent with droughts which have been linked to the Maya ‘collapse’ c. AD 900–1000 (Curtis et al., 1996; Hodell et al., 1995). However, the impact of the Maya on their environment and the nature and scale of vegetation change in the post ‘collapse’ period have also been a focus of attention. Reconstructions of vegetation cover have furthered our understanding of the causes and consequences of the ‘Maya Collapse’, with studies demonstrating links to anthropogenic impact (Abrams et al., 1996; Rue, 1987; Webster et al., 2000) and climate (Leyden, 1998) or, indeed, a combination of both factors (Aimers and Hodell, 2011; Metcalfe et al., 2009). There is clear evidence of anthropogenic disturbance over the Holocene, including examples of forest clearance associated with the appearance of crops (Jones, 1994; Leyden, 1998); intensive cultivation of crops linked with evidence of hydraulic manipulation (Beach et al., 2006); deforestation and management of arboreal resources (Leyden, 2002; McNeil, et al., 2010) and recovery of forest cover coincident with a decline in population (Bradbury et al., 1990; Islebe et al., 1996). Belize has extensive archaeological evidence for the occupation of the Maya, with crops appearing in pollen records throughout the region during 2000–1000 BC (Hansen, 1990; Jones, 1994) and large-scale agricultural terracing and major hydraulic manipulation in

evidence during the Classic period (AD 300–500) (Beach et al., 2006, 2009).

Using new pollen and charcoal records, we present a 3000 year (c. 1500 BC–AD 1500) vegetation history from the New River Lagoon (NRL), to document the nature of vegetation change near the Maya site of Lamanai, and to explore the impacts of the Maya on the floristic composition of the landscape, in particular the arboreal resources. Lamanai was one of the largest Maya settlements in Northern Belize and shows continuity of settlement through the late Classic ‘collapse’ period. Settlement began at c. 1500 BC, major construction and population peaking during the early Classic period (c. AD 300) and Maya settlement continuing into the 17th century. Metcalfe et al. (2009) suggest that population and erosion peaked during the Preclassic and early Classic, with a population of approximately 10,000. The Maya city (Graham, 1987, 2001, 2004, 2011; Pendergast, 1975, 1981, 1982a, 1982b, 1982c, 2002) was associated with complex ceremonial activity that is defined by a well established archaeological stratigraphy (Graham, personal communication, 2011). The continuous occupation of the site between c. 300 BC and AD 1675

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(Pendergast, 1986), means that the record from the nearby lagoon should document Maya influences on the abundance and composition of the adjacent vegetation for the entire period. To facilitate comparison with the archaeological and early historical record the calibrated years BC/AD are used throughout this paper.

The new pollen and charcoal analyses were undertaken on a 3 m core previously examined by Metcalfe et al. (2009), as part of study of environmental change since the latest Pleistocene using diatom and stable isotopes (supported by mineralogical and major elemental data). The research questions addressed in this new study include: What was the extent of Maya forest clearance around Lamanai and, furthermore, is it possible to distinguish different types of clearance events? Is there evidence of Maya management of vegetation resources? Is a period of 'Maya Collapse' visible in this vegetation record? Finally, does this record show any forest 'recovery' from periods of human disturbance?

The vegetation and Maya settlement of Northern Belize

Belize is situated in the southeast of the Yucatán Peninsula (between approximately 88°45' and 89°15'W and 18°30'N) with Mexico to the north, Guatemala to the south and west and the

Caribbean Sea to the east (Figure 1). The climate is defined as seasonally dry tropical and has a boreal summer wet season, directed by the movement of the Inter-Tropical Convergence Zone (ITCZ). Northern Belize has a drier more seasonal climate than the south (Esselman and Botes, 2001), with annual precipitation in the northern region in the range 1520–2030 mm (Walker, 1973). The vegetation of Northern Belize is mainly comprised of lowland broadleaved forest, lowland savanna and mangrove and littoral swamp. The ecology is driven by the underlying geology, with pine savanna found in well-drained acidic sand ridges, evergreen forest on calcareous sediments, and herbaceous swamps, seasonally inundated savanna and marshland in the freshwater lowlands (Metcalfe et al., 2009).

Lamanai is situated on the west side of the New River Lagoon, (located approximately at 88°40'W and 17°40'N), a freshwater lagoon within the river channel about 23 km long and 750 m wide, covering approximately 13.5 km² (Metcalfe et al., 2009). The lagoon is surrounded by a fringe of reeds dominated by *Phragmites australis* and *Cladium jamaicense*. To the west of the lagoon the reeds grade into a band dominated by logwood (*Haematoxylon campechianum*) and then into tropical evergreen seasonal broadleaved lowland forest (Meerman and Sabido, 2001) and this is the vegetation that today surrounds the archaeological

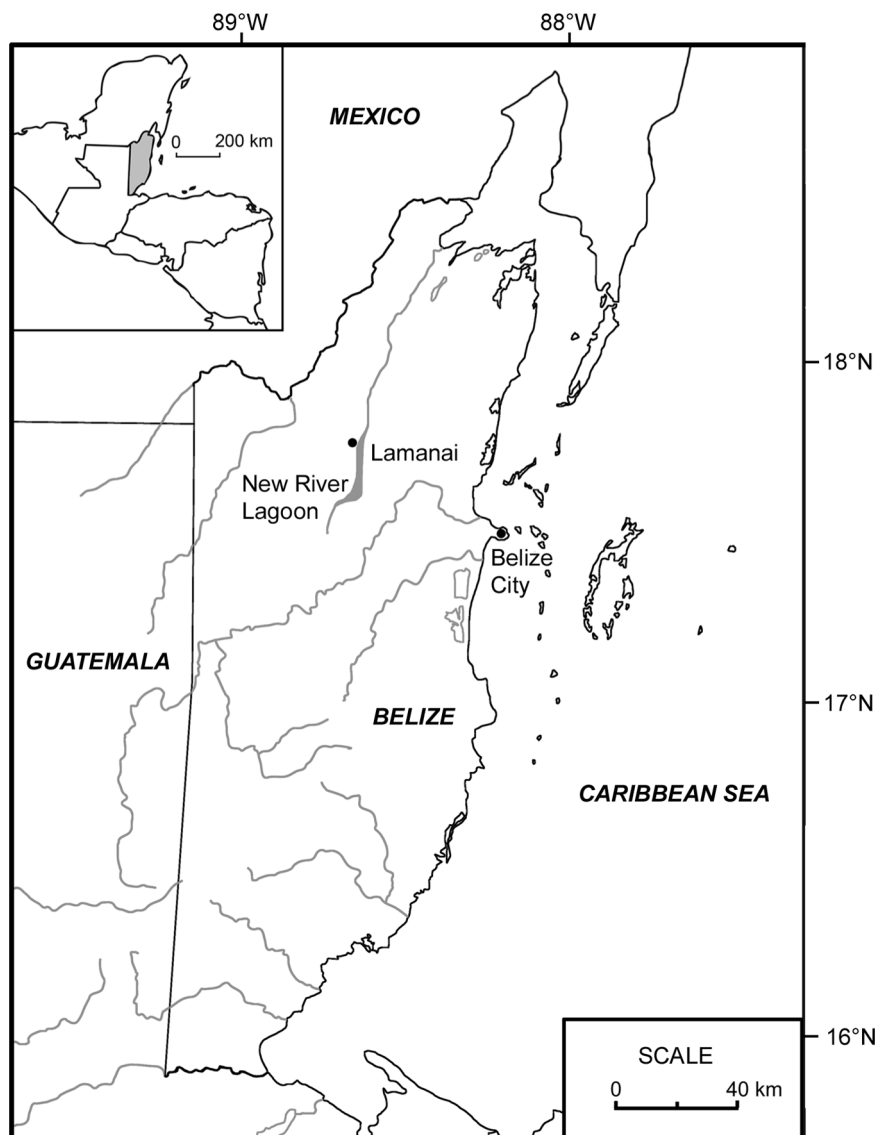


Figure 1. Location of the New River Lagoon, adjacent to the Maya settlement at Lamanai, Belize.

site of Lamanai. To the east of the lagoon, vegetation changes from a reed fringe to marsh land (dominated by *Eleocharis intersticta* and *C. jamaicense*) and then into a band of logwood, and finally into the savanna zone (Meerman and Sabido, 2001). The savanna zone has been described by Meerman and Sabido (2001) as short-grass savanna with scattered needle-leaved trees, with characteristic species including *Pinus caribaea*, *Metopium brownei* and *Byrsonima crassifolia*. Detailed ecological mapping of Belize has been undertaken by the Biodiversity and Environmental Data Resource System of Belize (BERDS) and is available at <http://www.biodiversity.bz/mapping/>

Materials and methods

Sediment collection

A 319 cm core was extracted in 1999 using a square-rod modified Livingston piston corer, from the end of a jetty adjacent to Lamanai in a water depth of approximately 2 m, and was shipped to the UK in plastic piping (Metcalf et al., 2009). A core top sample was extracted in 2010, from the same location and water depth using a Glew corer to retrieve the sediment–water interface intact. Samples were extruded in the field in 1 cm intervals and were shipped in sealed plastic bags. All material was stored at 4°C. From the main core samples for pollen analysis were taken at approximately 10 cm intervals and each of the stratigraphic subsections (described shortly after the core was extracted) were sampled. The top 1 cm surface sediment from the Glew core was analysed for comparison with the modern vegetation.

Chronology and stratigraphy

Metcalf et al. (2009) reported the results of six radiocarbon dates (one paired, comprising plant macrofossils and gastropods from the same level in the core) (Table 1), this previously established chronology is used by this study. Owing to the length of time that has elapsed since the core was first extracted, and multiple other proxies that have used sediment sampled from this core, the core length at the time of sampling for pollen analysis had decreased to 309 cm, with the majority of core lost in the basal section, however, all the units described in 2001 were visible when sampling for this study. The samples analysed for pollen analysis in 2010 were extracted from sediment that has been recalculated to represent the period c. 1650 BC–AD 1500.

Pollen and charcoal analysis

Standard chemical digestion protocol was used (Bennett and Willis, 2001; Faegri et al., 1989) including hot 10% NaOH and acetolysis treatments. Additional initial stages undertaken prior to chemical digestion included a sieving stage at 250 µm to remove larger shells and then a cold 10% HCl treatment to remove carbonates. HF was not used on the samples, but instead hot Calgon® was used to remove clays, and the samples were repeatedly rinsed with distilled water until the supernatant was clear. Initial scans revealed that *Zea* was absent from the record, and samples

from this core were included in a methodological trial to improve the recovery of *Zea mays* and other large cultigen grains as reported by Whitney et al. (2012). The application of this methodology on five initial samples was successful in recovering a *Z. mays* signal, and so this new methodology was applied to the remaining samples. Known concentrations of *Lycopodium* spores were added to each sample to enable the calculation of pollen and charcoal concentrations. Charcoal counts were made from material prepared for pollen analysis. Particles with the length of the longest axis greater than 20 µm were counted and concentrations were calculated relative to the *Lycopodium* spike. Samples were counted using a Zeiss Axioscope photomicroscope at ×100, ×400 and ×1000 magnification. Pollen grains were, in the main, identified using the Central American pollen reference collection held in the School of Geography, University of Nottingham. Pollen atlases were also consulted, including those of Quintana Roo, Mexico (Palacios-Chávez et al., 1991) and Barro Colorado Island, Panama (Roubik and Moreno, 1991), as well as digital images from the 'Neotropical Pollen Database' (Bush and Weng, 2007). A minimum of 200 and a maximum of 320 fossil terrestrial grains were counted: the pollen sum is exclusive of unidentifiable damaged grains, aquatic taxa and fungal spores. Cyperaceae was included in the pollen sum because sedges comprise a large proportion of the herbaceous component of the adjacent savanna communities, as well as forming the marginal fringing semi-aquatic vegetation at NRL. Species of Rhizophoraceae (mangroves) are components of littoral forest in central Belize, and were also included in the pollen sum.

Pollen taxa were separated according to ecological groups; seasonal forest, savanna, disturbance taxa, Arecaceae (palms) and crop taxa. Taxa were identified from other pollen diagrams from the wider region including those from Belize (Bhattacharya et al., 2011; Jones, 1994; Pohl et al., 1996), Mexico (Carrillo-Bastos et al., 2012; Islebe and Sánchez, 2002; Leyden, 1998, 2002) and Guatemala (Curtis et al., 1998; Islebe et al., 1996). Leyden (1998) and Bush et al. (1992) both record biporate and triporate grains from the Urticaceae/Moraceae families as arboreal taxa and these families were further differentiated with reference to Burn and Mayle (2008), enabling the identification of *Brosimum* type and *Maclura* type, all other Moraceae/Urticaceae were classed as other 2 pore Moraceae/Urticaceae. Chenopodiaceae and Amaranthaceae could not be distinguished and so were grouped together as Cheno/Ams in the pollen diagram. As a group Palms (Arecaceae) have been presented separately from ecological groupings as they are present in multiple formations. Palms have been described as economic taxa (Ford, 2008) that are 'selectively grown for their economic value particularly for use as thatch, and fruits' (Jones, 1994: 209), however, here palms have not been grouped with other agricultural crops, for example they are not included in 'Total crops' (Figure 2). The occurrence of *Z. mays* pollen has been established as a key indicator of pre-Columbian agriculture in palaeoecological records throughout South and Central America (Berrio et al., 2000, 2002; Bush et al., 1989, 2007; Clement and Horn, 2001; Kennedy and Horn, 2008; Niemann and Behling, 2010; Northrop and Horn, 1996; Piperno,

Table 1. AMS radiocarbon dates for the Lamanai, New River Lagoon core (Metcalf et al., 2009).

Code	Depth (cm)	Material	¹⁴ C yr BP	δ ¹³ CVPDB‰±0.1	Cal. yr BP (2σ)	Cal. yr BC/AD (2σ)
AA-35787	38.5	OM	810 ± 40	-32.4	AD 1224, 1231, 1239	AD 1161–283
CAMS-77196	38.5	G	2470 ± 40	-6.9	–	–
SUERC-4104	72-75	G	3260 ± 50	-6.7	–	(c. AD 400)
SUERC-4108	178-180	G	4445 ± 35	-5.6	–	(c. 900 BC)
AA-35786	259	OM	3070 ± 50	-27.1	3159–3383	1433–1132 BC
CAMS-77195	312	OM	3440 ± 40	-28.6	3629–3780	1880–1636 BC

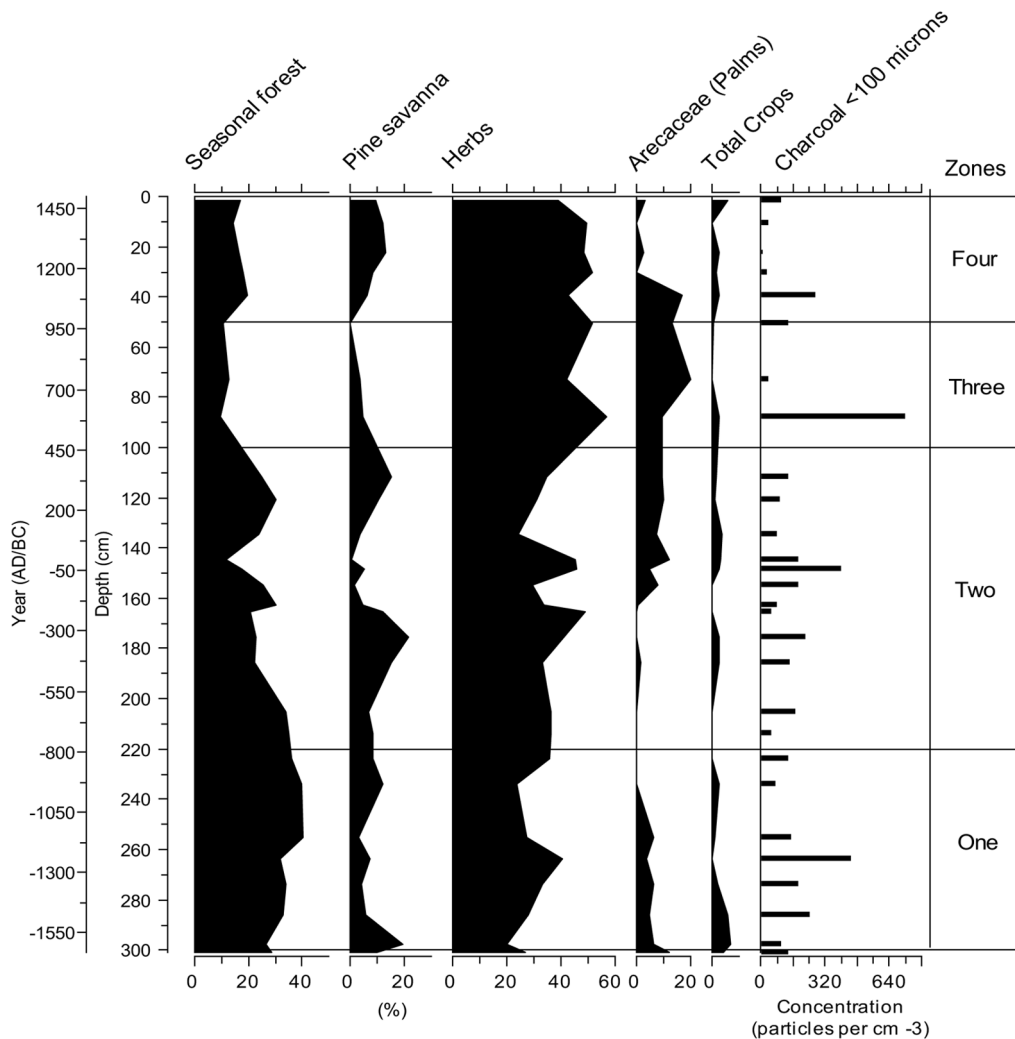


Figure 2. Summary pollen percentage diagram for the Lamanai, New River Lagoon core.

2006). *Z. mays* was separated from other wild grasses using the criteria set out by Holst et al. (2007), and included analysis of the distribution of exine intertactile columnellae using phase contrast at $\times 1000$ magnification, however it was not possible to distinguish it from its ancestor Balsas teosinte (*Zea mays* subsp. *parviglumis*) (Matsuoka et al., 2002; van Heerwaarden et al., 2011) because of morphological similarities, particularly size (Holst et al., 2007; Piperno et al., 2009). However, teosinte is not native to Belize and as such it is likely that observed pollen grains morphologically consistent with *Zea* are domesticated *Z. mays*. Other food crops include squash (*Cucurbita*) and chilli pepper (*Capsicum*) although there are insufficient morphological studies to distinguish domesticated varieties from their wild relatives. As with palms, taxa that occur in more than one ecological grouping have not been assigned a group in Figures 2–3. For example, Cyperaceae was not included as a ‘savanna’ pollen type, as although it is found in savanna, it is present in several vegetation formations, including fringing marsh. Cyperaceae and Rhizophoraceae have been defined as aquatic taxa indicative of a wet climate by Leyden (1998) and Bush et al. (1992). However, in this case Cyperaceae is not indicative of a particular climate, but of several vegetation formations. Rhizophoraceae pollen are assigned to ‘Mangroves’ in Figure 3.

Results (expressed as percentages) were plotted and analysed using C2 software (Juggins, 2003) and zoned using CONISS. Only pollen grains comprising 1% at one point in the sediment core were included (this cut-off was also applied to crop pollen) this analysis identified four zones (Figures 2–3).

Results

The charcoal record

Charcoal fragments are found throughout all four zones, though concentration in Zone Four is low (Figure 2). The peak concentration (725 particles/cm³) occurs at the base of Zone Three (c. AD 590). A secondary peak in charcoal (451 particles/cm³) is observed in Zone One (c. 1250 BC) and a tertiary peak (401 particles/cm³) in Zone Two (c. 40 BC). In the modern core top sample charcoal concentrations are 81 particles/cm³. All particles observed are <100 μ m in size, and as such represent a regional charcoal signal (Whitlock and Larsen, 2001).

Modern pollen assemblage

Seasonal forest taxa totalled 18% and this included Moraceae/Urtiaceae (4%), *Brosimum* type (3%), *Manikara zapote* (3%), and *Swietenia macrophylla* (2%). The pine savanna signal comprised *Pinus* (16%), and also *Mimosa* (4%), *Metopium brownei* (4%) *Byrsonima* (2.5%), *Quercus* (2.5%) and *Cecropia* (1%). Combretaceae/Melastomaceae comprised 12%, and could be representative of both pine savanna species, e.g. *Miconia* (Melastomaceae) and also seasonally inundated forest species associated with the logwood fringe (*H. campechianum*, 2%) that surrounds the modern NRL, including *Bucida buceras* (Bhattacharya et al., 2011). Herb taxa included Chenopodiaceae/Amaranthaceae (9%), Asteraceae (7%) and Poaceae (6%). There were low palm levels recorded (1%) and very low crop taxa, with only *Z. mays* present (1%).

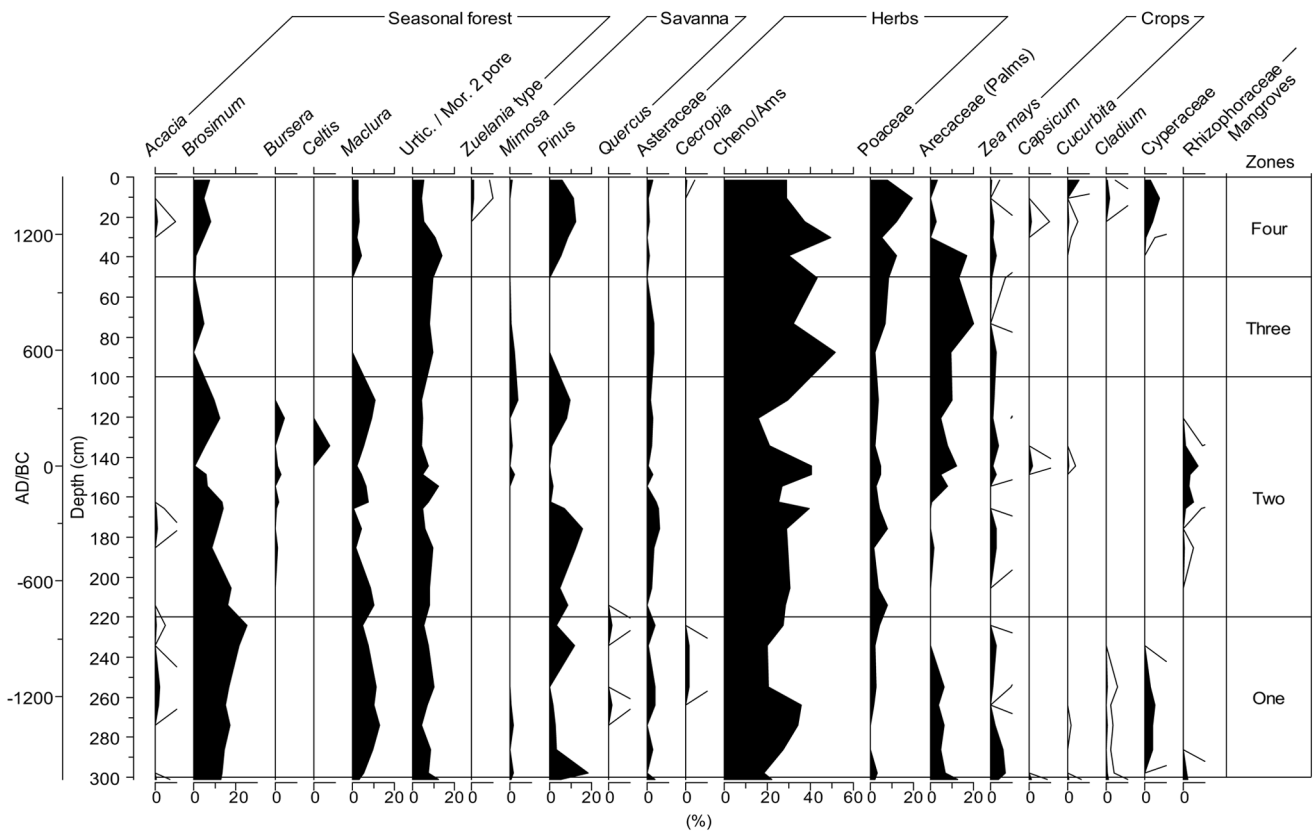


Figure 3. Detailed pollen percentage diagram for the Lamanai, New River Lagoon core ('Urtic.–Mor. 2 pore': Urticaceae/Morticeae 2 pore; 'Cheno/Ams': Chenopodiaceae/Amaranthaceae; the fine black line reflects a $\times 10$ exaggeration of pollen percentages).

Long core record

Zone One: 300–220 cm, c. 1630–900 BC. The arboreal signal for this zone is dominated by *Brosimum* type, *Pinus* and *Maclura* type with *Quercus* recorded in lower percentages (<2%). Seasonal forest cover ranges between 27% and 40.5% (average 34%) with a broadly increasing trend between c. 1630 and 900 BC. Pine savanna cover peaks (20%) in Zone One at c. 1600 BC (zone one average is 9%) and then declines during c. 1500–900 BC, ranging between 3.5% and 12% (average for this period is 4%). Herb taxa have an average of 29% throughout Zone One, with a low in this zone of 20% at 1600 BC and a peak of 40% at 1240 BC. Palms peak (16%) at 1630 BC, values ranging from 4% to 12% during the period 1630–1150 BC (average value 6.5%). No palms are present between 930 and 820 BC. *Z. mays* is present between 1630 and 930 BC (average value 3.5%) and has a peak (5%) at 1240 BC. *Cucurbita* and *Capsicum* are both present (<1%) at c. 1630 BC. Semi-aquatic pollen types including Cyperaceae, Rhizophoraceae and *Cladium* are also present during period 1630–1150 BC (average value 3.5%).

Zone Two: 220–100 cm, c. 900 BC–AD 350. In Zone Two the seasonal forest signal can be divided into two trends. Between 720 and 10 BC the arboreal signal declines from 35%, where Urticaceae/Moraceae, *Brosimum* type, *Maclura* type and *Pinus* dominate and *Bursera simaruba* is found in smaller proportions, to its lowest level of 11% at 10 BC. From 10 BC to AD 470 the arboreal signal increases, rising to 40% at AD 250. Here arboreal taxa include *Brosimum* type, Urticaceae/Moraceae, *Pinus* and *B. simaruba*. Pine savanna cover follows a similar trend, with cover ranging between 11.5% and 35% (zone two average is 25%) and a sharp decline in cover, and *Pinus* in particular, falling to <1% at 10 BC. Herbs have a mean value of 37% throughout this zone, with two notable peaks at 220 BC (49%) and 40 BC (46%). Palms are

either absent or present in relatively low abundance (<1.5%) between 720 and 190 BC, rising during the period 100–10 BC to between 4% and 12%. *Capsicum* and *Cucurbita* are both present in low abundance at 10 BC (<2% and <1%, respectively). *Z. mays* is not present between 820–640 BC and 220–190 BC, but is present between 430–320 BC (2.5%) and 40 BC–AD 350 (ranging between 2.5% and 4%). In this zone the highest levels of *Z. mays* occur at AD 100 (4%). Aquatics are found in low levels (<1%) between 220 BC and AD 100, peaking at 10 BC (7%).

Zone Three: 100–50 cm, AD 350–1000. Seasonal forest cover ranges from 12% to 20%, declining from 20% in AD 590, to 12% in AD 970. The dominant taxa are Urticaceae/Moraceae, with *Maclura* type, *B. simaruba*, and *Celtis* absent from this zone. Pine savanna cover is low, ranging between 0% and 4%, with *Pinus* absent from zone three. Herb taxa peak (56%) at AD 590, declining to 42% at AD 740. The levels of herbs increase to 51% between AD 740 and 970, and the decline at AD 740 may be caused in part by the peak in palms (20%) at this point. No Cyperaceae is present in this zone and *Z. mays* is the only crop taxa recorded. The peak in *Z. mays* for this zone (3%) is found at AD 590, with levels decreasing during AD 740–970.

Zone Four: 50–0 cm, AD 1000–1500. During AD 1000–1500 the seasonal forest cover ranges from 14.5% to 19.5% (average is 17%), with a peak of 19.5% in this zone at AD 1100. Arboreal taxa includes, *Brosimum* type, *Maclura* type, Urticaceae/Moraceae and *Zueliana guidonia*. The pine savanna cover ranges from 6.5% to 11.5%, with an average of 10%. *Pinus* dominates the pine savanna signal, with a tertiary peak (12.5%) from all zones, occurring at c. AD 1250. Herb taxa have an average of 37%, ranging from 37% to 55%. The secondary peak of palms occurs at AD 1090, however from AD 1190 to 1480 decreases to <4%. *Z. mays* is present between

AD 1090 and AD 1270 (1–2.5%) but is absent or represented by a single grain between AD 1390 and AD 1480. *Cucurbita* occurs at AD 1480 and both *Cucurbita* and *Capsicum* are present at AD 1270. Cyperaceae is present between AD 1180 and AD 1480 and peaks at AD 1390 (7%), accompanied by *Cladium* (<2%).

Discussion

Pollen source

The modern core top sample reflects the dominant ecosystem types that surround the site at Lamanai, and the wider New River Lagoon catchment, namely seasonal broadleaf forest, which is found to the west of the New River Lagoon and surrounds the present archaeological site, and pine savanna, which is found to the east. Seasonal broadleaf forest includes ecological dominants such as *B. alicastrum*, *B. simaruba*, *M. zapota* and *S. macrophylla* that are reflected in the modern pollen assemblage. However, compared with modern pollen spectra from forested sites in this region that report Moraceae/Urticaceae comprising >40% of the pollen assemblage (Bhattacharya et al., 2011), the modern core sample has a relatively low arboreal signal (18%). Correa-Metrio et al. (2011) reported that it was not possible to distinguish evergreen seasonal, tropical semi-deciduous and tropical deciduous using their modern pollen spectra, and that these subcategories had to be grouped as tropical seasonal forest. This large group of taxa meant that the pollen signal was wide ranging, and this could account for the comparatively low arboreal signal in the modern assemblage from the NRL.

Savannas dominated by *P. caribaea* are represented in the modern pollen assemblage by abundant *Pinus* pollen. Pines are prolific producers of wind-dispersed pollen, thus regional sources, such as high elevations from Mexico/Guatemala, may contribute some pollen to the *Pinus* signature in the NRL record. However, source plants located nearer to deposition sites contribute substantially larger proportion of pollen compared with regional or 'background' pollen where vegetation patches in a heterogeneous environment are larger than the lake area, as in the case of Belizean pine savanna (Sugita, 1994). Therefore, we can be confident that nearby pine savannas, adjacent to the east of the NRL, contribute the greatest proportion of pine pollen in NRL and past variations in the abundance of pine in these savannas are reflected in the pollen signature. *Byrsonima crassifolia* is also a characteristic taxon found in Belizean pine savannas and, although of low abundance in the modern pollen assemblage at NRL, *Byrsonima* has been identified as an important indicator species of pine savanna in the modern pollen rain from northern Belize, as it was exclusively found in the modern pollen spectra of pine savanna sites (Bhattacharya et al., 2011). Ledru (2002) and Gosling et al. (2009) have both demonstrated that *B. crassifolia* is a good indicator species of savanna (or cerrado) in the Neotropics and the presence of the less prolific *Byrsonima* (of which there is only one additional species found in Belize), combined with *Pinus* pollen, is indicative of local pine savanna.

The presence of *H. campechianum* and *M. brownei* most likely indicate the logwood fringe that surrounds the NRL today. Palms are not abundant in the modern pollen record, and this underrepresentation is possibly due to both the large grain size (>60 µm) and the large catchment of the New River Lagoon (13.5 km²). Crop taxa were only represented by a small amount of *Z. mays* however, it has been demonstrated in both field and laboratory settings that because of its large size (50–120 µm) *Z. mays* grains are poorly dispersed from the source plants (Jarosz et al., 2003; Raynor et al., 1972) and the condition of the pollen grain has been used as a proxy for taphonomy (Cushing, 1967; Lowe, 1982; Tipping, 1987). In experimental investigations into the preservation of pollen grains, Twiddle and Bunting (2010) reported that

mechanical damage (i.e. crumpling and folding of grains) was more prevalent in grains of a larger size. The presence of multiple, undamaged *Z. mays* grains most likely represent a distinctive local signal within a regional record of change, and therefore provides an opportunity to examine both local and regional change within this record.

Maya land clearance for agriculture and construction

Evidence of agriculture at Lamanai. The exact date of origin of a Maya settlement at Lamanai is unknown but it has been suggested as being c. 1500 BC (Pendergast, 1981, 1982a, 1982b, 1986). Our pollen data show that *Z. mays* and *Cucurbita* were being cultivated near the NRL by 1630 BC, indicating that the Maya were established and practising agriculture at Lamanai before 1500 BC. Agriculture is also indicated by the presence of economically important plants in other records from Northern Belize c. 2000–1000 BC, including Laguna de Cocos, Albion Island (Hansen, 1990); Cobweb Swamp (Jones, 1994) and Cob Swamp (Pohl et al., 1996). At 1240 BC synchronous increases in charcoal, disturbance taxa, *Z. mays*, coincident with a decrease in forest and savanna cover provides strong evidence for Maya land clearance for field-based agriculture. Throughout the record there is a clear and consistent *Z. mays* signal, with multiple pristine grains observed, and only two periods where *Z. mays* is absent (830–640 BC and 220–100 BC). This concentration of *Z. mays* is not found in other records from the region. By comparison, Hansen (1990) and Jones (1994) identify the presence or absence of large grain cultigens, such as *Z. mays*, *Manihot* and *Cucurbita* in some parts of their records using one or two grains. The high level of *Z. mays* observed in the record from Lamanai indicates the extent and close proximity of maize fields to the coring site.

Periods of pine clearance for construction, 170 BC–AD 150, AD 600–980 and AD 1500. Abrams and Rue (1998) and McNeil et al. (2010) have suggested that the Maya selectively used *Pinus* for construction and fuel, with vast quantities needed to produce the limestone for stucco work. In this record *Pinus* has periods where it is much reduced (170 BC–AD 150) or completely absent (AD 600–980). Both these periods of a substantial or complete absence of *Pinus* are consistent with periods of construction and development of the site in the archaeological record and the pollen record is consistent with the heavy exploitation of *P. caribaea* for timber in nearby savannas. Construction began on the largest known temple (High Temple or Str. N10-43) c. 100 BC and there was significant early Classic building in various areas of the site during AD 100–400 (Pendergast, 1981). Between AD 500 and 600 masks were added to the terraced faces of the Mask Temple (Str. N9-56, Pendergast, 1981) and during AD 600–700 a number of buildings around the main plazas were added to and expanded, including the addition of stelae (Graham, 2004; Pendergast, 1981, 1988). During the Terminal Classic (AD 800–1000) the construction of masonry platforms continued and the only ball court at the site dates from this period (Pendergast 1982c, 1986). The charcoal record is also consistent with *P. caribaea* being used for fuel, with the primary, secondary and tertiary peaks of charcoal at AD 590, 1250 BC and 40 BC, respectively, coincident with very low or absent *Pinus*. The palaeolimnological evidence is in agreement with the palynological and archaeological records. A secondary peak in silica, iron, and aluminium and magnetic susceptibility c. 170 BC to AD 270 (Metcalfe et al., 2009) indicates increased erosion from the NRL catchment which could be associated with increased building at Lamanai.

This is the first record which demonstrates that *Pinus* could be used as a proxy for periods of construction because it is possible to distinguish the extraction of *Pinus* for timber in savannas, from

clearance for agriculture (and initially, timber) in the broadleaf forest. This distinction is possible due to the edaphic controls on the distribution of these vegetation types (Furley, 1994, 2007). At Copán, Honduras, McNeil et al. (2010) reported the most substantial deforestation of pine (*Pinus*) during the Preclassic period (c. 1800 BC–AD 250), during periods of experimental agriculture, and, that pine levels increased during the Classic period as a result of management by the Maya. At Lamanai, *Pinus* increases post-AD 1000 after the end of major construction at the site whereas broadleaf seasonal forest species do not (e.g. *Brosimum* type, *Maclura* type). Furthermore, at the top most part of the core c. AD 1500 the decrease in arboreal signal is dominated by a reduction in *Pinus*, which could indicate the continued use of pine as a source of fuel and in construction, as it was a familiar resource to the European settlers, and easily accessible in the pine savannas. The early Spanish Colonial period at Lamanai dates from c. AD 1544–1641, with the construction of two churches (YDL I and YDL II) during this period (Graham, 2011; Pendergast, 1975), which further supports the interpretation of the use of pine at Lamanai as a source of fuel and building materials.

Multifaceted Maya management of vegetation resources

Alongside these periods of increased pine extraction associated with construction, the pollen record suggests an active and multifaceted management of vegetation resources. There is some evidence of palm cultivation. Palms including *Acrocomia aculeata* and *Attalea cohune* form part of the forest cover at the modern site of Lamanai (Meerman and Sabido, 2001) and palms are present in the modern pollen assemblage at low levels (1%), however in the pollen record there are two periods where the palm pollen signal is much higher (4–20%). During 1630–1150 BC the palm signal is much increased (4–13%), and again, to an even higher level during 100 BC–AD 1100 (5–20%). These two periods of abundant palms are separated by a c. 700 year period (c. 930–200 BC) where the palm signal is similar to the modern assemblage. The later period (100 BC–AD 1100) is one of substantial construction at Lamanai (Pendergast, 1981) and such disturbance might be associated with an increase in the palm signal. A substantial increase in palms also occurs during a period without significant clearance, during the earliest known Maya settlement at Lamanai (1630–1100 BC). This suggests that these periods of increased palm pollen may be due to Maya cultivation, as well as clearance associated with settlement. Jones (1994) also recorded increases in the palm signal during periods of Maya occupation and attributed this to Maya cultivation.

The pollen record has a low arboreal signal at AD 590, with an absence of *Pinus*, reflecting heavy timber extraction from the savannas, and a reduction in pollen reflecting high forest, such as *Brosimum* type and *Maclura* type. This is associated with high herb taxa, a peak in charcoal concentrations and a strong *Z. mays* signal. This record indicates that this is a period of substantial agricultural activity at Lamanai, and is consistent with both the interpretation of a reduction in pine as a signal for increased construction, as well as the archaeological record described above. Post-AD 590 there is a slight increase in seasonal forest taxa, *Z. mays* is present between AD 970 and AD 1100, and palms peak c. AD 740. These changes could represent an increase in diversification by the Maya, with the management of forest resources alongside the cultivation of palms and field based agriculture, providing multiple resources, from a ‘managed mosaic’ (Fedick, 1996).

This pollen record of management of vegetation resources is consistent with the archaeological record of continued occupation throughout the Terminal Classic (AD 800–1000). Papers from the wider Yucatán region have observed a period or periods of drought associated with the ‘collapse’ of Maya politics during the Terminal

Classic (Curtis et al., 1996; Hodell et al., 1995, 2007; Neff et al., 2006). Metcalfe et al. (2009) report that there is some isotopic enrichment c. AD 970, which could be indicative of a drying event, however this could be reflecting a regional drying signal rather than an event local to Lamanai. The local pollen record of large immobile grains (*Z. mays*, palms) and archaeology demonstrate that a regional-scale drying event found in other records c. AD 900 (Hodell et al., 2007) does not impact upon the settlement at Lamanai.

Forest recovery post periods of disturbance, 1150–800 BC and post-AD 1400

Two periods of forest recovery after periods of disturbance are visible in this record. The first occurs after 1150 BC until c. 800 BC, with the highest arboreal levels found at c. 900 BC. This increase in arboreal taxa is accompanied by a decrease in herbs and a decrease in particulate charcoal. This possible period of forest recovery is also visible in the C/N ratios, as the peak at c. 1300 BC declines until c. 900 BC (Metcalfe et al., 2009). At AD 1400 the arboreal signal increases, with a great variety of taxa including *Z. guidonia*. There also could be a recovery of fringing marsh that may have encircled the NRL as it does today, with the highest levels of Cyperaceae found at AD 1400 alongside a complete absence of crops (including palms), and low charcoal concentrations together suggesting decreased Maya activity. This is consistent with the record of Metcalfe et al. (2009), which also suggested reduced anthropogenic activity at Lamanai in the topmost part of the core, indicated by low magnetic susceptibility and $\delta^{13}\text{C}$ values. The first and second samples from the top of the core have the lowest C/N ratios which would be consistent with aquatic material comprising the majority of the organic matter deposited in the sediment core. There are no diatoms found in the period c. AD 1100–1400, which could suggest increased evaporation and increased alkalinity. Pollen evidence of forest recovery post-AD 1000 appears in other records from Northern Belize. Hansen (1990) observes forest recovery at AD 1000, indicated by a fall in *Ambrosia* pollen and an associated increase in arboreal taxa, and links this to a switch to less intensive farming methods consistent with a fall in population post-Collapse period. Jones (1994) also reports an increase in forest cover post-AD 900, which is consistent with the abandonment of the nearby site of Colha at c. AD 850. Brenner et al. (1990) date forest regeneration in the Petén region c. AD 1600, although other studies have suggested that it occurred c. AD 1000 (Curtis et al., 1998; Islebe et al., 1996) and c. AD 1000–1200 (Mueller et al., 2010). Mueller et al. (2010) suggest that in the absence of human populations and associated farming the Petén forests recovered within a period of 80–260 years.

Conclusions

The pollen and charcoal record from the NRL, near Lamanai, reflects a continuous vegetation history for the period c. 1630 BC–AD 1500. Crops, including *Z. mays* found at Lamanai from c. 1630 BC indicates cultivation of maize throughout the occupational history of Lamanai (Pendergast, 1987[AQ], 2002), and crops are also found c. 1600 BC in other records from Northern Belize (Hansen, 1990; Jones, 1994; Pohl et al., 1996). The almost continuous and abundant local *Z. mays* signal from the NRL highlights the potential for a dual regional/local signal within the same record. This may improve our understanding of site-specific responses to both climatic change and human disturbance, within a regional context. Three distinct periods of construction are visible in this record, with *P. caribaea* extracted from the pine savannas for timber and fuel. These periods occur during the Preclassic, late Classic and the early Spanish Colonial period, and concur

with the archaeological record of continuous occupation and development throughout these periods at Lamanai. Disturbance in the Preclassic was indicated in the record of Metcalfe et al. (2009) and this new palaeoecological record confirms this period as a time of anthropogenic disturbance at Lamanai, rather than reflecting regional climatic change. Furthermore this new record, combined with the previous record of Metcalfe et al. (2009) demonstrates that Maya management of resources continued into the Late Classic. Palm cultivation during the Classic and late Classic periods perhaps formed part of a suite of managed vegetation resources which also included arboreal and field-based crops. There is no evidence that climatic drying associated with 'Maya Collapse' found in other records from the region (Curtis et al., 1996; Hodell et al., 1995), had any substantial impact in the palaeolimnological, palaeoecological and archaeological records from Lamanai. There is a limited record of European contact *c. AD 1500*, with a reduction in palms and *P. caribaea*, however the analysis of pollen and charcoal material from the last 1000 years will allow us to better understand the relative impacts of pre- and post-Columbian land use.

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