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A Research Paper for *Journal of Quaternary Science*

Continuous human presence without extensive ecological disturbance over the past 2500 years in an aseasonal Amazonian rainforest

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Abstract

The magnitude of the impact of pre-Columbian indigenous communities on forest cover in Amazonia is highly contentious, particularly for the wettest forests. To contribute to this debate, we studied the vegetation and fire history recorded at Quistococha which lies within the aseasonal forests of the northern Peruvian Amazon and is associated with independently dated pre-Columbian and recent human occupation. Paired cores taken from swamp and lake environments were used to distinguish landscape-scale changes in vegetation from local-scale successional patterns, and the record of human occupation associated with the expansion of the city of Iquitos allowed us to compare the paleoecological signature of extensive, recent disturbance with the previous impact of indigenous communities. A rise in the abundance of disturbance-adapted taxa in the pollen record from the lake, but not swamp, since c. AD 1850 likely reflects an increase in landscape-scale deforestation rates since the earliest days of Iquitos. However, previous persistent occupation of the site by pre-Columbian indigenous communities, indicated by the charcoal record from the lake site, is not associated with evidence for similarly extensive disturbance of the landscape. The unique features of this site therefore demonstrate that occupation by indigenous communities over thousands of years was not associated with large-scale deforestation. These results support an emerging model of persistent but localised impacts by pre-Columbian indigenous communities on aseasonal Amazonian forests.

Keywords: Holocene; charcoal; paleoecology; palynology; disturbance; peatland

Introduction

Convincing evidence from archaeology and paleoecology clearly indicates that forest cover in at least some parts of Amazonia was strongly affected by prehistoric societies, particularly where climate is strongly seasonal and along navigable rivers (Bush et al., 2015). These impacts include forest clearance and burning, and construction of earthworks and field systems, often on a landscape scale (e.g. Balée and Erickson, 2006; McMichael et al., 2012, 2015; Carson et al., 2014; Bush et al., 2015; Watling et al., 2017). Such extensive perturbation may have left a substantial imprint in present-day patterns of biodiversity (Levis et al., 2017) and forest composition and dynamics (McMichael et al., 2017). However, the magnitude of past impacts in comparison to modern deforestation remains unclear.

The growing evidence for manipulation of some Amazonian landscapes also raises the issue of their spatial variability (e.g. McMichael et al., 2011, 2012, 2015). In particular, aseasonal forests – those that occur where there is no strong dry season – were probably more difficult to clear by burning or felling than the less dense, periodically dry vegetation of seasonal forests. Aseasonal forests are therefore, in general, likely to have been less heavily affected than more seasonal forests, and this appears to match the broad spatial distribution of evidence for impacts of prehistoric societies. However, the palaeoecology of aseasonal forests has been relatively understudied compared with drier parts of the Amazon. A better understanding of spatial variation in the magnitude of past impacts is needed to assess the links with current patterns of forest dynamics and diversity, including whether the high biodiversity of aseasonal forests (ter Steege et al., 2003) is associated with high levels of pre-Columbian human impact.

Addressing this problem requires paired archaeological and paleoenvironmental studies where evidence for settlement and environmental change can be compared directly, and an understanding of how deforestation within the historic period is represented in these records (Mayle and Iriarte, 2014). Here we present a new palaeoenvironmental dataset from a lake, Quistococha, situated on the outskirts of the city of Iquitos in NE Peru (Fig. 1). We compare the new record from the lake to an existing adjacent record from a peat swamp forest adjacent to the lake (Roucoux et al., 2013) and to the timing of independent records of pre-Columbian settlements. Uniquely for an Amazonian site, our interpretations of the pollen and charcoal data from the new lake sediment sequence are constrained by (a) comparisons with a pollen record from the adjacent swamp, which helps us to separate local from regional pollen inputs, and (b) the signature of significant 19th–21st century forest clearance, which provides a benchmark against which to measure the evidence for human impact related to both horticulturalists and hunter-gatherer phases in earlier parts of the sequence.

Study site

The site of Quistococha, located on the outskirts of Iquitos, is one of the most well-studied sites in Peruvian Amazonia. Quistococha itself is a small, shallow lake ('-cocha'), c. 1 km^2 in area and up to c. 3 m deep, occupying an abandoned channel of the Amazon River, which has since migrated c. 10 km to the east (Räsänen et al., 1991; Roucoux et al., 2013). The lake is bounded to the south and east by a c. 5 km^2 palm swamp containing up to 4 m of peat (Lähteenoja et al., 2009a), to the north by a shallow levee, and to the west by the edge of a c. 15 m fluvial terrace incised into Miocene-Pliocene sands, thought to mark the western extremity of the Holocene floodplain of the Amazon.

The climate, as measured at Iquitos, is hot and wet all year round (Marengo, 1998). Annual precipitation is 3087 mm and relative humidity is typically 80-90%. There is only a weakly-defined dry season; monthly precipitation varies between c. 165 mm (in August) and 295 mm (in March and April). Mean monthly temperatures vary between 25 and 27°C.

A small artificial beach has been constructed on a narrow strip of land between the western shore of the lake and the terrace, and is used for recreation, with a small complex of cafes and other amenities. The remainder of the lake is bordered by palm swamp forest overlying peat. The present-day vegetation in one forest census plot in the peat swamp was described by Roucoux et al. (2013). Three species, *Mauritia flexuosa, Mauritiella armata* (Mart.) Burret (both Arecaceae) and *Tabebuia insignis* Sandwith (Bignoniaceae), together represent 82% of the individuals. The aquatic plants on the lake itself occupy small patches mostly within 10 m of the shore line. There are small (c. 5 x 5 m) floating mats of Cyperaceae and Poaceae near to the eastern shore line, and larger patches of floating Nymphaeaceae around the lake margin (aff. *Nymphaea amazonum*).

Several previous studies have investigated both the lake of Quistococha and the adjacent peatland. Räsänen et al. (1991) dated a core from the lake and estimated its age at c. 6000 cal a BP (calendar years before present, i.e. AD 1950). Aniceto et al. (2014a, b) examined the sedimentology of three cores from the lake, concluding that an apparent hiatus from 4600–2000 cal a BP implied a period of climatic drying. In the peat swamp forest adjacent to the lake, Lähteenoja et al. (2009a, b) studied the carbon density and inorganic geochemistry of several peat sequences, showing that the peats were up to 2320-2350 cal a BP at the base, and that the peatland is likely fed by a mixture of rainwater and groundwater. Roucoux et al. (2013) and Lawson et al. (2014) presented a detailed study of the palynology and geochemistry of a 6 m core from the peatland, QT-2010-1, which will be discussed further below. Kelly et al. (2014) measured the hydraulic conductivity of the peats in order to explore their past and present sensitivity to climatic change, and Teh et al. (2017) studied present-day methane and nitrous oxide fluxes in the peatland.

Archaeological investigations began near Quistococha in 2005 with the discovery by A. Ovuela-Caycedo and colleagues of cultural soils and artefacts on the terrace immediately above the western margin of the lake (Fig. 1d). Archaeological excavations extending to the very edge of the terrace have produced abundant fragments of pottery, charcoal, phytoliths of palms and grasses, and cobs of corn (*Zea mays*), dating to two periods, 1740–1880 and 2350–2690 cal a

BP (Rivas Panduro, 2006; Rivas Panduro et al., 2006). These finds make Quistococha a regionally important archaeological site, being one of the few in Western Amazonia to contain *terra preta* or *terra mulata* (black or dark brown) soils (Rivas Panduro, 2006). *Terra preta* and *terra mulata* soils, which are more widespread in Eastern Amazonia, are considered to be anthropogenic, amended by additions of manure, charcoal and refuse, and indicative of human occupation and horticulture (Glaser and Woods, 2004). Below the strata containing ceramics was a further, undated, c. 50 cm thick stratum with its base up to 2.45 m below the modern surface. This stratum consisted of black earth with charcoal, but without ceramics or stone tools; it was interpreted as the first archaeological evidence for hunter-gatherer populations discovered from a floodplain-edge terrace of the Peruvian Amazon (Rivas Panduro, 2006). A similar deposit, this time with stone tools, has subsequently been discovered in the Cachiyacu River basin, closer to the eastern slope of the Andes (S. Rivas Panduro, unpublished data).

Since the mid-19th century, the landscape surrounding Quistococha has been deforested to accommodate the growth of Iquitos, which grew to international prominence during the rubber boom of 1890–1920. Currently, Iquitos has approximately 600,000 inhabitants. However, expansion of Iquitos has always been limited by its location on a peninsula of land locked between three rivers, and it is not connected to the national road network. The only road that leaves Iquitos, passing close to Quistococha and continuing south to the river port of Nauta 100 km away, was only paved in the 2000s. There has never been extensive deforestation for commercial agriculture, as for example, in the southern Brazilian Amazon. As a result, present-day deforestation in the area around Quistococha is moderate, at <50% within 10 km of the lake, which is important for interpreting the signal of this disturbance in the palaeoecological record.

Materials and Methods

Core sampling

A 364 cm long core from the lake at Quistococha was collected using a Russian-type corer (Jowsey, 1966) operated from a floating platform. Core sections were wrapped in cling-film and placed into protective plastic gutters before being wrapped in a further layer of thick plastic sheeting. The top 30 cm of the lake sediments, which were poorly consolidated, were collected using a kajak-type gravity corer (Renberg, 1991) into polythene sample bags at 5 cm intervals. The sampling location (03.8297°S, 073.3200°W, 94 m above sea level) was recorded using a

Garmin handheld GPS. The core was transported to the UK and stored under license at 4°C at the University of Leeds until analysis.

Dating

Twelve samples 1–2 cm^3 in volume were chosen for radiocarbon dating. Only a single plant macrofossil (an unidentified leaf) was recovered from the core for radiocarbon dating in the gyttja above 148 cm. Bulk organic lake gyttja samples were therefore used to obtain dates in this part of the core. In the lower, mineral-rich sediments, a comparison of bulk samples and picked samples of (unidentified) plant macrofossils was made to establish whether there was an old carbon offset. Samples were pre-treated in 2M HCl for 4 h before being washed in deionised water, and their $\delta^{14}C$ and $\delta^{13}C$ content was determined through accelerator mass spectrometry (AMS) by the NERC Radiocarbon Facility in East Kilbride, UK. An age model for the lake core was produced using the BACON package (Blaauw and Christen, 2011) in R (R Core Team, 2015).

Pollen and charcoal analysis

Sample preparation followed standard methods (Faegri and Iverson, 1989), including acetolysis, and digestion in hydrofluoric acid where necessary. Samples were mounted in silicone oil. Pollen and charcoal analysis was undertaken using a Leica DMLS binocular microscope, routinely at 1000x. A minimum total of 300 total land pollen (TLP) was counted. The pollen sum excluded spores of the Pteridophyta and the pollen of the aquatic plant *Pistia stratiotes*. Unknown pollen types were included in the pollen sum. Microcharcoal fragments in the pollen slides between 5 and 180 μm in size were counted.

Pollen identifications were based on pollen reference slides, pollen atlases (Roubik and Moreno, 1991; Colinvaux et al., 1999), the Neotropical Pollen Database (Bush and Weng, 2006) and other literature (Absy, 1979; Walker and Walker, 1979; Weber et al., 1999; van Geel, 2001; Nowicke and Takahashi, 2002; Dias Saba, 2007; Burn and Mayle, 2008). *Mauritia* type pollen grains were measured to help separate *Mauritia* from *Mauritiella* (Kelly et al., 2017). Optimal splitting by sum of squares was applied to produce a pollen zonation scheme in Psimpoll (Bennett, 2007). Only pollen taxa that exceeded 5% in one or more samples were included; spores and aquatic taxa were excluded.

Sedimentological analysis

Sediment descriptions were made in the field following Troels-Smith (1955), and checked in the laboratory. Volumetric magnetic susceptibility (MS) was measured using a Bartington MS2 meter and MS2c loop sensor at 2 cm intervals prior to subsampling. No magnetic susceptibility measurements were made on the poorly-consolidated material in the top 30 cm of the sequence. Loss-on-ignition (LOI) was carried out on 1 cm^3 sub-samples at 4 cm intervals (or on subsamples of the 5 cm thick samples from the top 30 cm) at 550°C for four hours (Heiri et al., 2001). For carbon and nitrogen analyses, 1 cm^3 sub-samples were dried at 105˚C and milled to homogenize the sub-sample. Each sub-sample was then weighed into a tin cap prior to analysis with a Eurovector Turboflash CNS combustion analyser. Vanadium pentoxide was used as a catalyst. The peat standard NJV942 was used with all sample batches, and experimental values for carbon and nitrogen were within 95% of the certified value for all sample runs.

Results

In this section we describe the new radiocarbon dates (Table 1) and sedimentological (Fig. 2) and palynological data (Fig. 3) for core QT-2010-3, using the pollen zonation as a framework and with reference only to depths down-core; the construction of an age-depth model for the core is described in the next section. A complete pollen diagram showing all taxa recorded is presented as Fig. S1 (Supplementary Information). The interpretation of the data in terms of past environments is discussed later.

The pollen diagram is divided into five zones, A (at the base) to E (see Table 2 for detailed descriptions). The clearest division in the pollen dataset is between zone A and zones B–E; a large number of significant indicator taxa (Table 3) collectively make zone A very distinctive compared with the others. This fundamental division of the sequence is also very clear in the sedimentology, e.g. in the loss-on-ignition data. Pollen zones B–E are comparatively alike in terms of palynology and sedimentology, and the zonation reflects gradual changes (e.g. a more or less steady increase in *Mauritia* t. throughout zones B–D) as well as sharper boundaries (e.g. the increase in *Cecropia* sp. across the zone D–E boundary).

Pollen Zone A

From 364–156 cm, which equates to Pollen Zone A, the core consists of sandy and clayey silts, characterised by high magnetic susceptibility, low organic carbon concentrations, and low C/N ratios. Their pollen assemblages are dominated by *Cecropia* sp.; Cyperaceae and Poaceae are also important in this zone. Pollen concentrations are low and preservation is less good than in overlying zones, consistent with the pollen having been transported. Charcoal abundance is very low. The six radiocarbon dates from this part of the sequence have calibrated ranges between 5603 and 2748 cal a BP, and are not all in stratigraphic sequence.

Transition between Pollen Zones A and B–E

The boundary between pollen zones A and B is gradational rather than abrupt, spanning much of the interval between 180 and 148 cm, and many taxa or variables begin to change well below the formal zone boundary (at 156 cm). The sediments gradually transition upwards from sandy and clayey silts to lake gyttjas similar to those being deposited today, with much lower magnetic susceptibility and higher carbon concentrations and C/N ratios. Different proxies respond at different rates: in particular, the main increase in pollen and charcoal concentrations and C/N ratios occurs some 20 cm below the main increase in loss-on-ignition values. Within the pollen assemblages, the major compositional change occurs at the zone boundary, but percentages of e.g. *Cecropia* sp., Moraceae undiff., and *Brosimum* sp. begin to change c. 20 cm below the boundary and continue their trajectory for several centimetres above it.

Pollen Zones B–E

The six radiocarbon dates that fall within Zones B–E are in stratigraphic sequence and have calibrated ranges between 2299 and 560 cal a BP. In general, Pollen Zones B–E contrast with Zone A in having lower proportions of *Cecropia* sp. (except for Zone E), Cyperaceae and Poaceae, and increased proportions of a range of tree and shrub taxa including *Ilex* sp., Melastomataceae/Combretaceae, *Brosimum* sp., *Alchornea* sp., *Euterpe* t. and *Mauritia* t.

Pollen Zone B is characterized by a number of indicator taxa including types typically found in wetland forest settings, including *Symmeria paniculata*, *Ilex* sp., and Myrtaceae undiff.; ferns are also abundant, and *Mauritia* t. begins to expand. In Zone C ferns decline, and *Mauritia* t. becomes consistently abundant at around 15%, accompanied by an increase in *Euterpe* t. Zone D is marked mainly by another increase in *Mauritia* t. to around 25%, at the expense of *Euterpe* t. Zone E is chiefly characterized by a renewed increase of *Cecropia* sp. For more detail, see Table 2.

Charcoal concentrations in Zones B-D are typically high by comparison with the concentrations in the lower part of Zone A, but with substantial variations; they are lower again in Zone E. The sediment is gyttja throughout, with minor and gradual variations in composition, the most marked of which as a decline in C/N ratios from the middle of Zone C upwards, and an increase in loss-on-ignition in the upper half of Zone D.

Age model

In the clay-rich sediments below 148 cm, some of the radiocarbon dates are out of stratigraphic sequence (Table 1). The sample from 280–282 cm (SUERC-46369) returned a calibrated age of 5333–5603 cal a BP, significantly older than the basal sample (357–360 cm, 4833–4967 cal a BP, SUERC-37523). Sample SUERC-46369 was composed of small picked fragments and, despite best efforts to extract as much material as possible from the core section, the sample size available for ^{14}C determination was <300 μg C, meaning that it may be unreliable. Accordingly, we chose not to include it in our age model.

Three further dates were also rejected. Two samples of picked plant fragments from the clayey silts, SUERC-37524 and SUERC-37521, produced radiocarbon dates which were at least 1000 years younger than bulk dates obtained from the same levels. An offset between macrofossil and bulk dates was anticipated by Räsänen et al. (1991), who argued that bulk dates on Amazon floodplain sediments were likely to contain old carbon introduced by fluvial inwash. The confirmation of an old carbon offset in the mineral-rich sediments calls into question the chronologies recently developed for three cores from Quistococha by Aniceto et al. (2014a, b). They inferred a hiatus in deposition between 4900 and 2600 cal yr BP, but this coincides with the transition from clayey silts to gyttja at the top of their cores. In our view, the old carbon offset in the mineral-rich sediments is sufficient to account for this 'hiatus'. There is no sedimentological indication of a hiatus in QT-2010-3, which instead shows a gradual change from inorganic to organic sediments. The very low C/N ratio of organic matter in the clayey silts was interpreted by Aniceto et al. (2014a) as indicating that the organic matter had largely been reworked from soils, consistent with our interpretation of the dates. The age model for QT-2010-3 presented here consequently relies only on picked macrofossil samples in the lower part of the sequence, and the bulk samples SUERC-37522 and SUERC-37524 were rejected.

One other macrofossil date was rejected: the sample from 229–231 cm (2751–2842 cal a BP, SUERC-37523) returned an age almost identical to that from 196–198 cm (2748–2838 cal a BP, SUERC-37521). Given no strong indication of which of these two macrofossil dates was more reliable, the one most in keeping with the rest of the dates (SUERC-37521) was retained.

Although we took these decisions to exclude four dates on the basis of the arguments presented here, a run of BACON using all of the dates treated the same four dates as outliers, which provides an independent line of support for our age model based on a different set of priorities (i.e. a preference for avoiding large changes in sedimentation rate, rather than taking into account the composition and size of individual samples).

In total therefore, eight of the twelve radiocarbon dates were used to produce an age model for the lake core (Figure 2). The age model appears to be reliable in the gyttjas above 148 cm, but should be treated with more caution in the mineral-rich sediments below.

Palaeoenvironmental reconstruction

Here we interpret the new palaeoenvironmental dataset from the lake core QT-2010-3 in terms of palaeoenvironments, taking into account the published data from the peatland core QT-2010-1 (Fig. 4; Roucoux et al., 2013; Lawson et al., 2014).

Zone A (c. 4490–2180 cal a BP)

In QT-2010-3 the sedimentology of Zone A, dominated by sands and silts, is interpreted as representing a combination of lake sediments and the sediment-laden flood deposits of a channel of the Amazon. The pollen assemblages should be interpreted cautiously, as they likely represent a mixture of pollen blown in from around the lake, and fluvially-transported pollen deposited during floods. The domination of pollen assemblages by *Cecropia* sp. is typical of river-influenced sediments; *Cecropia* species are pioneer trees found in abundance on riverbanks and disturbed floodplains (Pennington et al., 2004). Sedges (Cyperaceae) and grasses (Poaceae), two other indicator taxa in this zone, are also typically abundant plants in disturbed riparian environments. Within this zone the evidence for a gradual change in conditions, with magnetic susceptibility generally declining and loss-on-ignition slowly increasing, probably reflects a gradual decline in the influence of the River Amazon on the site, i.e. a reduction in the frequency and volume of sediment-laden floodwaters reaching the western edge of the floodplain, as the main river channel migrated eastwards.

Zone B (c. 2180–1660 cal a BP)

Beginning around 24 cm below (~300 years before) the base of Zone B, a faster transition to much more organic sediments takes place. We interpret this transition as marking the effective isolation of the basin from regular flooding by sediment-laden waters from the Amazon. At the present day the peatland around the lake floods in exceptional years but there is very little mineral material in the peats (Lawson et al., 2014), indicating that the floodwater originates primarily from groundwater and/or rainfall on the floodplain. Unlike the previous studies of Aniceto et al. (2014a, b), we find no evidence to suggest that sediment accumulation in the lake was discontinuous. This is important because it implies that this Amazonian floodplain lake, at least, contains a reliable record of environmental change, and that its hydrological balance has not been as strongly affected by past climatic change as has previously been argued.

From this point on we interpret the QT-2010-3 pollen record as representing the vegetation growing in and around the lake, including on the terrace as well as in the peat swamp, which was beginning to accumulate peats around the same time (Lähteenoja et al., 2009a; Roucoux et al., 2013).

The sequence of vegetation communities reconstructed from the peatland record QT-2010-1 is echoed in the new QT-2010-3 pollen record, but as might be expected from a lake record with a wider source area integrating over a somewhat heterogenous environment, changes appear more gradual and the pollen zones less distinct than in the peat core. Small-grained pollen types such as *Cecropia* sp. and Moraceae are always much more abundant in the lake core, while insect-pollinated taxa such as *Symmeria paniculata* and *Ilex* sp. are less abundant. These discrepancies are consistent with the usual taphonomic bias of lake sites towards well-transported anemophilous pollen types; *Cecropia*-type pollen typically occurs at 15–20% in lake sequences, even where *Cecropia* is not locally dominant (Bush and Colinvaux, 1988; Bush and Rivera, 1998, 2001; Weng et al., 2002; Gosling et al., 2009).

The peat core pollen record indicates that at its location, the vegetation in the first century of peat accumulation was open with abundant Cyperaceae. The lake record suggests that this was the case widely across the basin; not only are Cyperaceae abundant at the start of Zone B, but the high abundance of Melastomataceae/Combretaceae (many members of which are shrubs) and several fern taxa such as *Nephrolepis* sp. and *Polypodium* t. is strongly indicative of open conditions. Myrtaceae, typically shrubs of deeply-flooded environments in these types of landscapes, are also relatively abundant in this zone. Whereas the record from the peatland indicates little presence of *Mauritia/Mauritiella* in the early period of peat accumulation, the lake record suggests that suitable habitat for these palms (and others such as *Euterpe*) was present somewhere in the pollen catchment from the outset.

Charcoal is continuously present and much more abundant in Zones B-D than in Zone A, indicating that the vegetation was subjected to burning. The substantial variations in the charcoal concentration throughout this period suggest variations in the fire regime over time. Charcoal was all but absent in pollen slides from core QT-2010-1 so, unless QT-2010-1 was an exceptional location within the peatland, the charcoal in QT-2010-3 is very likely to originate from outside the permanently-wet peatland, most likely on the drier terrace above the lake.

Zone C (1660–680 cal a BP)

In Zone C the pollen evidence indicates a further step-like expansion of the palms *Mauritia/Mauritiella*, accompanied by a sharp decline in the abundance of ferns, which indicate open environments, and taxa such as Myrtaceae that are indicative of deeply-flooded hardwood communities. This shift in assemblages probably reflects the gradual lessening of the depth and/or frequency of flooding, due to the infilling of the basin with peat and the continued migration of the Amazon away from the site, and the closing up of the palm swamp forest canopy.

Zone D (680–90 cal a BP)

Zone D is marked by a further small step-expansion of *Mauritia/Mauritiella* at the expense of tree diversity in general, and Melastomataceae/Combretaceae and *Euterpe* in particular. This decline in diversity was also found in the peatland pollen record, which was taken to indicate that the very low tree diversity recorded at the peatland core site today is of relatively recent origin (Roucoux et al., 2013). The new lake record suggests that this was a general pattern across the Quistococha basin. It remains unclear whether this decline in diversity is the result of environmental changes such as homogenization of the peat swamp environment due to infilling, or the outcome of centuries of inter-specific competition.

Zone E (90 to -60 cal a BP)

The key characteristic of this uppermost zone is a renewed expansion of the disturbance indicator *Cecropia* sp. This likely reflects recent human activities around the lake, presumably focused on the western shore and the terrace above where much of the land has been cleared of forest (Fig. 1c). Perhaps counter-intuitively, charcoal concentrations are lower in Zone E than is typical in Zones B and C (Zone D being transitional), which suggests that the rate of burning (in terms of biomass per year) were higher in the more distant past than in recent decades.

Discussion

A key feature of our record is the high abundance of microcharcoal from c 2450 cal a BP until approximately 200 years ago. In general, charcoal is considered a key indicator of human presence (Bush et al., 2015), and this inference appears to be valid in this region. Although rich in pottery, few archaeological sites in Western Amazonia contain stone tools (Lathrap, 1970; Rivas Panduro et al., 2008) and without stone tools it would have been very difficult for people to substantially alter or clear forests without the use of fire (Bush et al., 2015). In addition, the majority of soil cores taken in interfluvial areas in Western Amazonia by McMichael et al. (2012) did not contain any charcoal, which indicates that natural fires are extremely rare and small-scale; Mayle and Power (2008) separately estimated the natural fire return interval in Western Amazonia at 900 years. We therefore interpret the microcharcoal record as indicative of the presence of people at the site.

The first increase in microcharcoal in the new lake record at c. 2450 cal a BP coincides with the change from minerogenic sediment to organic sediment in the sequence. It possibly indicates a taphonomic change rather than the arrival of people at Quistococha. However, this date coincides with the earliest known ceramics on the adjacent terrace, dated to 2350–2690 cal a BP (Rivas Panduro, 2006; Rivas Panduro et al., 2006). Charcoal is thereafter present in quantity in every sample in the lake record and it seems likely that, despite an apparent gap in the direct archaeological evidence, people were present in the area near Quistococha persistently up to the present day.

There is no clear indication in the Quistococha lake sequence (beyond its charcoal record) for a substantial impact by people on the surrounding *terra firme* forest until modern times. The main structural changes in the pollen assemblages are explainable in terms of changes in the peat swamp forest, which Roucoux et al. (2013) accounted for by a combination of a changing degree of influence from the River Amazon as it migrated away from Quistococha, and autogenic succession. *Mauritia* t. appears to have become generally more abundant over the last 2000 years in many parts of Amazonia, and this expansion has been linked to the use of fire, suggesting that humans may have been involved (Rull and Montoya, 2014). However, Roucoux et al. (2013) did not find it necessary to invoke human activities to explain the vegetation changes reconstructed from their peatland record, and they found little evidence to suggest burning.

Given the strong and varying representation of peatland taxa in the lake sediment pollen record, a very detailed reconstruction of the history of *terra firme* forest would not be justifiable, but some important inferences can nevertheless be made. The strongest palynological indicator of human impact in the new lake sediment record is the record of the key disturbance indicator *Cecropia* sp. It expands several times in Zones C and D, but never to the levels reached since the 19th century (Zone E), which still represent less than total deforestation: even today, most of the land around Quistococha remains covered in forest (Fig. 1). Pollen of the Moraceae family, typical of *terra firme* rainforest (Gosling et al., 2005), remains abundant throughout the last c. 2200 years. The pollen data are therefore consistent with, at most, small-scale clearances, and not landscape-scale deforestation.

This interpretation is consistent with the results of a previous study of soil cores from the region around Iquitos (McMichael et al., 2012, 2015), which found no evidence for deforestation (in three soil cores sampled for phytoliths) and much less evidence for past burning than in other parts of Amazonia (charcoal was present in nine out of 40 soil cores, a much lower proportion than in most other parts of Amazonia studied by McMichael et al. [2012, 2015]). By contrast, in many drier parts of Amazonia there is evidence for very extensive clearance of forest in pre-Columbian times. Networks of fields and geoglyphs from e.g. the Beni basin/Llanos de Mojos, Bolivia (Erickson and Balée, 2006), eastern Acre (Mann, 2008), or the upper River Xingu (Heckenberger et al., 2003), may imply largely unforested landscapes. A benchmark for the palaeoecological expression of this type of landscape is provided by Carson et al. (2014), who studied two lake sediment sequences (Lagunas Granja and Orícore, Fig. 1) close to a complex of geometric earthworks in the seasonally-dry Beni region of NE Bolivia. Their pollen data indicate that the vegetation was substantially more open than it is today, both before and during the period of earthwork construction, with >50% Poaceae (grass) pollen and <30% tree pollen in their sequences. Forest cover has expanded only in the last few centuries, possibly due to a combination of land abandonment and climatic change. However, such extensive maintenance of open environments was not ubiquitous, even in seasonally-dry regions: for example, in the Upper Beni, two lake records have been produced which indicate little reduction of the forest cover by pre-Columbian people (Lakes Chalalán and Santa Rosa: Urrego et al., 2013).

Another point of comparison is provided by palaeoecological research on lakes and soils in aseasonal, densely forested regions of Ecuador and SE Peru. Here Bush et al. (2007) and McMichael et al. (2011, 2012, 2015), in studies of five lakes (Ayauchi, Gentry, Parker, Vargas, Werth) and numerous soil sequences in interfluvial settings which were not associated with archaeological sites, showed that past human impact (crop pollen and charcoal) was patchy, with three out of five lakes producing temporally discontinuous charcoal records, and two lakes and many soil cores producing no charcoal at all; nowhere did they find indications of landscape-scale forest clearance (Bush et al., 2007a; McMichael et al., 2011, 2012, 2015). Continuity of forest cover over the past c. 5000 years was also inferred at Lake Kumpaka in the Andean foothills of eastern Ecuador (Liu and Colinvaux, 1988) and, in the lowlands, at Maxus 5, despite a continuous charcoal record (Athens and Ward, 1999).

Our dataset thus fits into an emerging pattern, whereby pre-Columbian landscapes in the wetter climatic regions of Amazonia were typically less likely to be deforested than those in seasonally dry climatic regions. Importantly, our dataset makes it clear that, even where there is direct archaeological evidence for human settlement adjacent to the palaeoecological record, forest cover could remain largely intact.

It is highly likely that people used forest and wetland resources in ways that are palynologically and archaeologically invisible, but there is no direct evidence in the new dataset, nor from the peatland pollen records from Quistococha (Roucoux et al., 2013) and San Jorge (Kelly et al., 2017), of human activities in the peatlands themselves. Phytoliths of palms which may have originated in the swamp were recovered from the archaeological site, although remains of the dominant palm *Mauritia flexuosa* were not observed (Rivas Panduro, 2006).

Our dating evidence indicates that hunter-gatherer communities were already living close to Quistococha before the lake became fully isolated from the Amazon. This is consistent with the so-called ‘bluff model’ of pre-Columbian settlement (Denevan, 1996), whereby settlements in the interior of the Amazon basin tend to occur on high, rarely-flooded terraces adjacent to navigable rivers. The later horticultural, ceramic-using occupations attested in the Quistococha archaeological record were likely living in a different landscape context, with less direct access to the main-stem Amazon, but still able to rely on the lake and wetland for important resources such as fish and maize cultivation on the open, seasonally flooded floodplain of the river. Our palaeoenvironmental reconstruction confirms that in this region of Amazonian Peru, pre-Columbian settlement was not restricted to the immediate shores of navigable rivers, but could extend at least to the edge of the active floodplain. Today Quistococha is separated from the main channel of the Amazon by 10 km of forested floodplain.

Conclusions

The palaeoenvironmental record from Quistococha and its associated archaeological dataset together provide an important piece of information that helps us to judge the extent of past human impact in this aseasonal region of Amazonia. The new pollen record from the lake provides evidence for prehistoric human activity in the form of a charcoal record which indicates continuous human activity since before the lake was isolated from Amazon floodwaters. This indicates that gaps in the archaeological record from the site adjacent to the lake do not imply an absence of human populations from the wider area. Occupation apparently persisted throughout the last c. 2500 years, even after the Amazon abandoned the Quistococha basin and the site became set back from the main navigable waterway. Crucially, throughout this period the relative abundance of the key forest disturbance indicator *Cecropia* remained low, before increasing sharply towards the very top of the sequence over the last 100 years. This indicates that pre-Colombian societies did not, even partially, deforest this landscape and that the present, moderate extent of forest disturbance around Quistococha is without precedent in the last 2500 years.

Small floodplain lakes occur frequently in the region south and west of Iquitos, and those that occur far from the present channel may well hold sediment records as old, continuous, and well-resolved as that at Quistococha. They provide an excellent opportunity for further investigation of the spatial variation in past human interaction with forests in Peruvian Amazonia, especially if integrated into regional archaeological research programmes.

Supplementary Information

Additional supporting information can be found in the online version of this article:

Figure S1 Full pollen percentage diagram for core QT-2010-3.

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Figure captions

Figure 1: Location of sites discussed in the text. (a) Location of the main study area. Published records referred to in the Discussion: 1, Ayauchi; 2, L. Kumpaka; 3, Lakes Werth, Gentry, Parker and Vargas; 4, Lakes Chalalán and Santa Rosa; 5, Lagunas Granja and Orícore. (b) Map indicating the context of Quistococha on the Amazon floodplain. The paleoecological site of San Jorge (open circle; Kelly et al., 2017) and the town of Tamshiyacu and city of Iquitos (filled circles) are shown for reference. Darker shading indicates land over 120 m above sea level, inferred from Shuttle Radar Topography Mission (SRTM) data (http://srtm.csi.cgiar.org). (c) False-colour Landsat TM image of the study site, covering the same area as panel d. Colours follow Draper et al. (2014): red and dark green indicate forest; black, open water; white and light blue, bare or open ground. (d) Key features of the area shown in panel c, including the location of cores QT-2010-1 and QT-2010-3.

Figure 2: Bayesian age-depth model for core QT-2010-3. The shaded area indicates the 95% probability interval of the model, given the assumptions underlying it (i.e. the prior information specified). The red line indicates the best-fit (most probable) age-depth relationship. For the key to lithological symbols see Figure 3.

Figure 3: Selected palynological and sedimentological data for core QT-2010-3. For the full pollen dataset, see Figure S1 (Supplementary Information). The dashed vertical line in the plot of *Mauritia* t. grain diameter indicates the approximate division between samples that are richer in *Mauritiella* (typically <40 μm) and samples that are richer in *Mauritia* (typically >40 μm). Measurements are indicated with a dot where only one measurement was possible, and with a horizontal bar indicating the 95% confidence interval of the mean where more than one measurement was made. Abbreviations: *Dal./Mach.*, *Dalbergia/Machaerium*; Mela.Comb., Melastomataceae/Combretaceae; part., particles; t., type..

Figure 4: Selected pollen taxa from cores QT-2010-3 (lake: this study) and QT-2010-1 (peat: Roucoux et al., 2013) plotted against age.

Table 1: Results of radiocarbon dating analyses undertaken on samples from the lake core at Quistococha (QT-2010-3). Analytical uncertainty is shown to 1 standard deviation (s.d.). Samples were analysed at the NERC facility at East Kilbride. (Note that sample marked ‡ contained <300 μgC). * denotes sample rejected from age model.

Laboratory code	Depth (cm)	Material	^{14}C age (a BP)	s.d.	δ^{13}C	Calibrated age (cal a BP)
SUERC-44979	40–41	Bulk gyttja	703	37	-25.9	560–710
SUERC-44980	60–61	Bulk gyttja	927	35	-26.2	765–927
SUERC-44981	88–89	Plant macrofossil	1357	37	-31.6	1182–1357
SUERC-38477	95–96	Bulk gyttja	1710	37	-29.0	1540–1705
SUERC-37520	127–128	Bulk gyttja	1942	37	-32.3	1830–1930
SUERC-44982	152–153	Bulk gyttja	2117	37	-31.3	1992–2299
SUERC-37521	196–198	Picked plant fragments	2669	37	-21.8	2748–2838
SUERC-37522*	196–198	Bulk	3728	35	-22.9	3914–4070
SUERC-37523*	229–231	Picked plant fragments	2678	37	-16.3	2751–2842
SUERC-37524*	229–231	Bulk	3667	35	-21.2	3926–4082
SUERC-46369*	280–282	Picked plant fragments ‡	4792	78	-37.1	5333–5603
SUERC-44986	357–360	Picked plant fragments	4311	36	-28.2	4833–4967

Table 2: Pollen assemblage zone descriptions for core QT-2010-3.

Zone (depths, age)	Pollen assemblage zone characteristics
E (1–10 cm, 90 to -60 cal a BP)	*Cecropia* sp. increases towards the top of this zone where it reaches 40%. *Mauritia* t. remains abundant (max. 22%); *Alchornea* sp. (max. 10%) and Moraceae (max. 17%) remain moderately abundant; *Euterpe* t. becomes rare (max. 2.5%). All fern spore types are rare, with many <1% in most samples.
D (10–44 cm, 680–90 cal a BP)	*Mauritia* t. increases to >20% for the first time and peaks at the top of this zone (38%). *Euterpe* t. declines to 3% at the top of this zone, and Cyperaceae and Poaceae decline further, dropping to <1% at the top of this zone. *Alchornea* sp. (max. 13%) and *Cecropia* sp. (max. 25%) remain abundant, and *Brosimum* sp. continues to be moderately abundant (max. 7%). Amongst the minor types, *Amanoa* sp. peaks towards the top of this zone (2%).
C (44–108 cm, 1660–680 cal a BP)	Moraceae, *Alchornea* sp. and *Cecropia* sp. remain abundant. *Mauritia* t. is moderately abundant in this zone (max. 16%), as is *Euterpe* t. which peaks at 72 cm (12%). Cyperaceae declines to <5%. Amongst the minor types, *Ilex* sp. declines from its values in the zone below, and is mostly <1% in this zone. Asteraceae declines to <1%. *Tapirira* t. peaks towards the top of this zone (max. 2.6%). *Trema* t. is most abundant in this zone (max. 3.5%).
B (108–156 cm, 2180–1660 cal a BP)	*Cecropia* sp. declines to <20%. Moraceae peaks in this zone at 128 cm (28%). Cyperaceae remains moderately abundant (max. 11.5%), and Poaceae declines to <5%. *Brosimum* sp. increases to >5% for the first time, and *Alchornea* sp. increases towards the top of this zone (max. 10%). *Mauritia* t. and *Euterpe* t. both increase to >5% for the first time. Amongst the minor types, *Ilex* sp., Asteraceae and Myrtaceae are consistently present. Several fern spore types are moderately abundant; *Nephrolepis* sp. (max. 10%), *Polypodium* t. (max. 6%), and Monolete spores (max. 14%) all peak in this zone.
A (156–330 cm, 4490–2180 cal a BP)	*Cecropia* sp. is dominant (max. 67%), with Moraceae, Poaceae, Cyperaceae and *Alchornea* sp. also abundant. Amongst the minor types, *Piper* sp., Mel./Comb., Asteraceae, and *Iriartea deltoidea* are all consistently present. Fern spore types never exceed 10%.

Table 3: Statistically significant indicator species ($p < 0.05$) identified for each pollen assemblage zone in core QT-2010-3.

Taxon	Zone	Indicator value	Probability
Pouzolzia	E	0.4578	0.012
Pourouma	E	0.4631	0.011
Euterpe t.	C	0.3691	0.047
Symmeria	B	0.4563	0.026
Moraceae	B	0.2879	0.020
Ilex	B	0.4480	0.011
Myrtaceae	B	0.4153	0.004
Melastomataceae/Comb.	B	0.3580	0.002
Asteraceae	A	0.3527	0.028
Cyperaceae	A	0.4234	0.013
Piper	A	0.5249	0.009
Cecropia	A	0.3450	0.003
Poaceae	A	0.6166	0.001

Supplementary information

Figure S1: Full pollen percentage diagram for core QT-2010-3.