Quaternary Science Reviews 73 (2013) 196–200

Contents lists available at SciVerse ScienceDirect

Quaternary Science Reviews

journal homepage: www.elsevier.com/locate/quascirev

Short communication

Pre-Hispanic agricultural decline prior to the Spanish Conquest in southern Central America

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ARTICLE INFO

Article history:
Received 8 October 2012
Received in revised form
20 May 2013
Accepted 21 May 2013
Available online 19 June 2013

Keywords:
Costa Rica
Lake sediments
Prehistoric agriculture
Stable carbon isotopes
Agricultural decline
Drought
Pre-Columbian

ABSTRACT

Archeological and paleoenvironmental records from southern Central America attribute population collapse to the Spanish Conquest about 500 years ago. Paleoclimate records from the circum-Caribbean have shown evidence of severe, regional droughts that contributed to the collapse of the Mayan Civilization, but there are few records of these droughts in southern Central America and no records of their effects on prehistoric populations in the region. Here we present a high-resolution lake sediment record of prehistoric agricultural activities using bulk sediment stable carbon isotopes from Laguna Zoncho, Costa Rica. We find isotopic evidence that agriculture was nearly absent from the watershed approximately 220 years prior to the Spanish arrival in Costa Rica and identify two distinct periods of agricultural decline, 1150–970 and 860–640 cal yr BP, which correspond to severe droughts in central Mexico. We attribute decreases in agriculture to a weakened Central American monsoon, which would have shortened the growing season at Laguna Zoncho, reduced crop yields, and negatively affected prehistoric populations.

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1. Introduction

Indigenous populations in southern Central America have practiced widespread maize agriculture for at least the past 3000–4000 years (Behling, 2000; Horn, 2006). Lake sediment records from the region have helped researchers reconstruct a timeline of agricultural activities, providing an important complement to archeological evidence. Maize pollen grains found in lake sediments are the most commonly used indicator of agriculture, but may not provide evidence sufficient to estimate the scale of agriculture (Lane et al., 2009a). Recently, stable carbon isotope analyses of lake sediments have enabled semi-quantitative estimates of agricultural activities (Lane et al., 2004, 2009a). These isotope records are particularly valuable because they offer the potential to examine the connection between climate change and agriculture. Paleoclimatological research has revealed that climate change, specifically drought, played a major role in the collapse of the Maya civilization (Haug et al., 2003; Hodell et al., 2005; Stahle et al., 2011). In southern Central America as throughout the circum-Caribbean, population collapse has been associated with the Spanish Conquest (Clement and Horn, 2001; Anchukaitis and Horn, 2005). Here, we present a high-resolution record of agricultural activities in southern Central America that reveals effects of climate change on the prehistoric inhabitants of the region and contains evidence of significant population decline prior to the arrival of the Spanish.

2. Study area

2.1. Physical and climatic setting

Laguna Zoncho is located in southern Costa Rica (8.813°N, 82.963°W, 1190 m elevation), on the Pacific side of the continental divide (Fig. 1). The 0.75 ha lake sits in a small (7 ha) watershed that likely formed as the result of a mass wasting event. Undisturbed areas near Laguna Zoncho support tropical premontane rainforest (Hartshorn, 1983), but most forest in the area has been cleared. The modern regional climate is characterized by a mean annual temperature of ~20 °C and annual rainfall of ~3300 mm, with the Central American Monsoon strongly controlling the timing of regional precipitation (Sup. Fig. 1). Northward migration of the

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http://dx.doi.org/10.1016/j.quascirev.2013.05.022

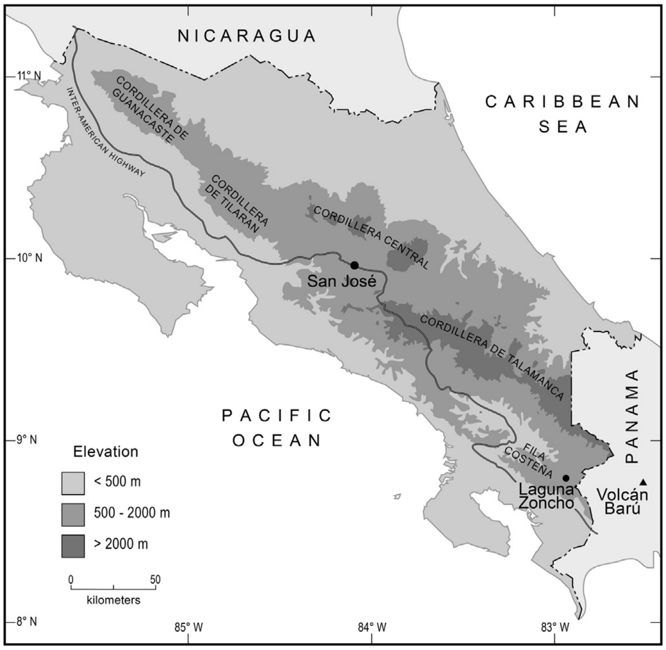

Fig. 1. Location of Laguna Zoncho and Volcán Barú in southern Costa Rica and westernmost Panama (after Clement and Horn, 2001).

Intertropical Convergence Zone (ITCZ) over Costa Rica creates a minor peak in precipitation in May, and a July dry period as the ITCZ moves over northern Central America. From August through October, the monsoon is sufficiently strong and far enough north to create a westerly flow over southern Costa Rica that brings moisture from the eastern Pacific (Hastenrath, 2002).

2.2. Cultural setting

Laguna Zoncho lies within the Diquís subregion of the Greater or Gran Chiriquí archeological area, which includes southern Pacific Costa Rica and western Panama. Archeologists recognize two distinct cultural periods in the past 2000 years, the Aguas Buenas or Bugaba (1650–1050 BP) and the Chiriquí (1050–450 BP) (Palumbo, 2009). Maize was grown during both periods, but the Chiriquí was characterized by a complex hierarchical society whose development may be linked with increased reliance on maize agriculture (Anchukaitis and Horn, 2005). The area was conquered by the Spanish in AD 1562 (388 BP), who recorded the presence of large-scale agriculture, extensive fortifications, and frequent conflicts among territorial chieftains (Fernández Guardia, 1913).

Prior analysis of a sediment core from the center of Laguna Zoncho revealed maize pollen to be present nearly continuously from lake formation ca 3000 cal yr BP (Clement and Horn, 2001). Pollen data also showed that forest species were partially replaced by grasses (Poaceae) and other weedy, disturbance-adapted herbaceous taxa (Amaranthaceae and Asteraceae) during times of heightened agricultural activity (Fig. 2A). Archeological surveys in the Zoncho watershed have documented extensive evidence of human occupation. Cemeteries on nearby hilltops contain artefacts consistent with the Aguas Buenas and Chiriquí periods (Laurencich de Minelli and Minelli, 1966), and large numbers of ceramic and lithic artefacts have been found immediately adjacent to the lake (Soto and Gómez, 2002). Charcoal associated with ceramics in three excavations by Soto and Gómez (2002) yielded radiocarbon dates that fall within the Aguas Buenas period. Their archeological survey also identified a large structure made of boulders that dates to approximately 650 cal yr BP.

3. Materials and methods

3.1. Field methods

We recovered sediments from six core sites in June 2007 using an anchored floating platform. Core site 6 was located at the center of the lake and core sites 1–5 were placed approximately equidistant between the shore and the center of the lake in a radial pattern (Taylor et al., 2013). At each site, we used successive 1 m drives to recover offset parallel cores to recover a complete sedimentary profile. Based on the work of Clement and Horn (2001), we recovered sediments from approximately 30–230 cm below the sediment–water interface to ensure the recovery of sediments from 2000 to 500 cal yr BP, which spans the latter part of the major archaeological period and the period of forest recovery.

3.2. Lab methods

Core sections were sliced longitudinally and sampled at a resolution of 1 cm. Each sample was freeze-dried and homogenized prior to decalcification using 1 N hydrochloric acid. After a second freeze-drying, samples were analyzed using a CosTech Elemental Analyzer coupled to a Thermo-Finnigan XL + Mass Spectrometer. The percentage of organic carbon (%OC) was determined using the elemental analyzer standardized with acetanilide. Reproducibility of standards and samples was $SD < 0.81$ and $SD < 1.16$, respectively. $\delta^{13}C_{TOC}$ values were calibrated using several internal laboratory standards selected to bracket experimental values. $\delta^{13}C_{TOC}$ data were standardized to V-PDB using internal standards ($SD < 0.13$, $n = 237$). A total of 1547 samples were analyzed with duplicate analyses performed on approximately 10% of samples. Mean variation on replicate analyses of samples was 0.47‰ for $\delta^{13}C_{TOC}$. We used a two-end-member mixing model to calculate the contribution of C4 carbon to the sediments of five cores as an estimate of the amount of agriculture in the watershed (Phillips and Gregg, 2001) (formulas and endmembers are described in the Supplementary Information). The entirety of core 5 showed evidence of oxidation and was excluded from the analysis.

3.3. Chronology and calculation of basinwide inputs

We obtained a total of 13 AMS radiocarbon dates (Supplementary Table 1), which, along with the Barú tephra (from Volcán Barú, Panama, see Fig. 1) provided chronological control (Behling, 2000). Dates were calibrated using CALIB 5.01 (Stuiver and Reimer, 1993) and the dataset of Reimer et al. (2004). We calculated the weighted means of the probability distributions of the calibrated ages to yield a single age estimate for each date (Telford et al., 2004). We excluded three out-of-sequence dates UG-04551, UG-04554, and UG-04555. Based on equivalent calibration of an AMS date from Laguna Volcán (Behling, 2000), we fixed the date of the Barú tephra at 537 cal yr BP. These data were used to create linear age models for each core to allow inter-core comparisons.

We determined basinwide inputs by calculating mean $\delta^{13}C_{TOC}$ and %OC values for 50-year increments in cores 1–4. Basinwide inputs are the means of incremented values for cores 1–4.

4. Results

Geochemical data show strong agricultural impacts beginning at 1750 cal yr BP, which corresponds with previously published pollen data (Clement and Horn, 2001) (Sup. Fig. 2). Tree pollen was reduced by 50% compared to the post agricultural period, replaced by grasses and other weedy taxa (Clement and Horn, 2001). Geochemically, the period was characterized by low %OC (mean

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