Environmental Change and Prehistoric Agriculture in the Mirador Basin

Research Year: 2002
Culture: Maya
Chronology: Pre-Classic to Post Classic
Location: North Central Petén, Guatemala
Site: Lago Puerto Arturo, Mirador Basin

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Abstract

Pollen, loss on ignition, magnetic susceptibility, and oxygen isotope analyses provide a high-resolution paleoenvironmental record from Lago Puerto Arturo, Petén, Guatemala. Chronologic control is based on eight AMS radiocarbon determinations. A long history of human activity in the Mirador Basin is indicated by 3600 years of watershed disturbance, from ~2700 B.C. to ~A.D. 900. This period coincides with a relatively dry climate in the southern Maya lowlands. Pollen shows an abrupt increase in anthropogenic disturbance in the Early Preclassic (~1450 B.C.), coincident with archaeological evidence of early settlement. The record indicates at least four phases of agricultural disturbance, with intervening periods of ecological recovery, during the following 2500 years. The last agricultural phase ended ~A.D. 900, coincident with the Late Classic abandonment of the southern Maya lowlands. There is no evidence for human activity in the region during the following 1000 years.

Resumen

Los análisis del polen, la pérdida por ignición, la susceptibilidad magnética, e isótopo de oxígeno proporcionan un registro paleo-medioambiental de alta resolución del lago Puerto Arturo, Petén, Guatemala. El control cronológico se basa en ocho determinaciones de radiocarbono AMS. Una historia larga de actividad humana en la Cuenca El Mirador se indica por 3600 años de disturbio en la cuenca, del ~2700 a.C. a ~900 d.C. Este período coincide con un clima relativamente seco en las Tierras Bajas Mayas. El polen muestra un aumento precipitado en disturbio antropogénico en el Preclásico Temprano (~1450 a.C.), coincidiendo con la evidencia arqueológica del establecimiento temprano. El registro indica por lo menos cuatro fases de disturbio agrícola, con períodos de intervención de recuperación ecológico durante los 2500 años siguientes. La última fase agrícola terminó ~900 d.C., coincidiendo con el abandono del Clásico Tardío de las Tierras Bajas Mayas. No hay evidencia de actividad humana en la región durante los 1000 años siguientes.

Submitted 08/19/2005 by:
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Introduction

During the past 40 years, several paleoecological and geochemical studies have been carried out in the Maya Lowlands. They show that climate in this important archaeological area has changed on a variety of time scales during the late Pleistocene and Holocene (Binford, *et al*. 1987; Curtis, *et al*. 1998; Hodell, *et al*. 2001; Hodell, *et al*. 1995; Leyden, *et al*. 1993, 1994; Leyden, *et al*. 1996). Some records also indicate that human impacts associated with agricultural activity and urbanization have caused significant forest clearance and soil erosion (Beach, *et al*. 2003; Binford, *et al*. 1987; Deevey, *et al*. 1979; Hansen, *et al*. 2002; Vaughan, *et al*. 1985). However, it is not always possible to distinguish between natural and of human induced environmental change (Curtis, *et al*. 1998; Islebe, *et al*. 1996; Leyden 1987; Vaughan, *et al*. 1985). This uncertainty has led to difficulty assessing the role of environmental change in the Late Classic Maya decline.

Most of the paleoenvironmental research in the Maya Lowlands has been conducted in the more accessible lakes of the southern Petén (Binford, *et al*. 1987; Dunning, *et al*. 1998; Islebe, *et al*. 1996; Wiseman 1974), Belizean swamplands (B.C.S. Hansen 1990; Jacob 1995; Jacob and Hallmark 1996; Jones 1991), and the few lakes in the northern part of the Yucatán Peninsula (Curtis, *et al*. 1996; Leyden, *et al*. 1998; Leyden, *et al*. 1996; Whitmore, *et al*. 1996). A problem with many of these sites is that the Late Classic population decline was not as abrupt as it was elsewhere on the peninsula and, at some sites, population actually increased in the Postclassic (Jones 1998; Rice 1986; Willey 1986). This has complicated the interpretation of some insecurely dated sediment sequences (Tsukada 1966; Vaughan, *et al*. 1985). This project has avoided these complications because it was carried out in the Mirador Basin, which was abandoned in the Late Classic and is still virtually unpopulated.

Background

The Mirador Basin, located in the north central portion of the Petén, Guatemala and southern Campeche, México, is one of the more remote areas of the Maya Lowlands (Figure 1). The area today is comprised of extensive seasonal swamplands (bajos) interspersed with relatively well-drained ridges and slopes. Its intense dry season, lack of perennial water sources, and extensive swamps form a formidable barrier to settlement. Yet the area was densely populated in the Middle and Late Preclassic periods (1000 B.C.–A.D. 150) and modestly occupied during the Late Classic (A.D. 600-900). Archaeological and ecological investigations, primarily conducted by the Mirador Basin Project have revealed a long history of human settlement (Dahlin 1984; R.D. Hansen 1990, 1991, 1992, 1998; Howell and Copeland 1989; Matheny 1987). The earliest evidence of permanent structures dates to approximately 1000 B.C. By 400 B.C., there were nearly a dozen urban centers in the area, including the large centers of Nakbé and El Mirador. Evidence of such large populations has led researchers to examine the environmental setting during the rise of large centers as well as the possible role of environmental change in their demise, which occurred on at least two occasions (ca. A.D. 150 and A.D. 900).

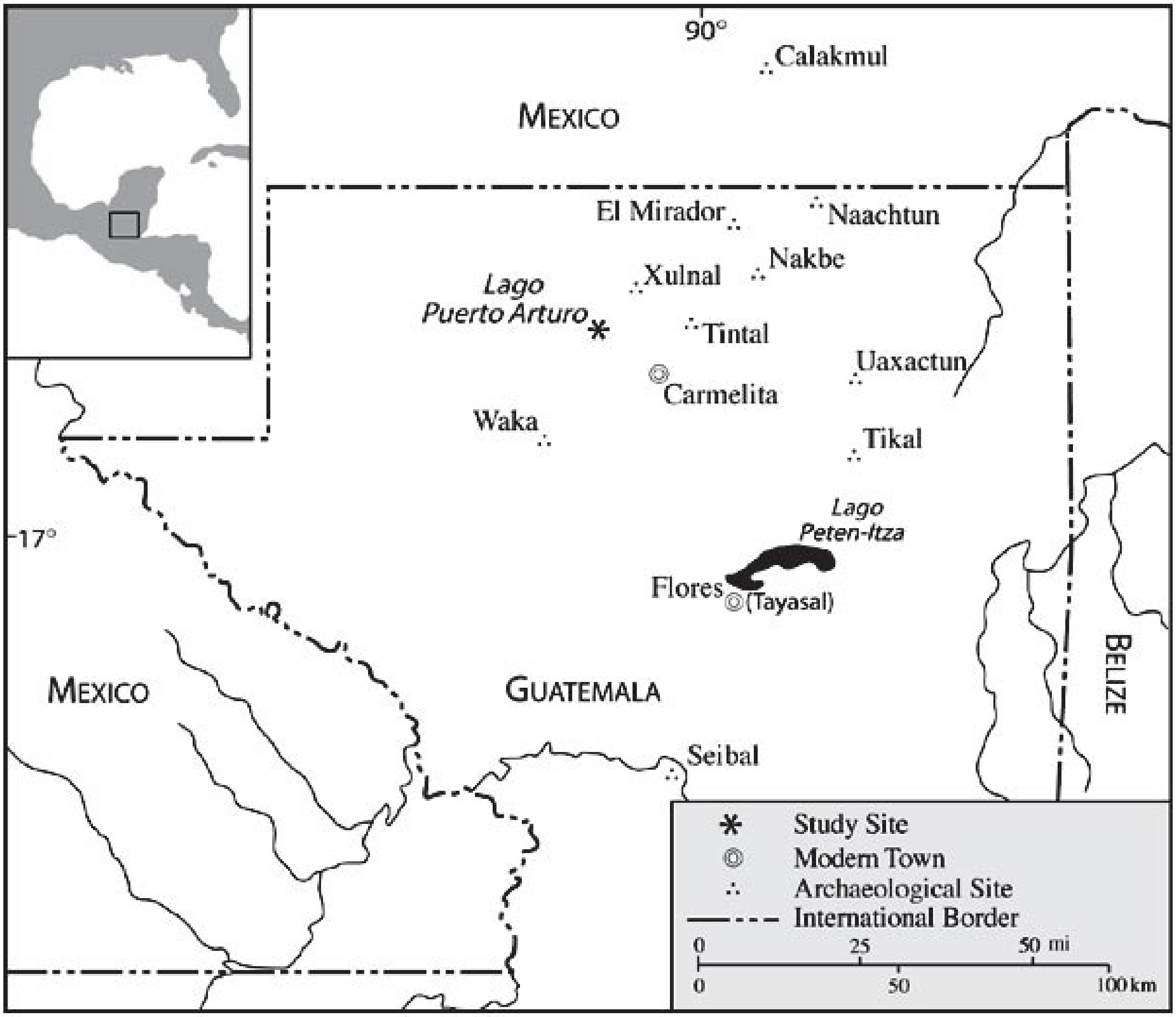

Figure 1. Map of Petén, Guatemala, including study site (Lago Puerto Arturo) and selected archaeological sites.

Previous paleoenvironmental work in the Mirador Basin has been limited by a lack of core material of sufficient age to allow a comparative analysis of the region before, during and after the periods of major Maya occupation. An initial pollen study on sediment from Aguada Zacatal, a Maya reservoir near Nakbé, established the existence of well-preserved microfossils (Weinstein 1993). In 1998, a series of sediment cores was raised from the aguada and a complete record was produced (Wahl 2000). The record, which covers the Late Classic to the present, shows two distinct zones; one of ecological disturbance and agriculture and one of forest regeneration and general stability. A dramatic shift in pollen and charcoal spectra between the zones marks the Classic period abandonment of the area (Wahl 2000).

Methods

A total of 7.28 m of sediment was recovered at Lago Puerto Arturo (17º 32' N, 90º 11' W; Figure 1), a crescent shaped lake (~1.5 km^2) located 22 km northwest of the town of Carmelita in the northern Petén. The lake occupies an extensive depression along the edge of an east-west trending scarp. The lake has held water since it started to fill ca. 9500 cal yr ago. The center is quite shallow and is dominated by emergent sedges. The northern part is ~8 meters deep, with at least one depression reaching 12 meters near the eastern shore. A small island on the lake contains the ruins of structures that appear to date to the Late Classic, though no archaeological investigations have been carried out on it. Cores were raised from an anchored raft using a 5-cm diameter Livingstone piston corer modified to accept butyrate liners (Figure 2). A replicate core, vertically offset by 50 cm, was taken to ensure complete recovery. The sediment/water interface was captured in a 3-inch diameter PVC tube using a micro-Kullenburg gravity corer. The cores were stored in a 5ºC cold room at U.C. Berkeley.

Figure 2. Coring Lago Puerto Arturo.

Prior to sampling the cores, a complete series of x-radiographs was taken and whole core magnetic susceptibility determined with a Bartington Magnetic Sensor MS2C coil.

The cores were then split and imaged using a Nikon digital camera. The digital images were spliced together to create a high-resolution composite. The x-radiographs, digital images and magnetic susceptibility were then used to correlate of overlapping cores. Core density was determined by analyzing scanned images of the x-radiographs with NIH *Image* 1.63, a public domain image analysis program.

Sediment composition was determined on by loss on ignition (LOI) (Heiri, *et al*. 2001). Sediment samples of 1.25 cc were oven dried at 100ºC for 24 hours to determine H_2O content (% wet weight) and combusted at 550ºC for two hours to determine organic content (% dry weight). Further combustion at 1000ºC determined carbonate content (% dry weight).

Samples were processed for pollen analysis using standard procedures (Faegri and Iverson 1989). Known quantities of exotic Lycopodium spores were added prior to digestion to allow calculation of pollen concentration and accumulation rates (Stockmarr 1971). Pollen was counted at 625x magnification with 1250x used to determine fine detail. Pollen grains and fern spores were identified to the lowest possible taxonomic level using the U.C. Berkeley Museum of Paleontology's collection of over 10,000 modern pollen samples, reference material collected in the field, and published pollen keys (Colinvaux, *et al*. 1999; B.C.S. Hansen 1990; Roubik and Moreno P. 1991). A minimum of 350 grains was counted in each sample. *Zea mays* was differentiated from other Poaceae pollen by size (>60 µm), long axis/pore ratio (5-9) and phase contrast light microscopy (irregular spacing of intertectile columella) (Irwin and Barghoorn 1965; Whitehead and Langham 1965). Zea grains ranged from 60-100 µm with a mean of 68 µm. To determine the first appearance of Zea in the record, the entire area of the cover slip was scanned at 125X. Three slides were scanned for Zea at each of the levels below 2.46 m. Pollen counts were compiled and plotted using CALPALYN (Bauer, *et al*. 1991).

Oxygen isotope ratios were measured on gastropod shells (*Pyrgophorus* sp.) from 136 levels and ostracod carapaces from 64 levels. Samples were run on a GV IsoPrime mass spectrometer in the Earth and Planetary Science Department, U.C. Berkeley. Results are presented in standard notation ($\delta^{18}O$) relative to Pee Dee belemnite (PDB). Overall analytical precision is ±0.07‰ (internal precision ±0.007‰) for ^{18}O. Multiple adult individuals were selected to create an aggregate sample for each level.

Twelve samples were taken for ^{14}C AMS radiocarbon age determinations (Table 1). Each sample was obtained by sieving through a 100-µm screen and sorting the larger fraction under a binocular microscope. Charcoal, macroscopic plant fragments, wood, and macroscopic insect fragments were selected. Only terrestrial or emergent aquatic plant material was selected for dating, thus avoiding "old carbon" contamination (Deevey, *et al*. 1954).

Depth (cm)	Lab No.	Radiocarbon Age ^{14}C yr B.P.	Median Age (cal yr B.P.)	Age Range 2 Sigma (cal yr B.P.)	Calendar Year (cal yr A.D./B.C.)
97	CAMS-94187	1040 ± 80	960	786-1142	A.D. 990
133	CAMS-102122	1660 ± 45	1563	1479-1692	A.D. 387
166	CAMS-105053	2020 ± 35	1968	1881-2062	18 B.C.
167[a]	CAMS-102123	8570 ±40	9537	9477-9601	7587 B.C.
244	CAMS-94186	3040 ± 120	3220	2918-3472	1270 B.C.
342	CAMS-94189	4540 ± 60	5170	5029-5325	3220 B.C.
530	OS-46419	7130 ±60	7940	7818-8035	5990 B.C.
560[a]	CAMS-94188	8370 ± 120	9350	9085-9543	7400 B.C.
584[a]	CAMS-102124	8560 ± 40	9533	9472-9560	7583 B.C.
632	CAMS-105054	8080 ± 60	9020	8767-9257	7070 B.C.
676	CAMS-105055	8465 ± 35	9492	9427-9532	7542 B.C.
713[a]	CAMS-102125	>55500			

Table 1. AMS radiocarbon determinations for the Puerto Arturo core. Calibrated ages and age ranges were calculated using Calib 4.4 (Stuiver *et al*. 1998). aSamples not used in age/depth model.

Results and Discussion

For the purpose of discussion, results of the Puerto Arturo core analyses have been divided into three zones and focus on the mid to late Holocene. The age model is based on a fourth order polynomial fit (age = $0.00000003814068depth^4 + -0.00008057484depth^3 + 0.04855236depth^2 + 6.278351depth + -42.17491$) with R^2 = 0.995. A basal date of >55,000 years indicates a hiatus of deposition between Pleistocene and Holocene sediment. Three dates have been excluded from the age model as they appear too old for their stratigraphic position.

Results of core stratigraphy, density, LOI, magnetic susceptibility and pollen are presented in Figure 3, and Figure 4. The strong correlation between lighter colored portions of the core and carbonate content indicates that these layers represent calcareous marl. Moreover, carbonate rich layers show up as relatively dense sections in the x-ray images.

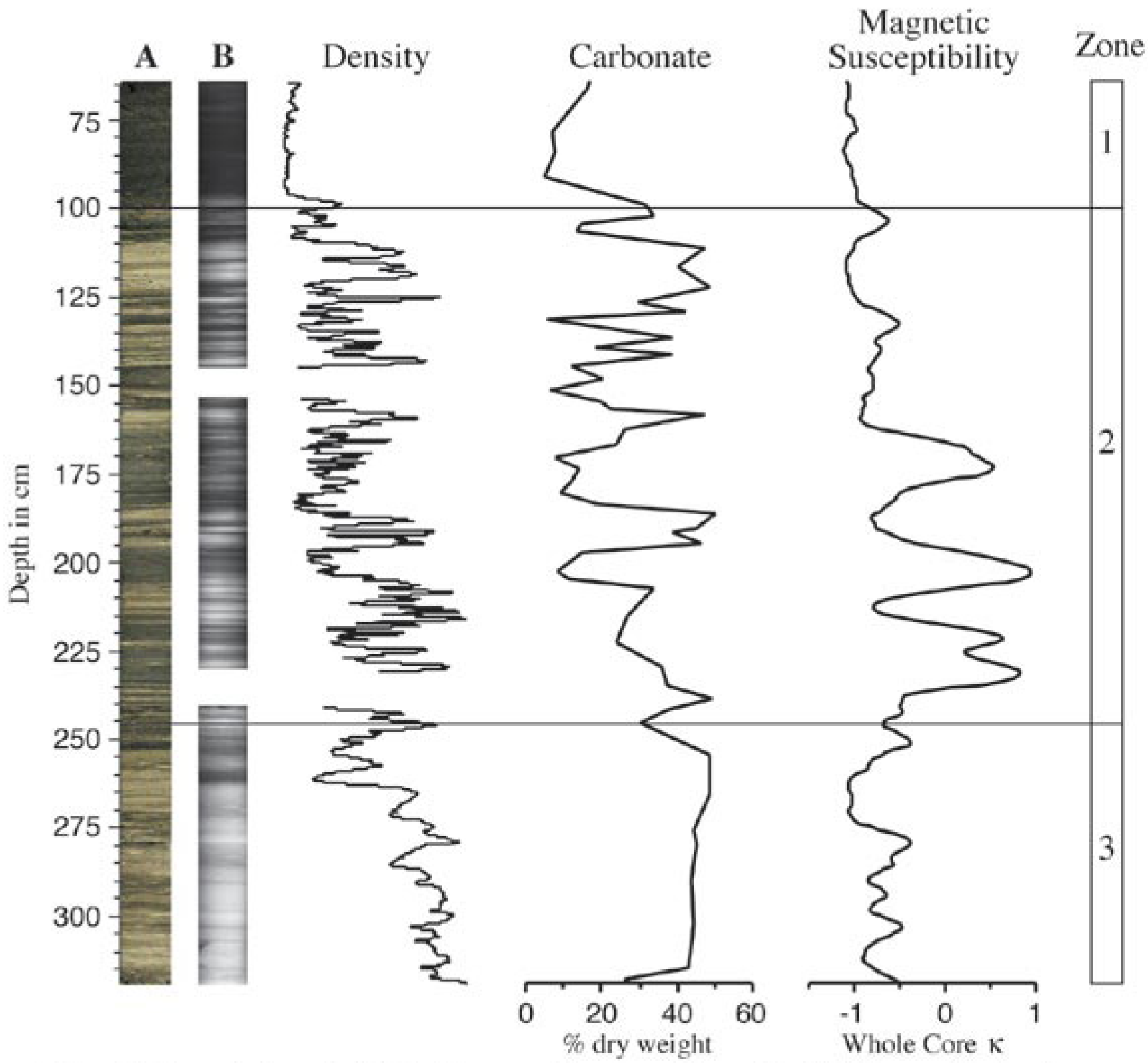

Figure 3. Core stratigraphy (digital imagery (A) and x-radiography (B)) shown with density, carbonate content, and magnetic susceptibility.

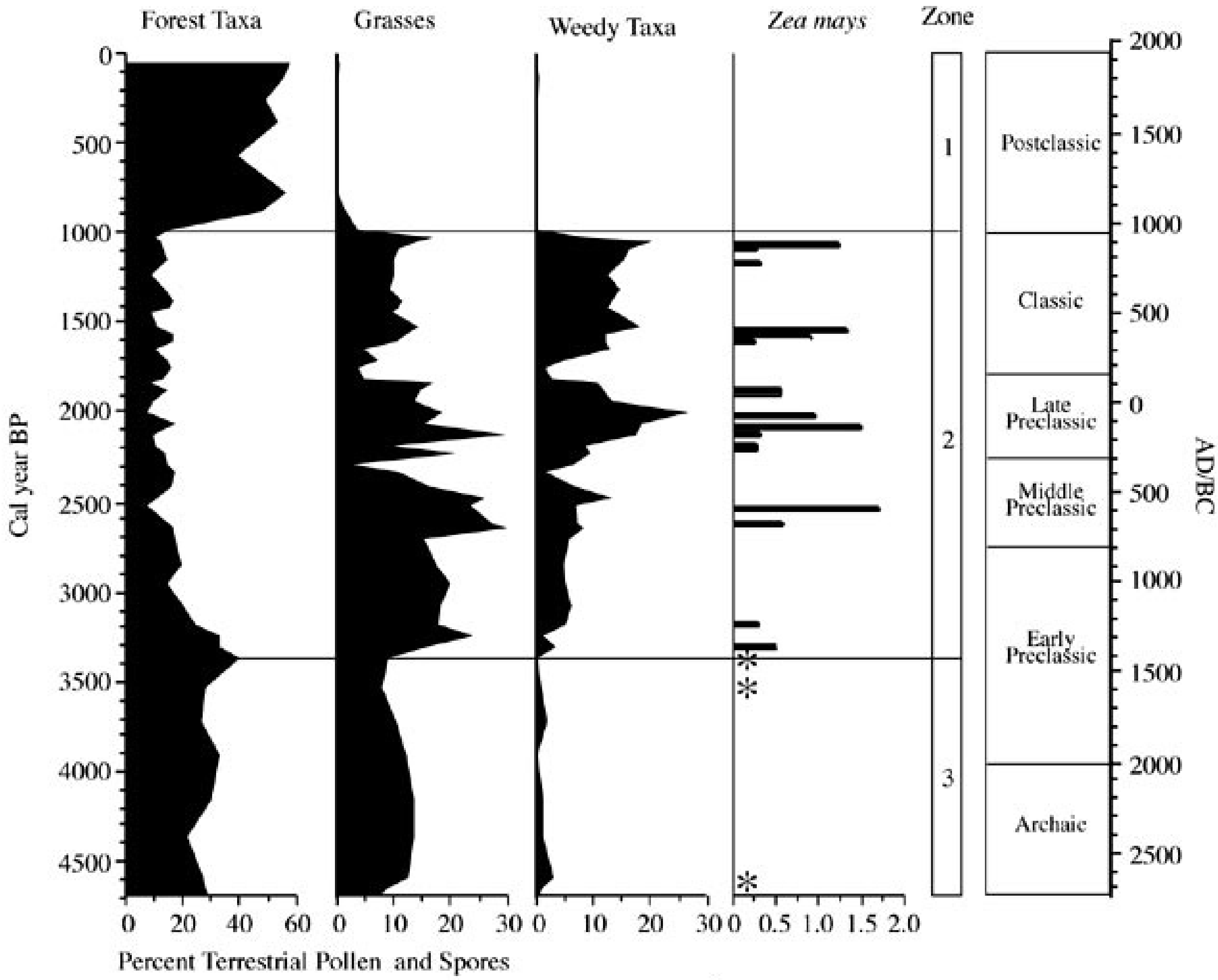

Figure 4. Percent pollen diagram from Lago Puerto Arturo. * = Zea encountered during low power scan. Forest taxa consists of the Moraceae and Urticaceae families; weedy taxa is the Asteraceae family.

The sediment in zone 3 (3.18 to 2.46 m; ~4700-3400 cal yr B.P.) is characterized by fine banding of light/dark layers and relatively high (50%) carbonate content. *Zea* is present as a single grain near the bottom of this zone (3.15 m), and is not present again until the upper part of the zone, at 2.55 m. Herbaceous taxa (grasses and weeds) maintain stable, relatively low levels throughout zone 3.

Carbonate content decreases in zone 2 (2.45 to 1.00 m; ~3400-1000 cal yr B.P.) and becomes more variable. Magnetic susceptibility values show three large peaks in zone 2, centered around 3100, 2600 and 2100 cal yr B.P., respectively. Two smaller peaks, at 1500 and 1000 cal yr B.P., follow. Non-carbonate inorganic percentages increase in this zone and positively correlate to magnetic susceptibility values. These curves undoubtedly reflect erosional input of upland clay into the lake. Carbonate content is out of phase with magnetic susceptibility in zone 2. The lower levels of zone 2 indicate an increase in herbaceous taxa coupled with a decrease in forest taxa. Around 2700 cal yr

B.P., the forest taxa group reaches relatively stable, values of around 15% of the terrestrial pollen sum. Zea pollen is intermittently present throughout zone 2.

The transition to zone 1 (1.00 to 0.15 m; ~1000-60 cal yr B.P.) is marked by an abrupt drop in density, inorganic content, and magnetic susceptibility values. It also exhibits a dramatic change in pollen frequencies. Forest taxa increase from 15% of the pollen sum at 1.0 m to 49% at 0.92 m. Herbaceous taxa, the dominant type of zone 2, abruptly drop to near zero values at the transition to zone 1.

The chronology of maize agriculture set forth in this record can be used to clarify pollen records from larger, less sensitive lakes in Petén. Other pollen records from the Petén that include the mid Holocene show decreasing forest taxa from ca. 4000-2000 B.C. (Leyden 2002). Without concurrent evidence of agriculture, it has been difficult to isolate a cause for this decrease. Zea pollen at ~2650 B.C. in the Puerto Arturo core suggests that forest clearance by early agriculturalists was responsible.

Changes in the local landscape correspond to the onset of sedentary village life. The pollen evidence shows an abrupt rise in grasses and weeds around 1450 B.C., concurrent with an accelerated decline in forest taxa. Similarly, the magnetic susceptibility indicates the first large pulse of erosion around 1400 B.C. (Figure 3 and Figure 4). Although populations must have been relatively small at this time, their land use practices had a clear impact on the environment. At least four more phases of increased disturbance alternating with periods of ecological recovery occurred during the following 2500 years.

Disturbance phases are characterized by the presence of *Zea* pollen, peaks of disturbance taxa (grasses and weeds), and higher magnetic susceptibility values (Figure 3 and Figure 4). Recovery phases consist of a general reversal of this trend. Disturbance/recovery phases occur approximately every 500 years during the period of prehistoric settlement. The final recovery phase began ~1000 cal yr B.P.

Three of the recovery phases are of particular interest. They correspond to the terminal phases of the Middle Preclassic, the Late Preclassic, and the Late Classic. Evidence of decreased disturbance at these times is present in multiple proxies from several sample levels, eliminating the possibility that they are statistical artifacts.

Middle Preclassic Recovery Phase (540–350 cal yr B.C.)

The Middle Preclassic recovery phase is characterized by a steep drop in grasses, weeds and agricultural indicators. Prior to this period, disturbance taxa and erosion reached a peak from ~700 to 540 B.C. Subsequently, clay input to the lake decreases abruptly until ~350 B.C. After 350 B.C., the trend reverses; grasses and weedy taxa increase, *Zea* is present, and erosional input dramatically increases. This recovery phase indicates a decrease in human activity in the local area.

The timing of this recovery phase is important because it coincides with a period of cultural change in lowland Mesoamerica. The ceramics of the Middle Preclassic largely fall into the Mamon tradition. Around 300 B.C., however, there is a shift toward early forms of the ensuing Chicanel types that characterize the Late Preclassic. The homogeneity and distribution of Chicanel ceramics in the Late Preclassic, across the entire Maya lowlands, has contributed to the conclusion that this period may have constituted "the rise of the first state-level society in Mesoamerica" (R.D. Hansen in press). Moreover, shortly after this transition from Middle to Late Preclassic, many centers in the Mirador Basin experienced accelerated growth. The major structures at El Mirador were constructed at this time (R.D. Hansen 1990; Howell and Copeland 1989). Although there is no evidence for an abandonment in the Mirador Basin at the end of the Middle Preclassic, the Puerto Arturo record suggests that decline in population may have accompanied the cultural transitions indicated by the archaeological record.

Late Preclassic Recovery Phase (cal yr A.D. 100–255)

Archaeological evidence indicates a large population decline in the Mirador Basin at the end of the Late Preclassic (300 B.C. to A.D. 250). The most important site, El Mirador, was abruptly abandoned around A.D. 150 (R.D. Hansen 1990; Howell and Copeland 1989). Excavations show that few, if any, of these structures were later renovated or occupied during the millennia that followed. The abandonment of El Mirador and the surrounding area appears to have been relatively rapid and enduring (R.D. Hansen 1990:98-100, 216). Small populations occupied the region during the Late Classic period (A.D. 600-900), but did not rival the cultural apogee of the Late Preclassic period. The pollen data from Puerto Arturo corroborate this abandonment.

The paleoenvironmental evidence for this abandonment is similar to that of the Middle Preclassic recovery phase. Increased values of grasses and weedy taxa, including maize pollen, from ca. 300 B.C. to A.D. 100, mark the intervening disturbance period. After A.D. 100, these taxa began a steep decline and minimum values persist from ~A.D. 130-225. Thus, it appears the Preclassic abandonment was underway shortly after A.D. 100.

Anthropogenic disturbance in the watershed increases again around the beginning of the Classic period. Magnetic susceptibility and LOI data show a small increase in erosion during the Early Classic (Figure 3). Likewise, pollen indicates a coeval increase in disturbance taxa. All analyses show that disturbance was greater during the Late Preclassic than the Classic, possibly reflecting smaller Classic populations in the region.

Late Classic Recovery Phase (cal yr A.D. 915–present)

The Late Classic collapse is clearly present in the Puerto Arturo pollen record. An abrupt drop in grass, weed and agricultural pollen begins around A.D. 915. By A.D. 960, pollen from these groups, which had dominated the record for 2400 years, dropped to near zero values which persist to the present. The rapid change of pollen frequencies at this time is similar to changes in the Late Classic pollen record from Aguada Zacatal, near Nakbé (Wahl 2000). Forest recovery was also relatively rapid; pollen from arboreal taxa reached pre-disturbance levels within 100 years.

Changing $^{18}O/^{16}O$ in biogenic carbonate of closed basin tropical lakes can be used to indicate changes in precipitation and evaporation (Covich and Stuiver 1974; Hodell, *et al*. 1995). Lake water becomes enriched in ^{18}O (relative to source water) as ^{16}O is selectively evaporated during periods of high evaporation/low precipitation. Past changes in lake water $\delta^{18}O$ are recorded in carbonate shells as they precipitate.

The $\delta^{18}O$ results shown to the right in Figure 5, are generally similar to those reported from sites in northern Yucatán (Curtis, *et al*. 1996; Hodell, *et al*. 1995). Evidence of persistent arid conditions in the early centuries of the Holocene is found across southern Mesoamerica (Hodell, *et al*. 1995; Islebe, *et al*. 1996; Leyden 1984; Leyden, *et al*. 1998).

Decreasing $\delta^{18}O$ values from ~8200-7900 cal yr B.P. represent increasing humidity in the early Holocene. Low values from 7900-4600 cal yr B.P. indicate a more humid early to mid Holocene. From ~4600 to 1050 cal yr B.P. conditions are relatively dry. A wet early to mid Holocene followed by a late Holocene dry phase is reported from the Caribbean, Yucatán, and Central America (Dull 2004; Hodell, *et al*. 1995; Hodell, *et al*. 1991).

Around 1050 cal yr B.P. (A.D. 900), $\delta^{18}O$ values drop dramatically to the lowest values of the entire Holocene.

The pollen record shows settlement and agricultural activity from ~4600-1050 cal yr B.P., which corresponds to the late Holocene dry phase. Zea pollen first appears ~4600 cal yr B.P. and is present off and on until ~1050 cal yr B.P., after which it drops out permanently. Pollen from grasses and weedy taxa shows an abrupt and sustained increase during this period. Although these increases may in part reflect drier climate, the concurrent presence of *Zea* during this period is strong evidence of anthropogenic impacts. Moreover, magnetic susceptibility (a proxy for watershed erosion) shows peak values corresponding to peaks in disturbance taxa pollen, further pointing to human agency. The highest values of disturbance proxies occur during the Late Preclassic (B.C. 300–A.D. 250), when the area was most heavily occupied (R.D. Hansen 1990, 1998).

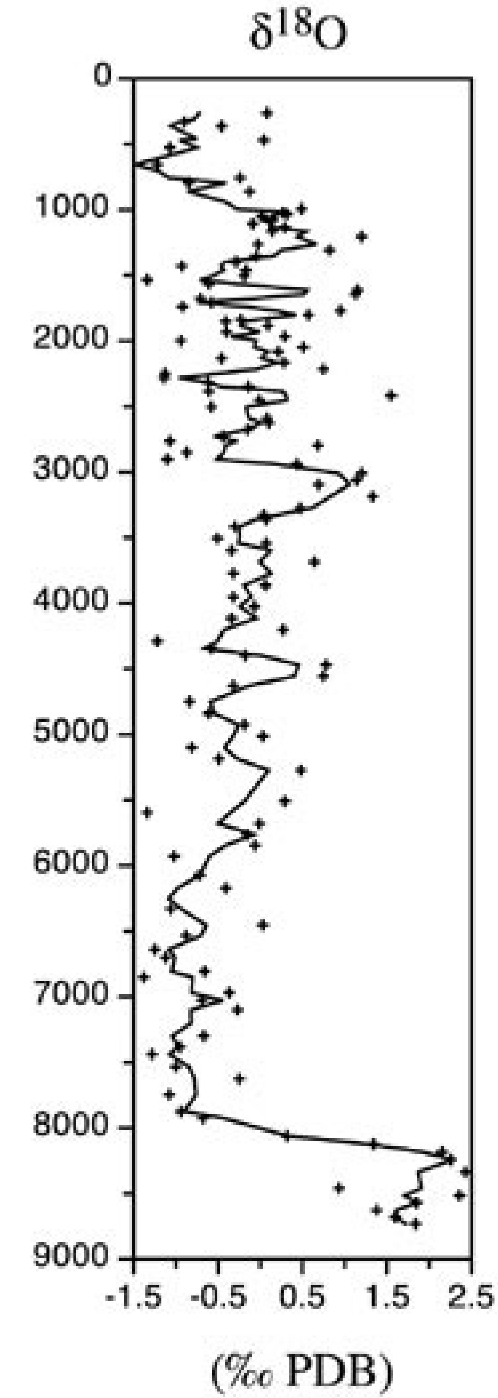

Figure 5. Results of the oxygen isotope analysis. Line is a 3 pt. running mean.

The Late Classic dry period that has been identified in the northern Maya lowlands (Curtis, *et al*. 1996; Hodell, *et al*. 2001; Hodell, *et al*. 1995) is reflected in the Puerto Arturo record from ~1300-1050 cal yr B.P. Inter-site differences in the timing of this event most likely represent the uncertainties of radiocarbon dating. It is important to note that this dry phase comes at the end of nearly 3500 years of relatively dry conditions and that pollen evidence indicates nearby agriculture in the area throughout the Late Classic (Figure 4). Agricultural activity apparently ended when more humid conditions set in ~1050 cal yr B.P. (A.D. 950). Within ~40 years after this date, weedy taxa drop to near zero values and Zea pollen disappears completely. The area has not supported large populations since.

Conclusion

The results of this study provide a Holocene length record of climate and human activity in southern Maya lowlands. Humid conditions of the early Holocene gave way to a relatively dry climate from ~4600-1000 cal yr B.P. This 3500 yr period coincides with prehistoric settlement in the area, which suggests a drier climate may have been optimal for prehistoric farmers. The late Holocene was a period of high population pressure in the Mirador Basin. Around 3200 cal yr B.P. evidence for deforestation, agricultural activity, and erosion all increase dramatically. These results corroborate the archaeological record, which shows the establishment and growth of permanent settlements at this time. Forests were significantly restricted for the entire period of prehistoric settlement, from ~3200-1000 cal yr B.P.

The vegetation record shows three discrete periods of decreased disturbance and/or abandonment in the late Holocene: ~2500-2300 cal yr B.P. (550-350 B.C.), ~1820-1725 cal yr B.P. (A.D. 130-225), and ~1000 cal yr B.P. (A.D. 950)–present. The first period coincides with cultural transitions in the region and is the first evidence of a possible decrease in population at this time. The latter two periods represent the Late Preclassic and Late Classic abandonments identified in the archaeological record. Forest recovery occurred rapidly when the area was permanently abandoned around 1000 cal yr B.P.

Acknowledgements

This project would not have been possible without the generous support of the Foundation for the Advancement of Mesoamerican Studies, Inc., (FAMSI). Additional support was provided by the Mirador Basin Project, the National Science Foundation, the U.C. Pacific Rim Research program and the Stahl Foundation. Cooperative support from the Instituto de Antropopogía e Historia de Guatemala was much appreciated.

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