El Colegio de la Frontera Sur

Paleoecología e historia climática de la costa de Chiapas durante el Holoceno tardío

TESIS
presentada como requisito parcial para optar al grado de
Maestría en Ciencias en Recursos Naturales y Desarrollo Rural

por

Juan Carlos Joo Chang

2013

Dedicatoria y agradecimientos

Quisiera agradecer a los profesores, a los compañeros, a los amigos y a mis padres, cuyas experiencias, observaciones y apoyo enfilaron hacia buen camino esta tesis. A los compañeros de laboratorio, esas personas que tenemos más a la mano y nos permiten aclarar nuestras muchas dudas y que muchas veces desatienden sus obligaciones por aclarar nuestras frustraciones: Alejandro Antonio Aragón Moreno, Alicia Carrillo Bastos, Luz Verónica Gutiérrez Ayala y Alejandro Antonio Vela Peláez. A los técnicos involucrados durante el trabajo de campo, Margarito Tus Novelo y Gerardo De la Cruz Montes, cuyos conocimientos y habilidades permitieron afrontar los retos presentados en los muestreos. A las autoridades de la Reserva de la Biósfera La Encrucijada por permitirnos el acceso al área natural protegida.

Los tutores y asesores de un trabajo de investigación esclarecen las dudas existenciales de los alumnos de maestría, al mismo tiempo que crean nuevas interrogantes. Son ellos quienes, con su particular estilo, siembran la mayor inspiración, satisfacción y desasosiego en el corazón de los estudiantes. Dr. Gerald Islebe, Dra. Nuria Torrescano Valle y Dr. Cristian Tovilla Hernández, mis mayores agradecimientos hacia ustedes.

"*La diligencia en escuchar es el camino más rápido hacia la ciencia*"

Juan Luis Vives (1492 – 1540). Escritor y poeta español

Dedicado a aquellas personas iniciadas en el quehacer científico.

“*Las raíces de la ciencia pueden ser muy amargas, pero los frutos son siempre dulces*”

Aristóteles

Índice

Introducción

El Holoceno es el periodo que abarca los últimos ~10 000 años, en el cual concluyó el retroceso de las masas de hielo formadas durante la última era glaciar, lo que permitió la formación de suelos y lagos, el establecimiento de la línea de costa en los continentes y la distribución actual de las comunidades vegetales (Roberts, 1998). Comparado con el periodo anterior (Pleistoceno), el Holoceno presenta menor variabilidad en la temperatura (Oldfield, 2005). Sin embargo, se reconoce que durante el Holoceno temprano se presentaron fuertes cambios climáticos con diferentes efectos en la vegetación, y los primeros efectos del ser humano sobre el ambiente se observan a partir de este periodo (Anderson, Goudie, y Parker, 2007).

La importancia del estudio de las condiciones pasadas del Holoceno radica en que, si bien la fase de fuertes cambios climáticos y del nivel del mar culminó hace aproximadamente 4000 años, durante la segunda mitad del Holoceno se han registrado variaciones importantes en la precipitación. A partir de este punto, las variaciones en el nivel del mar, cobertura de hielo y sucesión de ambientes es similar a la observada durante el último milenio, por lo tanto se infiere que los mismos procesos que provocaron estos cambios continúan actuando hoy en día (Oldfield, 2005).

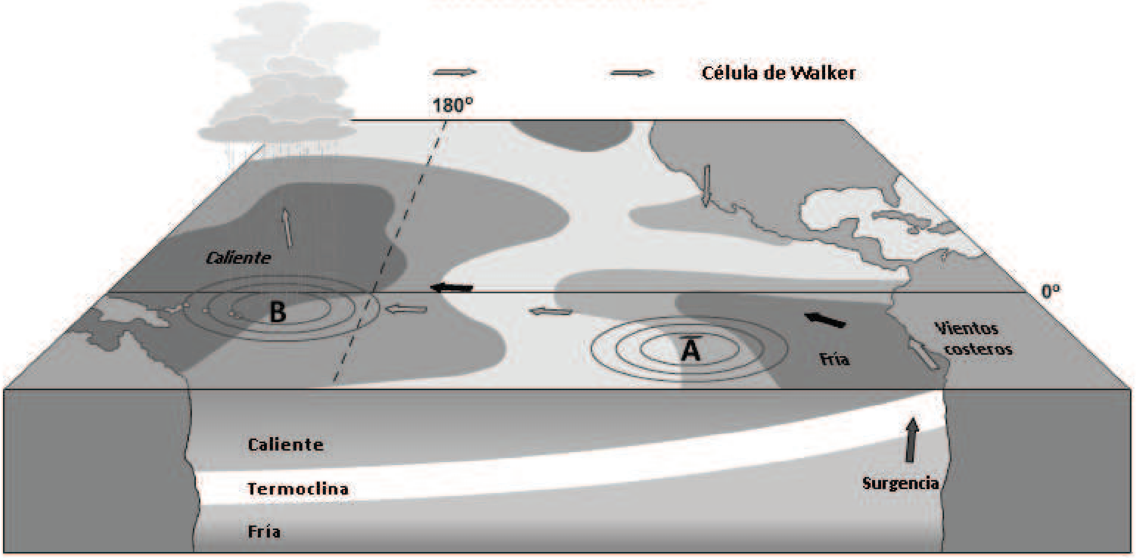
Los estudios paleoecológicos posibilitan analizar y comprender la forma en que se dieron los cambios ambientales del Holoceno desde una perspectiva dinámica, espacial y temporal (Islebe et al., 1996). El estudio de ambientes pasados requiere el entendimiento de tres factores: el ambiente actual (el sistema climático o la vegetación) y los procesos que lo modifican; la cronología, dimensión del tiempo en la que se observan los cambios ambientales; y los indicadores o proxies que registran dichos cambios (Cronin, 1999).

Los eventos que producen cambios en la vegetación pueden estar relacionados con el sistema climático o fuera de éste. Dentro de los primeros, uno de los eventos climáticos con mayor influencia sobre los sistemas de precipitación a nivel global es la anomalía climática de El Niño – Oscilación del Sur (ENSO, por sus siglas en inglés) (Fig. 1). Los eventos ENSO generan el intercambio de zonas de precipitación por zonas de sequía en el Pacífico tropical y el océano Índico (Cronin, 1999). Este intercambio provoca el movimiento hacia el sur del cinturón de precipitaciones o zona de inter-convergencia tropical (ITCZ, por sus siglas en inglés) (Fig. 2), lo cual genera condiciones secas en Centroamérica y el norte de Sudamérica (Neff et al., 2006a). Los registros paleo-climáticos muestran un aumento en la frecuencia de eventos ENSO desde el 4000 años AP (Moy et al., 2002), mientras que el registro histórico denota reducciones en los ciclos de 90 – 50 – 24 – 22 años, hasta los ciclos actuales presentes cada 3 – 7 años (Cronin, 1999).

Por otro lado, la vegetación puede cambiar debido a eventos ajenos al clima como epidemias en las plantas, actividades humanas o erupciones volcánicas (Bradley, 1999). Sin embargo, es importante resaltar que los eventos que generan cambios en la vegetación pueden actuar al mismo tiempo (Cronin, 1999) y a diferentes escalas espaciales o temporales (Bradley, 1999). La escala de muestreo adecuada es trascendental para lograr una interpretación correcta de los cambios en la vegetación. Al mismo tiempo, es importante reconocer la presencia de respuestas no lineales de la vegetación, que se dan abruptamente al pasar un umbral de condiciones, y que pueden ser identificadas con estudios de alta resolución temporal (Bradley, 1999).

Figura 1. Diagrama esquemático de las condiciones oceánicas y atmosféricas en el océano Pacífico bajo condiciones normales y de El Niño. A y B representan zonas de alta y baja presión, respectivamente. Modificado de El Niño and La Niña (2004).

Condiciones normales



Condiciones de El Niño

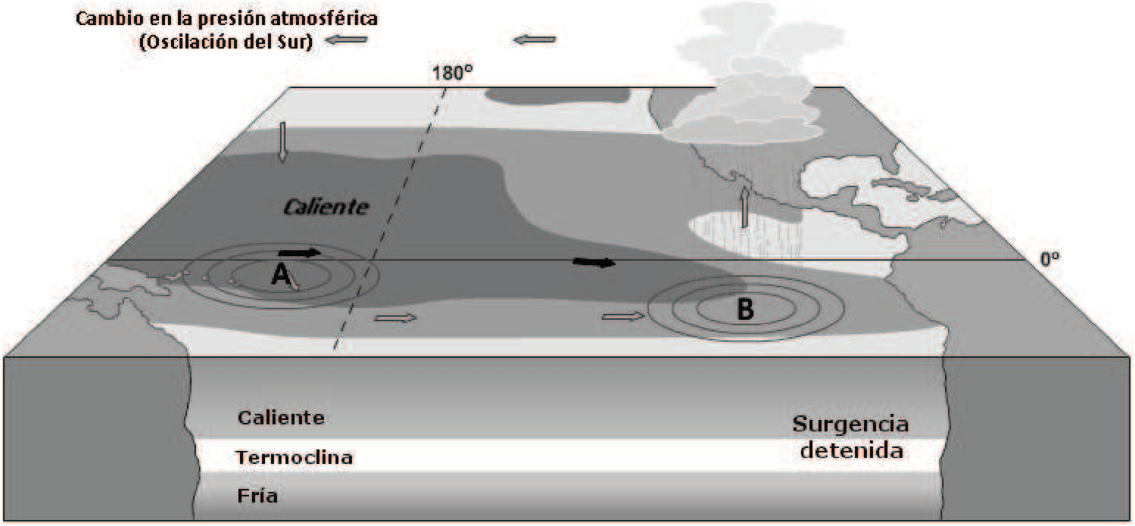
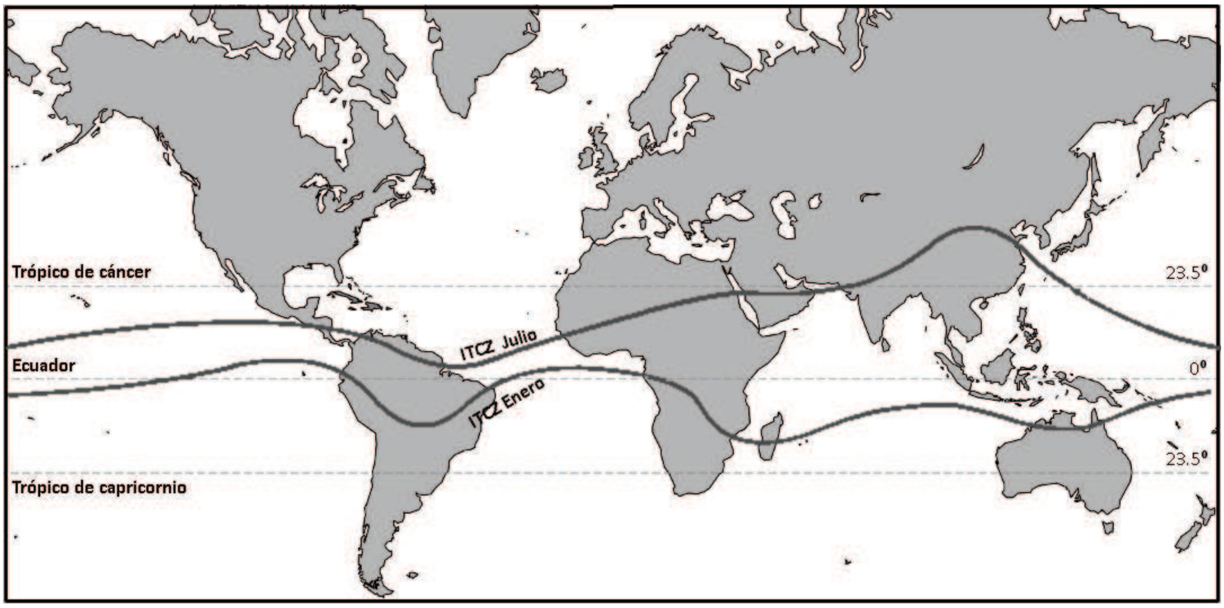


Figura 2. Diagrama esquemático del rango de movimiento de la Zona de inter-convergencia tropical (ITCZ) a lo largo del año.



El análisis de polen fósil en los sedimentos permite identificar cambios en la vegetación de cierta región a través del tiempo (Islebe, 1998). La morfología del polen muchas veces permite su identificación a nivel de especie, además, los granos de polen poseen gran resistencia en ciertos ambientes, y son una representación de la vegetación al momento del depósito (Bradley, 1999). Las condiciones climáticas pueden ser inferidas puesto que generalmente se trabaja con asociaciones de plantas actuales de las que se conocen sus requerimientos ecológicos (Traverse, 2007). Adicionalmente, el análisis de polen nos permite identificar cambios en la vegetación producidos por el establecimiento de cultivos (Mueller et al., 2009).

Para reconocer la sensibilidad de los proxies ante cambios ambientales, primero se debe comparar la respuesta de indicadores modernos ante diferentes condiciones actuales en un proceso de calibración (Bradley, 1999). En el caso del polen fósil, la calibración se hace al comparar la relación del polen presente en sedimentos actuales y la vegetación adyacente por medio del análisis de lluvia de polen en diferentes ambientes (Moore, Webb, y Collinson, 1991). El depósito de polen en los sedimentos es afectado por la frecuencia de árboles productores de polen, por las diferencias en producción y los mecanismos de dispersión de las diferentes especies, así como por factores estratigráficos que intervienen en la preservación del polen (Faegri et al., 1989). Por lo tanto, resulta necesario contar con una amplia base de datos sobre lluvia de polen en diferentes ambientes para interpretar de mejor manera el polen fósil en los sedimentos (Bradley, 1999).

Es muy importante establecer las fechas precisas en que ocurrieron los cambios en la vegetación, tanto para generar una cronología de eventos, como para calcular la duración y esclarecer el origen de cada episodio (Roberts, 1998), además de determinar sincronías entre eventos (Bradley, 1999). Una técnica de datación muy utilizada en las reconstrucciones paleoambientales del Holoceno es la datación por radio-isótopos de carbono 14 (Roberts, 1998). Lo anterior debido a que este isótopo presenta distribución uniforme en el globo, puede usarse en restos orgánicos e inorgánicos de diferente origen, y posee un tiempo de vida que abarca cambios climáticos globales importantes y el desarrollo del ser humano (Bradley, 1999).

Las técnicas paleoecológicas poseen diferentes aplicaciones prácticas en el manejo de áreas costeras, debido a que permiten conocer las dinámicas que han operado en el pasado de un ecosistema y predecir la forma en que estos ambientes responderán a diferentes cambios en el futuro. Los registros palinológicos son un importante primer paso en la definición de factores que han afectado a las zonas costeras durante el Holoceno (Leyden, 2002). Dentro de las zonas costeras, los manglares resultan buenos indicadores de cambios climáticos pasados (Torrescano-Valle y Islebe, 2012), debido a que generan gran cantidad de sedimentos orgánicos que proveen las condiciones húmedas y anóxicas necesarias para la preservación de polen a largo plazo (Ellison, 2008). Además, la localización de los manglares en la parte final de las cuencas bajas, en las planicies costeras (López-Portillo y Ezcurra, 2003), favorece a la acumulación de sedimentos provenientes de toda la cuenca hidrológica. Por último, la distribución de los manglares en zonas inter-mareales, bordeando las costas, los hace sensibles ante cambios hidrológicos (Tomlinson, 1986), por lo que son útiles para identificar cambios en el nivel del mar o entradas de agua salobre.

Los manglares de la costa de Chiapas son áreas naturales protegidas de gran importancia ecológica y económica. Proveen numerosos servicios ambientales de los que dependen un número cada vez mayor de pobladores (INE, 1999). Sin embargo, el cambio climático global amenaza seriamente a ésta y otras zonas de manglares alrededor del mundo (Gilman et al., 2008). En específico, los manglares de la costa de Chiapas se encuentran amenazados por una creciente frontera agrícola y ganadera, además del manejo ineficiente de los recursos naturales en las cuencas altas, que producen cambios profundos en el paisaje (Tovilla-Hernández et al., 2009). Por lo anterior, resulta indispensable realizar estudios paleoecológicos que permitan vislumbrar la respuesta de los manglares de la costa de Chiapas ante cambios climáticos futuros y contribuir en el diseño de planes de manejo y estrategias de restauración ecológica exitosas (Schoonmaker y Foster, 1991).

Se han realizado estudios paleoecológicos en el Pacífico de Centroamérica. En la cuenca de Panamá, González, Urrego, y Martínez (2006) reconocieron eventos de humedad e introgresión marina ocurridos de ~11300 – 5600 años antes del presente (años AP), con una tendencia a la desecación a partir de ~7000 - 5640 años AP, y una intensa sequía a ~6500 años AP. Mientras tanto, Popenoe de Hatch (2004) describió cambios en la vegetación asociada a la actividad de grupos humanos en el área cercana al sitio arqueológico de Tak´alik Ab´aj en Guatemala a partir de ~3000 años AP.

En los manglares del Pacífico norte de Guatemala, Neff et al. (2006a) reportan condiciones húmedas para el Holoceno medio (~6000 – 4300 años AP). El paso hacia el Holoceno terminal está marcado por eventos de introgresión marina y sequías puntuales ocurridos de 4300 – 4000 años AP. Condiciones variables en humedad y temperatura caracterizan el final del Holoceno, aunque un aumento de precipitación se reporta de ~2800 – 1900 años AP, y a 1800 – 1200 años AP, éste último con presencia de cultivos. A partir de ~1250 años AP, se observa una sequía de larga duración relacionada con el colapso de la civilización Maya.

Por su parte, de acuerdo con Neff, Bove, y Genovez (2006), los manglares de la costa sur en el Pacífico de Guatemala presentan condiciones variables para el Holoceno terminal. Aunque en esta área se logra apreciar una sequía prolongada de ~1100 – 600 años AP.

Neff et al. (2006b) encontraron que la dominancia de especies arbóreas cambió por ambientes más abiertos a partir de ~3 500 años AP en tres sitios de las tierras bajas del Pacífico de Guatemala. Estas alteraciones se dieron de manera asincrónica en cada sitio, lo que sugiere que los cambios en la vegetación fueron provocados por efectos de tipo local, como la actividad humana, y no por efectos de cambio climático.

Un estudio sobre uso de recursos en la costa de Chiapas durante el Holoceno, sugiere que la estacionalidad estable ocurrida de ~3000 – 1800 años AP permitió la extracción de productos provenientes de los humedales (Kennett y Voorhies, 1996). A partir de ~1800 años AP, se observa un cambio en la preferencia de alimentación de los pobladores por productos agrícolas.

El trabajo realizado en los manglares de la costa de Chiapas por Kennett et al. (2010) muestra evidencias sobre el aprovechamiento intensivo de recursos costeros en la región desde hace ~ 7 500 años AP. El cultivo del maíz se registró hace ~ 6 500 años AP, con la aparición de estrategias de roza tumba y quema involucradas con este cultivo a partir de ~4 100 años AP. Esto demuestra que la zona ha sido sujeta a intensa actividad humana desde mucho antes del establecimiento de la civilización Maya. En adición, los autores infieren cambios en la salinidad del ecosistema, de salobre (~6 600 - 4 100 años AP) a un ambiente de agua dulce (4 100 - 400 años AP), basados en la dominancia de especies vegetales asociadas a estos ambientes.

Todos estos estudios aportan información valiosa acerca de los factores que han afectado la vegetación de las costas del Pacífico de Centroamérica durante el Holoceno. Sin embargo, dichos muestreos carecen de resolución óptima para determinar cambios precisos, o sus interpretaciones se enfocan en determinar la presencia de asentamientos humanos. Por lo que se conoce poco acerca de los cambios ambientales que pudieron existir de manera natural en la zona, así como los factores que permitieron el establecimiento de la vegetación actual en la costa de Chiapas.

Algunos estudios en regiones más alejadas a la costa de Chiapas han logrado determinar con bastante precisión los cambios ocurridos en periodos posteriores a la actividad humana. A partir de muestras de polen del lago Petén-Itzá, Mueller et al. (2009) observaron una rápida recuperación de la vegetación arbórea tropical posterior al colapso de la civilización maya. Por lo que proponen que la disminución de apertura boscosa provocada por la falta de la actividad humana, combinado con condiciones ambientales más húmedas permitieron una rápida regeneración arbórea alrededor del lago Petén Itzá en Guatemala a comienzos del periodo post-clásico (~ 1 000 años AP).

Diversos estudios paleoecológicos en diferentes sitios de la región circum Caribe, como El Petén, Guatemala (Islebe y Leyden, 2006), la selva Lacandona (Islebe y Sánchez, 2002) y la península de Yucatán (Carrillo-Bastos et al., 2010; Monacci et al., 2011; Aragón-Moreno, Islebe, y Torrescano-Valle, 2012; Gutiérrez-Ayala, Torrescano-Valle, e Islebe, 2012; Torrescano-Valle e Islebe, 2012), muestran descripciones detalladas de los cambios en la vegetación y de la historia climática durante el Holoceno. Mientras que Haug et al. (2001), a partir de datos de escorrentías, infieren la presencia de mayor variabilidad en la precipitación sobre toda la región circum Caribe a partir de ~3 600 BP. Estos estudios asocian los cambios climáticos con movimientos de la ITCZ. Por lo tanto, son útiles para comparar estudios realizados en sitios bajo la influencia de la ITCZ, la cual determina el clima en las zonas tropicales (Fritz, 2005).

Este trabajo tiene como objetivo analizar la paleoecología de la costa de Chiapas durante el Holoceno tardío. Por ende, se enfocará en la descripción del proceso de sucesión vegetal a escala milenaria durante los últimos 4 500 años, así como en la identificación de su origen, climático o antropogénico, asociado también con cambios en el nivel del mar.

Área de estudio

El sitio de muestreo (15°8.98'N, 92°45.06'W) se localiza dentro de La Reserva de la Biósfera La Encrucijada (RBLE), en el estado de Chiapas, México, el cual comparte características físicas y ambientales con el resto de la costa de Chiapas. Presenta clima cálido húmedo con lluvias en verano (Aw), la temperatura media anual es 28 °C, con valores de precipitación anual entre 1,300 y 3000 mm. La estación húmeda se presenta de mayo a noviembre, con sequía intraestival (canícula) durante julio y agosto; mientras que la estación seca aparece de diciembre a abril, con algunas lluvias esporádicas en marzo y abril (INE, 1999). La posición latitudinal de la RBLE la ubica bajo la influencia de la ITCZ, la cual establece el régimen de precipitación en el área.

La fisiografía del lugar corresponde a la llanura costera de Chiapas y Guatemala, una intrincada red de abanicos aluviales localizada a lo largo de la costa, formada por depósitos volcánicos acumulados durante el cuaternario (Marshall, 2007). Los suelos son principalmente aluviales, aunque también están presentes suelos lacustres, palustres y litorales. Los tipos de suelo principales son solonchak, regosol, cambisol, gleysol, feozem y fluvisol. El escurrimiento de numerosos ríos provenientes de la Sierra Madre de Chiapas y la presencia de mareas del océano Pacífico permiten el llenado de complejos sistemas lagunares (INE, 1999).

Los principales tipos de vegetación en la RBLE son manglar, selva alta, bosque de galería, vegetación acuática, vegetación de duna costera y bosque de zapotón (*Pachira aquatica*). Las especies de manglar están representadas por *Rhizophora mangle*, *R. harrisonii*, *Laguncularia racemosa*, *Avicennia germinans* y *Conocarpus erectus*, con alturas medias de 5.9 – 7.9 m (*C. erectus*), hasta 22 – 27.6 m (*R. mangle y R. harrisonii*) (Tovilla-Hernández et al., 2009). La vegetación alrededor del sitio de muestreo consiste de un bosque puro de *R. mangle* (8 – 10 m de alto) localizado a 8 km de la línea de costa. El sedimento presente en el sitio está compuesto por una turba orgánica lodosa.

ARTICULO SOMETIDO

El artículo fue sometido a Quaternary Research como:

Research article

Mangrove response to Holocene climate change in Pacific south-eastern Mexico

Juan Carlos Joo-Chang

El Colegio de la Frontera Sur, Unidad Chetumal, Herbario. A.P. 424, C.P. 77014, Chetumal, Quintana Roo, México. Phone: +52 983 83 50440, Ext. 4342. E-mail: jjoo@ecosur.edu.mx

Gerald Alexander Islebe (corresponding author)

El Colegio de la Frontera Sur, Unidad Chetumal, Herbario. A.P. 424, C.P. 77014, Chetumal, Quintana Roo, México. Phone: +52 983 83 50440, Ext. 4300; Fax: +52 983 83 50440, Ext. 4300. E-mail: gislebe@ecosur.mx

Nuria Torrescano-Valle

El Colegio de la Frontera Sur, Unidad Chetumal, Herbario. A.P. 424, C.P. 77014, Chetumal, Quintana Roo, México. Phone: +52 983 83 50440, Ext. 4317. E-mail: ntorresca@ecosur.mx

Abstract

Palynological survey of a mangrove core from southern Pacific Mexico provides accurate information about past vegetation changes from ~6200 – 900 cal yr BP. Highest percentages of mangrove pollen suggest moister and warmer than today conditions from ~6200 – 5400 cal yr BP related with global high rates of sea-level rise and northward position of the Intertropical Convergence Zone (ITCZ), suppressing El Niño-Southern Oscillation (ENSO) events. Dry conditions and globally decreasing rates of sea-level rise at ~5400 – 4400 cal yr BP are suggested by the lowest mangrove and highest presence of disturbance pollen. Recovery of mangroves and tropical forests occurs from ~4400 cal yr BP suggesting moister conditions, while sedimentation rates and lack of variation in pollen composition account for stabilization of the shore line. Agricultural activities are recognized at ~2400 cal yr BP during a moist episode, although human occupation was scarce. A protracted drought is observed at ~1800 – 1000 cal yr BP characterized by proportions in montane forest pollen and may be related with southern oscillation of the ITCZ and the Classical Mayan Demise.

Keywords

Tropical paleoclimate; vegetation change; sea level; Holocene; pollen analysis; Pacific; south-eastern Mexico; mangrove sediments; Central America; Chiapas.

Introduction

Mangroves are complex plant communities fringing coastal areas (Lugo and Snedaker, 1974), developing in tidal zones of the tropics and sub-tropics, where soil is often or permanently water-saturated and salinity may be as high as that of the sea (Hogarth, 1999). Mangroves distribute along the Pacific Coast of Mexico (Rzedowski, 2006) and are considered one of the most diverse, rich and productive ecosystems in Mexico (INE, 1999a). In the Mexican state of Chiapas, mangroves provide environmental services as soil retention, protection from floods during high tides, rain-storms (INE, 1999a) and tsunamis (Alongi, 2008), and also provide refuge and nesting areas for several birds as well as nurseries for marine species (Tovilla-Hernández et al., 2009), turning mangroves in the main food source for the people living within (INE, 1999a). Mangroves around the world are impended by predicted consequences of global climate change (Gilman et al., 2008). In the coast of Chiapas these environments are threatened by expansion of agricultural and livestock frontiers, fast growing human population, and inefficient management of natural resources in the high basins, producing profound changes on the landscape (INE, 1999a).

It is known that Holocene climate conditions have not been stable (Mayewski et al., 2004) and plant communities answer according to the intensity and duration of climate events (Williams et al., 2002). It is also known that local occurrence of mangroves is determined by soil availability, physiographic and coastal conditions (Tomlinson, 1986), and hydrological properties of the basins (Soares, 2009). The linkage between climate and ecological conditions affecting mangroves, makes them ideal indicators of past climate changes (Torrescano-Valle and Islebe, 2012), since their own deposits (peat) provide wet and anaerobic conditions required for long-term preservation of environmental proxies (Ellison, 2008).

All over the world shifts in past climate conditions have been inferred from surveys of mangrove peat. Records from New Zealand, Oman and West Africa reveal that during early to mid-Holocene increased sea-level rise and global warm conditions favored development of mangroves at sites where they no longer occur (Mildenhall, 2001), or allowed more extensive distribution than present relict areas (Lézine, 1997; Lézine et al., 2002). Stanley and Hait (2000) found that mangrove peat records and sedimentation rates in the Great Sundarbans (Bangladesh and India) are best explained by subsidence processes occurring during the Holocene. While rising sea-levels in Bengala Bay caused brackish and mangrove environments dominating intermittently from 7500 to 5500 calibrated years before present (cal yr BP), later (~ 4870 – 4780 cal yr BP) fresh-water dominance resulted as sea-levels decreased (Rashid et al., 2013). Similar conclusions are proposed by Cohen et al. (2012) for Brazil, northern Amazonia, although tectonic subsidence and low river discharge are also responsible for mayor mangrove belt development along the coast during early and middle Holocene; then, increased precipitation during late Holocene transformed the mangrove belt at the estuaries, turning them into fresh-water systems.

Precipitation in the Pacific Coast of Chiapas is related with climate conditions of the circum Caribbean region, since both regions are influenced by the Intertropical Convergence Zone (ITCZ), which north-south movements determine the amount of moisture transported from the Caribbean sea onto the Pacific Ocean via the Panamá Isthmus (Leduc et al., 2007). Palaeoenvironmental records from Caribbean Central America indicate increased precipitation, temperature and sea level from ~8000 to ~4000 cal yr BP (Islebe and Sánchez, 2002; Mueller et al., 2009; Monacci et al., 2011) disrupted by lesser humid episodes (Haug et al., 2001; Carrillo-Bastos et al., 2010) and reduced sea-levels (Wooller et al., 2007). From ~4000 cal yr BP, those records indicate reductions in available moisture. At ~3000 cal yr BP records show discrepancies in timing, strength and length of climate conditions: humid conditions are reported for Puerto Morelos (Islebe and Sánchez, 2002), Punta Laguna (Curtis et al., 1996) and the Lacandon rainforest (Domínguez-Vázquez and Islebe, 2007); drying episodes prevail in the Cariaco basin (Haug et al., 2001) and Lake Tzib (Carrillo-Bastos et al., 2010); while intense human activities are present in the lowlands of northern Guatemala (Mueller et al., 2009). Albeit of contrasting conditions, those records show a drying trend towards ~1000 cal yr BP coinciding with the Classical Mayan Demise.

Few surveys of past environmental conditions have been carried out in the Pacific Coast of Central America. In the Panama Basin mayor introgression events are recorded from 11300 to 5600 cal yr BP coupled with higher precipitations and warmer temperature, except for a period of reduced moisture at 7000 cal yr BP – 5640 cal yr BP (González et al., 2006). Records from Guatemala (Neff et al., 2006a, 2006b, 2006c) and Chiapas (Kennett and Voorhies, 1996; Kennett et al., 2010) bring important insights about human occupation in the area. Those studies provide first significant knowledge about climatic factors that affected Pacific Central America; although, they do not present enough resolution or they are focused on human activities, hence they lack precise information about vegetation responses to past climate changes.

This study refers to vegetation responses to climate changes during the middle and late Holocene using pollen as a proxy, since pollen records are a first step in order for unravel particular effects influencing coastal areas during the Holocene (Leyden, 2002). Particularly, we are interested in dealing with climate or human contributions producing vegetation changes in the mangrove area. We compare our findings with other studies in search for regional or global climate correspondences and discuss the sources of these events.

Study area

Sampling site (15°8.98'N, 92°45.06'W) is located within La Encrucijada Biosphere Reserve (RBLE) in the Mexican state of Chiapas (Figure 1). Climate in the area is Tropical Wet/Dry (Aw), mean annual temperature is 28 ^{o}C with annual precipitation between 1,300 and 3,000 mm. Rainy season occurs from May to November with a mid-summer drought in July and August. Dry season is present from December to April with occasional precipitation in March and April (INE, 1999a). Latitudinal position of RBLE places it under influence of the Intertropical Convergence Zone (ITCZ) which establishes precipitation regime in the area.

Physiographics correspond with the Coastal plain of Chiapas and Guatemala, an intricate network of debris fans along the coast consisting of volcanic deposits accumulated during the Quaternary (Marshall, 2007). Soils are mainly alluvials and lacustrines, although palustrines and littorals may occur. Main soil types are Solonchak, Regosols, Cambisols, Gleysols, Feozems and Fluvisols. Complex lagoon systems are created by infilling of rivers running down from the Sierra Madre de Chiapas and tides from the Pacific Ocean (INE, 1999a). Principal vegetation types in the reserve are mangrove, high tropical forest, gallery forest, salt marshes, coastal dune vegetation and *Pachira aquatica* forest. *Rhizophora mangle* , *R. harrisonii*, *Laguncularia racemosa*, *Avicennia germinans* and *Conocarpus erectus* represent the species of mangroves in the area, with medium heights from 5.9 – 7.9 m of *C. erectus* to 22 – 27.6 m of *R. mangle* and *R. harrisonii* (Tovilla-Hernández et al., 2009). Vegetation surrounding the sample site comprises a low-stature pure stand of *Rhizophora mangle*, 8 - 10 m high and 8 km inland from the shore line. Sediment in the coring site consists of muddy organic peat.

Materials and methods

Selection of coring site was focused on areas with little or none currents-influence and high sedimentation on a mud-water interface. Core CERRITOS02 was extracted using a mud-water interface Russian corer in 50cm-long sections, with a total depth of 600 cm. Each core section was wrapped, labeled and transported to the ECOSUR palynology laboratory. Samples for pollen extraction were taken at 5 cm intervals. A total of eighty pollen samples were treated with standard HCl, KOH and Acetolysis method (Erdtman, 1943; Faegri et al., 1989). Exotic *Lycopodium* spores were used in each pollen sample to assess the pollen concentration and pollen influx. Identification of pollen taxa was possible with the keys of Hooghiemstra (1984), Palacios-Chávez et al. (1991), Roubik and Moreno P. (1991), Sanchez-Dzib et al. (2009), and the pollen reference collection of ECOSUR – Unidad Chetumal.

At least 350 pollen grains were counted per sample using a 400X-magnification light microscope. In samples with low pollen counts a minimum of 100 pollen grains was obtained. Pollen taxa were grouped according with ecological affinity in mangroves, tropical forest, montane forest, disturbance, cultivars and aquatics. Aquatic elements (Cyperaceae, Nymphaceae and *Typha*), fungal elements and fern spores were counted, but not added to the pollen sum, because of over-representation from local elements. In order to recognize additional environmental features, Foraminifera and Charcoal was also noted in presence/absence counts.

Integrated data were presented in a percentages pollen diagram created in TILIA 1.17.16 software package (Grimm, 2001). Pollen zones were delimited according with composition and abundance of pollen taxa using CONISS (Constrained Incremental Sum of Squares) in TILIA.

Three radiocarbon ages were obtained by accelerator mass spectrometry (AMS) and measured from wood and plant material at Beta Analytic Inc., Miami, Florida. Calibration was performed with Calib Radiocarbon Calibration Program 6.1.0 (Stuiver and Reimer, 1986-2011) using the Intcal09 curve (Reimer et al., 2009) with 2σ probability intervals (Table 1). Chronology was calculated by two-linear regression between the three calibrated ages and linear extrapolation for ages out of bounds. Comparison with an age-depth model made in Calib corroborates this chronology.

Results

Core CERRITOS02 represents the last 6250 years with mean annual sedimentation rate of 0.9603 mm/yr. Sample resolution was ~52 years. Change in sedimentation rate was observed at ~3400 cal yr BP (370 cm) (Figure 2). As stated by Neff et al. (2006) in a nearby study site, sand layers were not found in the stratigraphy, discarding intense rainstorms and tsunami events.

Sixty two pollen taxa were identified in the analysis, but only taxa reaching at least 1% are represented in the pollen diagram (Figure 3). Changes in composition and abundances allowed CONISS for delimitation of five pollen zones. However, pollen zone V presented low pollen concentration and high concentrations of silicates which highly reduced observation of pollen grains; hence changes in pollen composition in zone V could not be inferred.

Zone I (~6200 – 5400 cal yr BP; 600 – 530 cm)

Mangrove elements dominate this zone (> 85%) with *Rhizophora mangle* as the dominant species (> 80%). *Laguncularia racemosa* values are low (< 5%) but high peaks (7 – 11%) are present at ~5900, 5800, and 5400 cal yr BP. *Avicennia germinans*, *Conocarpus erectus* and other Melastomataceae/Combretaceae (Melasto/Comb) are low through this zone.

Tropical forest are relatively low (4 – 8 %) but suddenly rises (10 – 18%), indicated by Fabaceae, Moraceae and *Ficus* values*,* at the same lapses as *L. racemosa.* Montane forest pollen was scarce (0 - 3%) represented by *Quercus, Alnus* and *Pinus*. Disturbance taxa show the lowest values in the entire record (0 – 4%). At the end of the period, mangroves sharply decline (91 – 73%), *R. mangle* shows the highest decrease (90 – 60%), while increments in tropical forest (4 – 12%), montane forest (0 – 8%) and aquatics (0 – 1.4%) are noticed.

Zone II (~5400 – 4400 cal yr BP; 530 – 455 cm)

The initial stage of this period denotes the continued trend of declining mangroves started at the end of Zone I. The rest of Zone II presents fluctuations and the lowest values of mangroves for the entire record (2 – 35%; *R. mangle* 2 – 34%), except at ~4900 and ~4800 cal yr BP when high percentages of *L. racemosa* occurred (36 and 34%, respectively).

Higher diversity and abundance of tropical forest taxa account for higher pollen values (9 – 34%). Fabaceae, Moraceae and Euphorbiaceae contribute the most along with Bignoniaceae, *Ficus*, Sapotaceae and *Pouteria.* Montane elements show slight increases (up to 13%), *Quercus* and *Pinus* occurred at higher values (up to 5 and 7%, respectively), and *Abies* occurs at the bottom.

Disturbance taxa present the highest values for the entire record (80%). Chenopodiaceae/Amaranthaceae (Cheno/Ams, up to 73%), Poaceae (up to 10%) and *Cleome* (up to 6%) present higher contributions, although Asteraceae and *Croton* are often represented. Cucurbitaceae pollen is present at ~4900 and 4700 cal yr BP and coinciding with high values of disturbance taxa. Cyperaceae and *Typha* are present though the entire episode with higher and fluctuating values than Zone I (0.09 – 16% and 1 – 14%, respectively).

Zone III (~4400 – 3200 cal yr BP; 455 – 355 cm)

High fluctuations in mangroves characterizes this period, towards higher percentages. *R. mangle* presents great variability (30 – 52%) along the zone, except for a period between ~4000 – 3600 cal yr BP with high stable values. Low oscillations in *L. racemosa* (1 – 10%), Melasto/Comb (< 2%), and *C. erectus* (< 3%) are noted in the whole period, except at ~4400 cal yr BP with a peak of *L. racemosa*. *A. germinans* is absent in this period except of ~4100 – 3500 cal yr BP. Tropical forest elements also exhibit high variability (5 – 42.5%) with the highest values in the record as opposed with mangroves. Main representatives are Fabaceae, Euphorbiaceae and *Ficus*, frequent but with lower values are Moraceae, Sapotaceae and Bignoniaceae. Two peaks of tropical forest taxa at ~4300 and 3600 cal yr BP are opposed to both mangrove elements and disturbance taxa.

Montane forest show a steady low values during this zone. *Quercus* is expressed more often and with higher values (up to 4%) than Zone II, while *Pinus* decreases in frequency and abundance (up to 3%). *Alnus* presents high frequency but with low percentages. Disturbance taxa show lower and more variable values (11 – 32%) than the previous zone. Cheno/Ams suddenly increases (52%) at ~4100 cal yr BP, corresponding with the lowest values of mangroves (19%). Aquatics are scarce but a dominance of *Typha* over Cyperaceae is noticed. Foraminifera are present from ~4100 – 4000 cal yr BP, whereas charcoal is very often.

Zone IV A (~3200 – 2500 cal yr BP; 355 – 290 cm)

Mangroves steadily increase with higher values (73 – 88%). *R. mangle* is favored (61 – 82%), while *L. racemosa* is high at first (8 – 10%) but is lowered (0 – 5%) in later episodes. *Conocarpus erectus* shows a lowering trend, while *A. germinans* disappears from the record.

Tropical forests taxa are low (4 – 26%) during this phase, Fabaceae and Euphorbiaceae are best represented. Moist tropical forest elements (Moraceae, *Ficus* and Sapotaceae) are diminished; except for *Haematoxylum* (up to 3%) at different intervals. Montane forests decline in this period (2 – 6%) with *Quercus* and *Pinus* (up to 3%, both) as the dominant species, *Alnus* is through this zone with low values as in zone III.

Reduced abundance and frequency of disturbance taxa is observed in this sub-zone. Cheno/Ams (0.5 – 13%) and Asteraceae (0.5 – 1.5%) are most frequent taxa, with a continuous reduction trend in the former. Aquatics are highly reduced in this episode (< 3%), with alternate dominance between *Typha* and Cyperaceae. Discarding the early and later phases, Foraminifera is recognized through the whole sub-zone (~3100 – 2700 cal yr BP), while charcoal occurs from ~3200 – 2900 cal yr BP.

Zone IV B (~2500 – 900 cal yr BP; 290 – 135 cm).

A sudden drop in mangrove elements distinguishes the early phase (~2600 – 2300 cal yr BP) of this zone, and then a fluctuating trend unto higher percentages (73%) is observed until the end of the zone, when variability declines. *Rhizophora mangle* is the dominant species during this period (24 – 72%) and counter-oscillates with *L. racemosa* values (0.5 – 13%). *C. erectus* and Melasto/Comb occur during this phase at low accounts (< 4 and < 2%, respectively), coinciding with high values of *R. mangle. Avicennia germinans* is present only at ~1900 cal yr BP.

Tropical forest taxa display higher and steadier values (9 – 25%) than the previous zone. Fabaceae is the dominant species (up to 20%) and shows a declining trend towards the end of the zone. Euphorbiaceae is the second most abundant with higher percentages (up to 4%) at the early phases. Less frequent taxa are Moraceae, *Ficus*, Sapotaceae, *Pouteria* and Loranthaceae (< 1%). Montane forests maintain low values (up to 9%) with three-mode dominance among *Quercus* (up to 6%, ~2500 – 1900 cal yr BP), *Alnus* (up 2%, ~1800 – 1700 cal yr BP) and *Pinus* (up to 2%, ~1500 – 1100 cal yr BP).

High variability in disturbance taxa with relative high values (up to 41%) is observed from ~2500 – 2300 cal yr BP and corresponds with high values in tropical forest while it contrasts with mangroves abundance. Variability is then lowered at later stages. Representative taxas are Cheno/Ams, Asteraceae and Poaceae. Important increases in *Croton* are observed at ~2500, 2400, and 2300 cal yr BP. A single pollen grain of *Zea mays* through the entire record is found at ~2400 cal yr BP. Cyperaceae and *Typha* are present with a lowering trend until ~2000 cal yr BP, after which they are present at low values. Charcoal particles are observed continuously from the early zone to ~1900 cal yr BP. Foraminifera is absent in this zone, except at ~1200 cal yr BP.

Discussion

Middle Holocene (6200 – 4400 cal yr BP)

Values of mangrove pollen and foraminifera at 6200 – 5400 cal yr BP indicate a fringe mangrove around the coring site, dominated by *R. mangle* pure stands and with high tidal-influence (Pool et al., 1977; Medeanic et al., 2008; Urrego et al., 2009) (Figure 3). Presence of *C. erectus* and *L. racemosa* may be explained by water-transportation since both species are best represented on riverine and in-land environments (Pool et al., 1977; Tomlinson, 1986; Urrego et al., 2009). Despite low counts, we cannot rule out *Avicennia germinans* as a main element simply by pollen analysis, since this species present low pollen production (Tomlinson, 1986) and it often occurs in patchy distributions (Urrego et al., 2009).

This episode of mangrove favored ecosystems corresponds with episodes of rising sea levels, high precipitation and warm temperature reported for the Panamá Basin (11300 – 5600 cal yr BP; González et al., 2006), the Cariaco Basin (10500 – 5400 cal yr BP; Haug et al. 2001), North of Mexico (mid-Holocene to ~4000 cal yr BP; Metcalfe et al. 2000), and the lowlands of north Guatemala (~8000 – 4500 cal yr BP; Mueller et al. 2009). In Southern Chiapas, a dominance of mangrove forests is observed from 6600 to 4100 cal yr BP (Kennett et al., 2010). Meanwhile, Neff et al. (2006) reported high precipitations and a high forest cover at ~6000 cal yr BP in North-Pacific of Guatemala, with a drying trend from ~5850 to 5000 cal yr BP, although conditions were humid enough to support mature rainforests. Increased humidity and temperature during this period is related with increased insolation reported for the Caribbean region (Leyden, 2002), forcing the ITCZ to move north-ward, increasing precipitation over Mesoamerica (Haug et al., 2001), and finally suppressing ENSO events (Roy et al., 2010). Latitudinal extent of this events points for an orbital-induced insolation event as the causing factor behind the warm-humid events of the mid-Holocene (Clement et al., 2000).

Low values of montane forest and somehow dominance of *Quercus* in these forests at 6200 – 5400 cal yr BP support warmer and moister conditions (Correa-Metrio et al., 2011). Rodgers and Horn (1996) and Bush (2000) warn about miss-interpretation of *Quercus* pollen in the lowlands, since *Quercus oleoides* is present from 50 – 500 m above sea level (a.s.l.) (Horn, 1985). *Quercus* forests are reported over 700 m a.s.l. in the Pacific side of the Sierra Madre Oriental (INE, 1999a, 1999b; Salas Morales et al., 2007; Martínez-Meléndez et al., 2008; Pérez-Farrera et al., 2012) and pollen representation out of range is explained because this genera is one of the few wind-pollinated montane species (Jacobs, 1982; Islebe and Hooghiemstra, 1995).

Starting at ~5400 cal yr BP (Zone II), sharp drops in mangrove elements, increases in tropical forest taxa and lack of foraminifera, suggest the environment rapidly changed into an in-land mangrove (Urrego et al., 2009)(Figure 3). Increment of disturbance taxa pollen could also reflect expansion of drier environments like tropical sub-deciduous forests and secondary vegetation, since pollen from these environments is mainly represented by Cheno/Ams, Asteraceae and Poaceae (Jacobs, 1982). Additionally, Amaranthaceae are representative herbs of tropical sub-deciduous and thorn forests in the Pacific Coast of Chiapas and Oaxaca (Salas Morales et al., 2007; Martínez-Meléndez et al., 2008; Pérez-Farrera et al., 2012). Higher counts on montane forest pollen and dominance of *Pinus* indicate regional reductions in the temperature (Correa-Metrio et al., 2011) and probably less precipitation that accounted for more open vegetation (Domínguez-Vázquez et al., 2004). In open vegetation forests erosion by runoff is more frequent and could explain increased occurrence of tropical forest pollen in the sediments coupled with higher accounts of disturbance taxa. Abundance of tropical forest and disturbance taxa versus mangrove forests also suggests periods of decreasing sea-level rise, allowing succession in areas previously occupied by mangroves (González et al., 2006). Increments in Cyperaceae and *Typha* pollen from 5400 – 4400 cal yr BP could be interpreted as growing salt-marshes derived from rising sea-levels and increased fresh-water input (Urrego et al., 2009; Kennett et al., 2010). Although, higher values in these taxa could be better explained by basin geomorphology, as water level decreased in response for less humidity and retiring sea-shore, availability of environments with different salinities could have increased (Bush, 2002).

The middle Holocene features a strong lowering of sea-level rise from ~7700 – 4760 cal yr BP. Affected mangrove ecosystems are reported in the Caribbean region (Toscano and Macintyre, 2003), Sibun River, Belize (Monacci et al., 2011), the coast of Oman (Lézine et al., 2002) and Bangladesh (Rashid et al., 2013). In addition, the late of the middle Holocene is also associated with decreased humidity periods. González et al. (2006) reported a phase of mangrove reduction in the Panama Basin at 6500 cal yr BP coinciding with a dry event reported for South America. A dry episode is observed in Central Mexico at 6000 – 5000 cal yr BP, albeit much variability exists among sites (Metcalfe et al., 2000); precipitation decreases in the Cariaco Basin at ~5000 cal yr BP (Haug et al., 2001), while Mayewski et al. (2004) observe a global scale event of "cold poles, dry tropics" at 6000 – 5000 cal yr BP, probably caused by diminished solar radiation. In Lake Tzib, the Yucatan Peninsula, lower precipitation is inferred at 6500 – 4700 cal yr BP (Carrillo-Bastos et al., 2010). In North Pacific Guatemala, higher aridity index is recorded at 5270 – 4750 cal yr BP with arboreal taxa reduced to a minimum at 4750 cal yr BP and a dominance of Cheno/Ams (Neff et al., 2006c). Meanwhile, Kennett et al. (2010) attribute high percentages of Cheno/Ams and Asteraceae at 4200 – 3900 cal yr BP to human activities near from our study site.

Sudden rises of *L. racemosa* are observed at ~5900, 5800, 5400, 4900, 4800 and 4400 cal yr BP (Figure 3) suggest short periods (~50 years) of fresh-water dominated environments as a result of intense precipitation, since *L. racemosa* occurs in fresh-water inundated areas (Rodgers and Horn, 1996) of riverine environments (Pool et al., 1977). However, highest values of *L. racemosa* pollen at 4900, 4800 and 4400 cal yr BP could result as this species colonizes disturbed areas, forming pure stands (Tomlinson, 1986), hence allowing best representation of *Laguncularia* pollen in sediments. At those ages, rapid colonization of *L. racemosa* could have occurred after fresh-water inundated areas formerly dominated by open vegetation during dry episodes.

Rapid episodes of fresh-water input are reported by Kennett et al. (2010) in core SOC05-2 at times between 6600 to 4100 cal yr BP in a nearby study, although ages are dissimilar. Elemental data in the Pacific Coast of Guatemala indicates higher precipitation after 4940 cal yr BP, and tropical forests recover after 4750 cal yr BP (Neff et al., 2006c). In Lake Tzib, ^{18}O records shows increased precipitation during a short period at ~5000 cal yr BP in a longer dry phase (Carrillo-Bastos et al., 2010). Those records evidence the presence of brief periods of augmented moisture-availability during the Middle Holocene.

Late Holocene (~4400 – 0 cal yr BP)

Change in sedimentation rates indicate that sea-level stabilization occurred prior 3390 cal yr BP (Figure 2), however lack of extended variations in pollen composition since ~4400 cal yr BP, suggests establishment of the present shore line at that date (Figure 3). Differences in rates of sea-level rise among sites will depend on regional (i.e. geomorphology) and local (i.e. deltaic processes) factors (Ellison and Stoddart, 1991; Soares, 2009). Recovery of *Rhizophora* mangroves at 4400 cal yr BP indicates increased sea-level combined with higher precipitation, enhancing sediment input to the basin, hence spaces for mangrove establishment became available (González et al., 2006). Dominance of *Quercus* and reduced values of *Pinus* and *Alnus* support for regional warm-humid conditions (Metcalfe et al., 2000; Domínguez-Vázquez and Islebe, 2007) during 4400 – 3200 cal yr BP. At ~4300 and 3400 cal yr BP tropical forest taxa are opposed with disturbance taxa and mangroves, suggesting increased moisture. A stable period of mangrove growth from ~4000 to 3600 cal yr BP, occurrence of foraminifera and reductions in aquatics elements suggest marine introgressions.

Contrasting climate conditions have been described for the beginnings of Late Holocene by different authors. A less extensive period of “cold poles, dry tropics” at 4200 – 3800 cal yr BP is observed in several sites around the globe (Mayewski et al., 2004). In Lake Cobá, reduced fluctuations in precipitations are reported from pollen of mesic dry forests around 4700 cal yr B.P. (Leyden, 2002). While, Mueller et al. (2009) suggest a dry period at 4500 – 3000 cal yr BP in the Petén, Guatemala. Increased precipitation is suggested from 4600 to 4100 cal yr BP and a dry episode at 3500 cal yr BP in Lake Tzib (Carrillo-Bastos et al., 2010). Aragón Moreno et al. (2012) reported enough precipitation to support moist tropical forest from 4500 to 3000 with a drying trend started at 3460 cal yr BP in the northern Peninsula. Records from Puerto Morelos show higher values in mangrove elements and tropical forest taxa suggest a sustained and higher-than-today humid episode at 3600 – 3300 cal yr BP (Torrescano-Valle and Islebe, 2012). Neff et al. (2006c) reported humid conditions for northern Pacific Guatemala from 4750 – 4300 cal yr BP; then, reductions in organic carbon and increased carbonates at 4200 – 4000 cal yr BP may suggest marine introgression, and brief dry events are reported at 4300 and 4100 cal yr BP, with the driest event observed after 4000 cal yr BP (Neff et al., 2006c). Results are also corroborated with records from southern Chiapas where environmental change from brackish to fresh-water dominated is observed at 4700 – 4200 cal yr BP, and recovery of mangroves at 4200 – 3900 cal yr BP suggests slight marine-influenced conditions (Kennett et al. 2010).

A transition towards steady and more favorable conditions for mangrove development was established at 3200 cal yr BP. Increasing values of *Rhizophora mangle* and presence of foraminifera suggests a transition to brackish environments (Figure 3). Little reduction of tropical forest pollen is observed suggesting reduced moisture, but precipitation was enough to allow persistence of tropical forests. Reductions in montane elements suggest increasing temperatures; although elements from colder areas (*Pinus* and *Alnus*) persist at low values, indicating persistence of these forests at higher altitudes.

At 2500 – 2300 cal yr BP reductions of mangroves and increased values of disturbance and moist tropical forest elements could suggest decreased precipitation. However, presence of *Zea mays* pollen (~2400 cal yr BP) (Figure 3) and continual charcoal occurrence (~2500 to 1900 cal yr BP) suggest agricultural activities in the area, since disturbance taxa are well represented in human environments (Leyden, 2002). Dominance of *Quercus* in the montane forests also suggests regional warm-humid climates in a longer period (3200 – 2500 cal yr BP).

Our results correspond with those reported for the Gulf of Mexico, the Yucatan Peninsula and the Pacific Coast of Chiapas and Guatemala. Leyden (2002) reported a mangrove – brackish – fresh-water transition observed at 3400 – 3150 cal yr BP in coastal Tabasco, related with increased moisture and reduced sea-level rise (Leyden, 2002). The pollen record from Lake Tzib indicates higher precipitation at 3000 – 1900 cal yr BP and the development of a medium-statured tropical forest (Carrillo-Bastos et al., 2010). Kennett and Voorhies (1996), in a study performed near our site, observed stable temperature and precipitation at 3000 – 1800 cal yr BP, very similar to present days. Stable humid conditions are reported from 2800 to 1900 cal yr BP in Pacific Guatemala, with reduced moisture from 2600 to 2400 cal yr BP (Neff et al., 2006c). This short episode of reduced moisture during a longer humid episode could have facilitated agricultural labors in the area (Mueller et al., 2009).

Regional changes toward lower temperatures and slightly dryer conditions are inferred at ~1800 – 1700 cal yr BP from changes in dominance of *Quercus* to *Alnus* forests in the highlands (Figure 3). *Alnus* occurs in colder conditions than *Quercus* at upper latitudes (Islebe and Hooghiemstra, 1995) and it is a opportunistic species in disturbed montane forests (Weng et al., 2004). At 1700 – 1000 cal yr BP montane forest became *Pinus* dominated, indicating cooler and dryer conditions. Additionally at ~1700 – 1000 cal yr BP, lower values of *Rhizophora* pollen than in the two previous zones, reductions in *Laguncularia racemosa* along with tropical forest elements, and sustained presence of disturbance taxa are explained as a result of decreasing moisture availability in the lowlands.

Elemental proxies along with reductions in forest cover and increments in disturbance taxa and charcoal account for increased agricultural activities during high moisture conditions in the Pacific coast of Guatemala for the period 1800 – 1200 cal yr BP (Neff et al., 2006c). However, lack of charcoal and cultivar pollen in our record at this time support inferences about conditions with reduced moisture.

Discrepancies between records may result since geochemical and sedimentological proxies indicate local effects, while pollen is a better indicator for regional effects (Mueller et al., 2010).

Dry conditions at 1200 cal yr BP are reported in tropical and subtropical areas (Mayewski et al., 2004), coinciding with the Classic Mayan Collapse. In lake Chichancanab a dry trend is observed at 3800 – 1400 cal yr BP, in spite of date corrections by hard water effects (Leyden, 2002). A drying trend is suggested from 1300 – 1200 cal BP in Lake Tzib, with higher peak at 1200 cal yr BP; although dry conditions occurred until 850 cal yr BP (Carrillo-Bastos et al., 2010). Records from Punta Laguna indicate a dry event from ~1700 to 840 cal yr BP, with higher intensity from ~1170 to 840 cal yr BP (Curtis et al., 1996). Strong dry events are reported in Puerto Morelos at ~1380 – 1180 cal yr BP, then from ~1180 – 890 cal yr BP humid conditions are observed, and from ~890 cal yr BP to present, dry conditions are suggested (Islebe and Sánchez, 2002). The San José Chulchaca record in the Yucatan peninsula show the driest period reported for this area at 1500 – 900 cal yr BP (Metcalfe et al., 2000).

Several peaks in tropical forest taxa coincide with high values of disturbance taxa suggesting short periods (~50 years) of reduced humidity within more humid phases at 4400 – 3200 and 2500 – 900 cal yr BP. Conversely, sudden rises in *L. racemosa* pollen coupled with tropical forest and disturbance taxa are noticed during the same periods, indicate short periods of higher precipitation and reduced marine influence (Figure 3). Intermittent presence of *Typha* also suggests short-periods of fresh-water entrance (Urrego et al., 2009), even at low values.

Reduced intensity and length between short humid-dry events during Late Holocene may result from more frequent ENSO events, established at ~4000 cal yr BP (Toth et al., 2012), with highest frequency reported at ~1200 cal yr BP (Moy et al., 2002). Width century-scale oscillations are observed in the Cariaco Basin from 3800 – 2800 cal yr BP and correlate increased ENSO variability with movements of the ITCZ (Haug et al., 2001). Clay deposits in Lake Petén Itzá indicate unstable climate conditions around

1750 – 1000 cal yr BP (Mueller et al., 2010). The Coast of Pacific Guatemala present dry and variable conditions at 1250 – 470 cal yr BP in the north (Neff et al., 2006c), and from 1100 to 600 cal yr BP in the south (Neff et al., 2006a). All these records manifest the high variability in climate conditions during late Holocene.

Causes of environmental change in the Pacific coast

According with Curtis et al. (1996), changes in precipitation were the dominant factor during the Holocene. These changes are related with movements of the Intertropical Convergence Zone, reaching northern latitudes in humid times, and southern locations in arid periods (Haug et al., 2001). The ITCZ displaces to southern position in warm ENSO events, resulting in precipitation deficit during the rainy season in Central America and the north side of South America (Neff et al., 2006c). Simulation models associates a reduction in frequency and intensity of ENSO events in the mid- to late-Holocene with reduced insolation during the boreal summer as a result of orbital induced changes (Clement et al., 2000). However, insolation drops do not account for the dry events reported at 4300 – 3800 and 1200 – 1000 cal yr BP (Mayewski et al., 2004). Dry episodes during late-Holocene may also depend on the strength and location of the Bermudas High (Metcalfe et al., 2000), which restricts northern movement of the ITCZ, and on variations in the atmospheric and oceanic circulations (Curtis et al., 1996).

Human activity was inferred from charcoal concentrations in the swamps of Pacific Guatemala from 5000 cal yr BP at three different sites intermittently (Neff et al., 2006b). Presence of Cucurbitaceae pollen at ~4900 and ~4700 cal yr BP in our data could support the above. However, charcoal remains are not continuously present during zone I, and neither at ~4700 cal yr BP, suggesting little or none human activities in the mangrove area. Charcoal could be a result from fires ignited in strong thunder-storms during dry events, like in the Petén, Guatemala (Mueller et al., 2009). In addition, Cucurbitaceae occur nowadays in tropical forests upslope from the study site (Martínez-Meléndez et al., 2008; Pérez-Farrera et al., 2012), thus presence of pollen of this cultivars might better be explained by water transport from highlands.

Detection of human populations in the area is difficult due to different factors. First, evidence from different sites of the Pacific coast of Guatemala suggests that human occupation was extensive at low populations in the area, and movements to another area occurred when resources were depleted (Neff et al., 2006b). Second, very few areas near mangroves are able to sustain crop cultivation nowadays (Kennett and Voorhies, 1996), mainly due to lack of hydrological control (Prager, 2006). And third, morphology and weight of *Zea mays* pollen account for lower representation, even in proximity of crop fields (Kennett et al., 2010). Scarcity of evidence of human impacts in our study site also agrees with the statement that enormous variability in the environment explains low populations and lack of permanent establishment in the mangrove area (Neff et al., 2006b).

Abrupt climate changes could increase mortality of adult trees by increasing susceptibility to environmental stressors (Williams et al., 2002). Evidences indicate that, though fragile, mangroves can persist over abrupt climate change. Complexity index may express the environmental limitations at which any given vegetation is exposed, restricting resources availability needed for full development (Pool et al., 1977). For the mangroves from the Pacific Coast of Chiapas complexity index (calculated from Tovilla-Hernández et al. 2009) lay under the parameters indicated for the Pacific Coast mangroves. Pacific coast mangroves are thought to have lower complexity index because they present lower humidity than Caribbean Sea mangroves, however greater run-off and subsequent sediment catching by mangroves permit higher complexity in the Pacific Coasts (Pool et al., 1977). These features altogether may explain the high resilience of mangroves in the Pacific Coast of Chiapas to Holocene climate changes.

Diverse factors are responsible for maintenance of mangroves. Mangrove response to sea-level rise will depend on rates of rise and sediment accumulation, changes on elevation, space availability for migration and ecological competition present in those areas. Mangrove extinctions may occur if sea-level rising rates are higher than sedimentation and migration rates (Soares, 2009). While, future migrations of vegetation may be limited by fragmentation caused by humans activities, or enhanced by intentional propagule dispersal (Williams et al., 2002). But predicted sea-level rise of 100-200 cm for the next 100 years (Ellison and Stoddart, 1991), and the constant threatening of a growing agricultural and livestock frontier (INE, 1999a), envisage a dark panorama for the persistence of the mangroves in the Coast of Chiapas.

Conclusions

Core CERRITOS02 represents changes in vegetation for the time frame between ~6200 and 900 cal yr BP, and provides evidence of environmental changes affecting mangrove vegetation in the coast of Chiapas. The most humid and warmest phase is observed for the middle Holocene, related with high rates of sea-level rise that favored *Rhizophora mangle* forests development; intense effects of reduced precipitation and abrupt slowing sea-level rises may account for the lowest proportion of mangrove pollen observed in our record at 5400 – 4400 cal yr BP. The late Holocene boundary is recognized by recovery of mangroves and lack of important changes in pollen taxa at 4400 cal yr BP suggesting increased moisture and establishment of the actual coast line, highly supported by changes in sedimentation rates; a mild stable dry phase is observed at 3200 cal yr BP, allowing marine introgression and development of a brackish environment. Intense agricultural activities are suggested for the 2500 to 1800 cal yr BP period, while regional moist conditions are inferred from montane taxa pollen. Drying trends are observed from 1800 to 1000 cal yr BP, characteristic of Late Holocene conditions. High resolution acquired in our samples allowed us to identify rapid changes in precipitation regime (~50 years); these events are observed in the entire record, although a trend to more frequent and less intense events is noted since the beginning of Late Holocene. A fast-changing environment could have forbidden high human concentrations in the area (Neff et al., 2006b), thus facilitating interpretation of climate events in our results.

In general our data indicate that mangrove from coastal Chiapas are good indicator of past environmental changes in a local and regional extension. However, modern pollen rain studies are desirable for better interpretation of vegetation types coupled with different environmental sets.

Inferences about vegetation changes are obscured for last 900 years in our core. Nevertheless, intense agricultural activities are reported for the last 1000 years in a nearby area (Kennett et al., 2010), and they may explain sedimentological changes observed in the upper sections of core CERRITOS02. Therefore, high-resolution multi-proxy surveys are desired for deciphering regional and local climate events that occurred in the area, and also for precise recognition of human activities at different sites in the upper basin.

Acknowledgements

We thank Cristian Tovilla Hernández, Alicia Carrillo Bastos, Luz Verónica Gutiérrez Ayala, Alejandro Antonio Aragón Moreno and Alejandro Vela Peláez for their support and observations. Also, we would like to thank to Margarito Tuz-Novelo and Gerardo De la Cruz Montes for their help during field work. This work was financed by CONACYT grants program (CVU 384724) and supported by CONACYT research program “Variabilidad climática y paleoecológica de los últimos 1,500 años del sureste de México”.

References cited

Alongi, D.M., 2008. Mangrove forests: Resilience, protection from tsunamis, and responses to global climate change. Estuarine, Coastal and Shelf Science 76, 1–13.

Aragón-Moreno, A.A., Islebe, G.A., Torrescano-Valle, N., 2012. A ~ 3800-yr, high-resolution record of vegetation and climate change on the north coast of the Yucatan Peninsula. Review of Palaeobotany and Palynology 178, 35–42.

Bush, M.B., 2000. Deriving Response Matrices from Central American Modern Pollen Rain. Quaternary Research 54, 132–143.

Bush, M.B., 2002. On the interpretation of fossil Poaceae pollen in the lowland humid neotropics. Palaeogeography, Palaeoclimatology, Palaeoecology 177, 5–17.

Carrillo-Bastos, A., Islebe, G.A., Torrescano-Valle, N., González, N.E., 2010. Holocene vegetation and climate history of central Quintana Roo, Yucatán Península, Mexico. Review of Palaeobotany and Palynology 160, 189–196.

Clement, A.C., Seager, R., Cane, M.A., 2000. Suppression of El Niño during the Mid-Holocene by changes in the Earth’s orbit. Paleoceanography 15, 731–737.

Cohen, M.C.L., Pessenda, L.C.R., Behling, H., De Fátima Rossetti, D., França, M.C., Guimarães, J.T.F., Friaes, Y., Smith, C.B., 2012. Holocene palaeoenvironmental history of the Amazonian mangrove belt. Quaternary Science Reviews 55, 50–58.

Correa-Metrio, A., Bush, M.B., Pérez, L., Schwalb, A., Cabrera, K.R., 2011. Pollen distribution along climatic and biogeographic gradients in northern Central America. The Holocene 21 , 681–692.

Curtis, J.H., Hodell, D.A., Brenner, M., 1996. Climate Variability on the Yucatan Peninsula (Mexico) during the Past 3500 Years, and Implications for Maya Cultural Evolution. Quaternary Research 46, 37–47.

Domínguez-Vázquez, G., Islebe, G.A., 2007. Protracted drought during the late Holocene in the Lacandon rain forest, Mexico. Vegetation History and Archaeobotany 17, 327–333.

Domínguez-Vázquez, G., Islebe, G.A., Villanueva-Gutiérrez, R., 2004. Modern pollen deposition in Lacandon forest, Chiapas, Mexico. Review of Palaeobotany and Palynology 131, 105–116.

Ellison, J.C., 2008. Long-term retrospection on mangrove development using sediment cores and pollen analysis: A review. Aquatic Botany 89, 93–104.

Ellison, J.C., Stoddart, D.R., 1991. Mangrove Ecosystem Collapse during Predicted Sea-Level Rise: Holocene Analogues and Implications. Journal of Coastal Research 7, 151–165.

Erdtman, G., 1943. An introduction to pollen analysis. Chronica Botany Company, Waltham, Massachussetts, E.U.A., 239 pp.

Faegri, K., Johs, I., Kaland, P.E., Krzywinski, K., 1989. Textbook of Pollen Analysis. John Wiley and Sons, 328 pp.

Gilman, E.L., Ellison, J., Duke, N.C., Field, C., 2008. Threats to mangroves from climate change and adaptation options: A review. Aquatic Botany 89, 237–250.

González, C., Urrego, L.E., Martínez, J.I., 2006. Late Quaternary vegetation and climate change in the Panama Basin: Palynological evidence from marine cores ODP 677B and TR 163-38. Palaeogeography, Palaeoclimatology, Palaeoecology 234, 62–80.

Grimm, E., 2001. TILIA. Illinois State Museum, Research and Collections Centre, Springfield, E.U.A.

Haug, G.H., Hughen, K. a, Sigman, D.M., Peterson, L.C., Röhl, U., 2001. Southward migration of the intertropical convergence zone through the Holocene. Science 293, 1304–1308.

Hogarth, P.J., 1999. The biology of mangroves. Oxford University, Oxford, 228 pp.

Hooghiemstra, H., 1984. Vegetational and climatic history of the high plain of Bogotá, Colombia ⍰: a continuous record of the last 3.5 million years. J. Cramer, Vaduz, 368 pp.

Horn, S.P., 1985. Preliminary Pollen Analysis of Quaternary Sediments from Deep Sea Drilling Project site 565, Western Costa Rica. In: Von Huene, R., Aubouin, J., Arnott, R.J., Baltuck, M., Bourgois, J., Helm, R., Ogawa, Y., Kvenvolden, K.A., McDonald, T.J., Taylor, E., McDougall, K., Filewicz, M. V., Winsborough, B., Lienert, B., Orlofsky, S. (Eds.), Initial reports of the Deep Sea Drilling Project covering Leg 84 of the cruises of the Drilling Vessel Glomar Challenger; Balboa, Panama, to Manzanillo, Mexico, January-February 1982. Texas A & M University, Ocean Drilling Program, College Station, TX, United States, College Station, Texas, pp. 533–547.

INE, 1999a. Programa de Manejo. Reserva de la Biósfera La Encrucijada. Instituto Nacional Ecología, México, 184 pp.

INE, 1999b. Programa de Manejo. Reserva de la Biósfera La Sepultura. Instituto Nacional Ecología, Mexico, 248 pp.

Islebe, G.A., Hooghiemstra, H., 1995. Recent pollen spectra of highland Guatemala. Journal of Biogeography 22, 1091–1099.

Islebe, G.A., Sánchez, O., 2002. History of Late Holocene vegetation at Quintana Roo , Caribbean coast of Mexico. Plant Ecology 187–192.

Jacobs, B.F., 1982. Modern Pollen Spectra from Surface Soil Samples, Northern Nayarit, Southern Sinaloa, Mexico. Journal of the Arizona-Nevada Academy of Science 17, 1–14.

Kennett, D.J., Piperno, D.R., Jones, J.G., Neff, H., Voorhies, B., Walsh, M.K., Culleton, B.J., 2010. Pre-pottery farmers on the Pacific coast of southern Mexico. Journal of Archaeological Science 37, 3401–3411.

Kennett, D.J., Voorhies, B., 1996. Oxygen Isotopic Analysis of Archaeological Shells to Detect Seasonal Use of Wetlands on the Southern Pacific Coast of Mexico. Journal of Archaeological Science 23, 689–704.

Leduc, G., Vidal, L., Tachikawa, K., Rostek, F., Sonzogni, C., Beaufort, L., Bard, E., 2007. Moisture transport across Central America as a positive feedback on abrupt climatic changes. Nature 908–911.

Leyden, B.W., 2002. Pollen evidence for climatic variability and cultural disturbance in the Maya lowlands. Ancient Mesoamerica 13, 85–101.

Lézine, A.-M., 1997. Evolution of the west African mangrove during the late Quaternary: a review. Geographie physique et Quaternaire 51, 405–414.

Lézine, A.-M., Saliège, J.-F., Mathieu, R., Tagliatela, T.-L., Mery, S., Charpentier, V., Cleuziou, S., 2002. Mangroves of Oman during the late Holocene; climatic implications and impact on human settlements. Vegetation history and archaeobotany 11, 221–232.

Lugo, A.E., Snedaker, S.C., 1974. The Ecology of Mangroves. Annual Review of Ecology and Systematics 5, 39–64.

Marshall, J.S., 2007. Geomorphology and Physiographic Provinces of Central America. In: Bundschuh, J., Alvarado, G. (Eds.), Central America: Geology, Resources, and Hazards. Taylor & Francis, London, pp. 75 – 122.

Martínez-Meléndez, J., Pérez-Farrera, M.Á., Farrera-Sarmiento, O., 2008. Inventario florístico del Cerro El Cebú y zonas adyacentes en la Reserva de la Biosfera El Triunfo (Polígono V), Chiapas, México . Boletín de la Sociedad Botánica de México 21–40.

Mayewski, P., Rohling, E., Curtstager, J., Karlen, W., Maasch, K., Davidmeeker, L., Meyerson, E., Gasse, F., Vankreveld, S., Holmgren, K., 2004. Holocene climate variability. Quaternary Research 62, 243–255.

Medeanic, S., Zamora, N., Correa, I., 2008. Non-pollen palynomorphs as environmental indicators in the surface samples from mangrove. Revista Geológica de América Central 39, 27–51.

Metcalfe, S.E., O'Hara, S.L., Caballero, M., Davies, S.J., 2000. Records of late Pleistocene - Holocene climatic change in Mexico - a review. Quaternary Science Reviews 19, 699–721.

Mildenhall, D.C., 2001. Middle Holocene mangroves in Hawke's Bay, New Zealand. New Zealand Journal of Botany 39, 517–521.

Monacci, N.M., Meier-Grünhagen, U., Finney, B.P., Behling, H., Wooller, M.J., 2011. Paleoecology of mangroves along the Sibun River, Belize. Quaternary Research 76, 220–228.

Moy, C.M., Seltzer, G.O., Rodbell, D.T., Anderson, D.M., 2002. Variability of El Niño/Southern Oscillation activity at millennial timescales during the Holocene epoch. Nature 420, 162–165.

Mueller, A.D., Islebe, G.A., Anselmetti, F.S., Ariztegui, D., Brenner, M., Hodell, D. a., Hajdas, I., Hamann, Y., Haug, G.H., Kennett, D.J., 2010. Recovery of the forest ecosystem in the tropical lowlands of northern Guatemala after disintegration of Classic Maya polities. Geology 38, 523–526.

Mueller, A.D., Islebe, G.A., Hillesheim, M.B., Grzesik, D.A., Anselmetti, F.S., Ariztegui, D., Brenner, M., Curtis, J.H., Hodell, D. a., Venz, K. a., 2009. Climate drying and associated forest decline in the lowlands of northern Guatemala during the late Holocene. Quaternary Research 71, 133–141.

Neff, H., Bove, F.J., Genovez, J. V., 2006a. El clima y la naturaleza de la ocupación del Postclásico en la Costa Sur de Guatemala. In: Laporte, J.P., Arroyo, Bárbara, Mejía, H. (Eds.), XIX Simposio de Investigaciones Arqueológicas en Guatemala, 2005. Museo Nacional de Arqueología y Etnología, Guatemala, pp. 149–155.

Neff, H., Pearsall, D.M., Jones, J.G., Arroyo, B., Collins, S.K., Freidel, D.E., 2006b. Early Maya Adaptive Patterns: Mid-Late Holocene Paleoenvironmental Evidence from Pacific Guatemala. Latin American Antiquity 17, 287–315.

Neff, H., Pearsall, D.M., Jones, J.G., Arroyo de Pieters, B., Freidel, D.E., 2006c. Climate change and population history in the Pacific Lowlands of Southern Mesoamerica. Quaternary Research 65, 390–400.

Palacios-Chávez, R., Ludlow-Wiehchers, B., Villanueva G., R., 1991. Flora palinológica de la Reserva de la Biósfera de Sian Ka'an, Quintana Roo, México. Centro de Investigaciones de Quintana Roo, México, 321 pp.

Pérez-Farrera, M.Á., Martínez-Camilo, R., Martínez-Meléndez, N., Farrera-Sarmiento, O., Maza-Villalobos, S., 2012. Listado florístico del Cerro Quetzal (Polígono III) de la reserva de la biosfera El Triunfo, Chiapas, México. Botanical Sciences 90, 113–142.

Pool, D.J., Snedaker, S.C., Lugo, A.E., 1977. Structure of mangrove forest in Florida, Puerto RIco, Mexico and Costa Rica. Biotropica 9, 195–212.

Prager, C., 2006. Jaina: The Island Necropolis. In: Grube, N., Eggebrecht, E., Seidel, M. (Eds.), Maya: Divine Kings of the Rain Forest. Könemann, Cologne, pp. 308 – 309.

Rashid, T., Suzuki, S., Sato, H., Monsur, M.H., Saha, S.K., 2013. Relative sea-level changes during the Holocene in Bangladesh. Journal of Asian Earth Sciences 64, 136–150.

Reimer, P.J., Baillie, M.G.L., Bard, E., Bayliss, A., Beck, J.W., Blackwell, P.G., Ramsey, C.B., Buck, C.E., Burr, G.S., Edwards, et al., 2009. IntCal09 and Marine09 Radiocarbon Age Calibration Curves, 0-50,000 Years cal BP. Radiocarbon 51, 1111–1150.

Rodgers, J.C., Horn, S.P., 1996. Modern pollen spectra from Costa Rica. Palaeogeography, Palaeoclimatology, Palaeoecology 124, 53–71.

Roubik, D.W., Moreno P., J.E., 1991. Pollen and spoes of Barro Colorado Island. Missouri Botanical Garden, 268 pp.

Roy, P.D., Caballero, M., Lozano, R., Ortega, B., Lozano, S., Pi, T., Israde, I., Morton, O., 2010. Geochemical record of Late Quaternary paleoclimate from lacustrine sediments of paleo-lake San Felipe, western Sonora Desert, Mexico. Journal of South American Earth Sciences 29, 586–596.

Rzedowski, J., 2006. Vegetación de México. Comisión para el Conocimiento y Uso de la Biodiversidad, Mexico, 504 pp.

Salas Morales, S.H., Schibli, L., Nava Zafra, A., Saynes Vásquez, A., 2007. Flora de la costa de Oaxaca, México (2): lista florística comentada del parque nacional Huatulco. oletín de la Sociedad Botánica de México 101–130.

Sanchez-Dzib, Y. de L.A., Sosa-Najera, S., Lozano-Garcia, M. del S., 2009. Morfología Polínica de Especies de la Selva Mediana Subperennifolia en la Cuenca del Río Candelaria, Campeche. Boletín de la Sociedad Botanica de México 84, 93–104.

Soares, M.L.G., 2009. A Conceptual Model for the Responses of Mangrove Forests to Sea Level Rise. Journal of Coastal Research 267–271.

Stanley, D.J., Hait, A.K., 2000. Holocene Depositional Patterns, Neotectonics and Sundarban Mangroves in the Western Ganges-Brahmaputra Delta. Journal of Coastal Research 16, 26–39.

Stuiver, M., Reimer, P.J., (1986–2011). Calib Radiocarbon Calibration Program. .

Tomlinson, P.B., 1986. The botany of mangroves. Cambridge University, Cambridge, 419 pp.

Torrescano-Valle, N., Islebe, G.A., 2012. Mangroves of Southeastern Mexico ⍰: Palaeoecology and Conservation. The Open Geography Journal 5, 6–15.

Toscano, M.A., Macintyre, I.G., 2003. Corrected western Atlantic sea-level curve for the last 11,000 years based on calibrated 14C dates from Acropora palmata framework and intertidal mangrove peat. Coral Reefs 22, 257–270.

Toth, L.T., Aronson, R.B., Vollmer, S. V, Hobbs, J.W., Urrego, D.H., Cheng, H., Enochs, I.C., Combosch, D.J., Van Woesik, R., Macintyre, I.G., 2012. ENSO drove 2500-year collapse of Eastern Pacific coral reefs. Science 336, 81–84.

Tovilla-Hernández, C., Aguilar-López, E., Gordillo-Solís, O.G., Rojas-García, J., Vázquez-Lule, A.D., 2009. Caracterización del sitio de manglar La Encrucijada. In: (CONABIO), Comisión Nacional para el Conocimiento y Uso de la Biodiversidad (Ed.), Sitios de manglar con relevancia biológica y con necesidades de rehabilitación ecológica. CONABIO, México, pp. 1–15.

Urrego, L.E., Bernal, G., Polanía, J., 2009. Comparison of pollen distribution patterns in surface sediments of a Colombian Caribbean mangrove with geomorphology and vegetation. Review of Palaeobotany and Palynology 156, 358–375.

Weng, C., Bush, M.B., Silman, M.R., 2004. An analysis of modern pollen rain on an elevational gradient in southern Peru. Journal of Tropical Ecology 20, 113–124.

Williams, J.W., Post, D.M., Cwynar, L.C., Lotter, A.F., 2002. Rapid and widespread vegetation responses to past climate change in the North Atlantic region. Geology 30, 971–974.

Wooller, M.J., Morgan, R., Fowell, S., Behling, H., Fogel, M., 2007. A multiproxy peat record of Holocene mangrove palaeoecology from Twin Cays, Belize. The Holocene 17 , 1129–1139.

List of Tables

Table 1. Radiocarbon (AMS) dates and calibrated dates for core CERRITOS02.

List of figures

Figure 1. Location of Coring site, main water bodies and main vegetation types in the area.

Figure 2. Age-depth model, showing probability for each radio-carbon date.

Figure 3. Pollen diagram.

Table 1

Laboratory code	Sample code	Depth (cm)	Description	Radiocarbon age (yr BP)	2σ calibration (cal yr BP)	Average age (cal yr BP)	2σ probability
BETA333846	CERRITOS577	577	plant remains	5220 ± 40	5907-6026	5966.5	0.834448
BETA335127	CERRITOS370	370	plant remains	3150 ± 30	3333-3446	3389.5	0.986056
BETA333844	CERRITOS292	292	wood	2520 ± 30	2488-2644	2566	0.710524

Figure 1

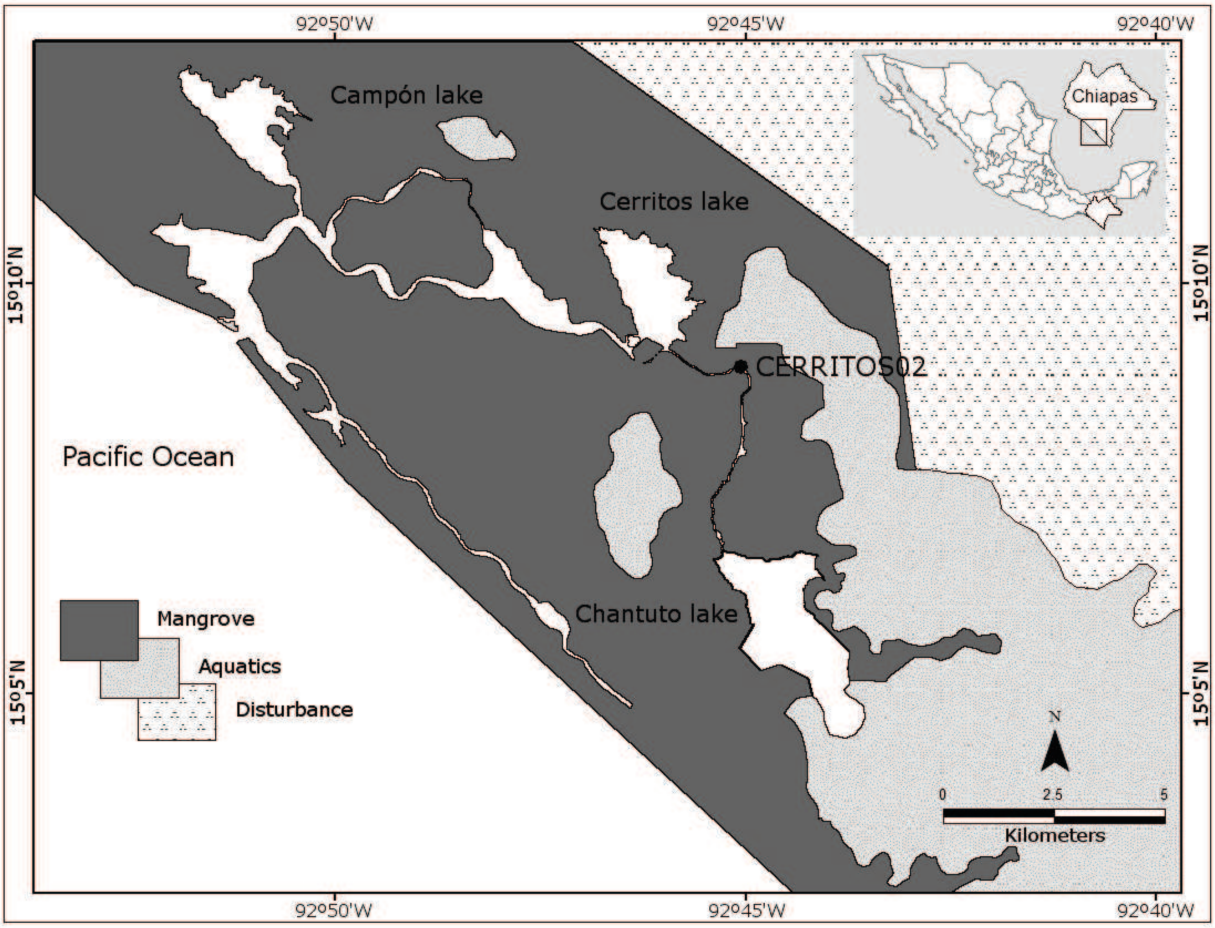

92°50'W
92°45'W
92°40'W
15°10'N
15°5'N
Campón lake
Cerritos lake
Chantuto lake
CERRITOS02
Pacific Ocean
Chiapas
Mangrove
Aquatics
Disturbance
N
0
2.5
5
Kilometers

Figure 2

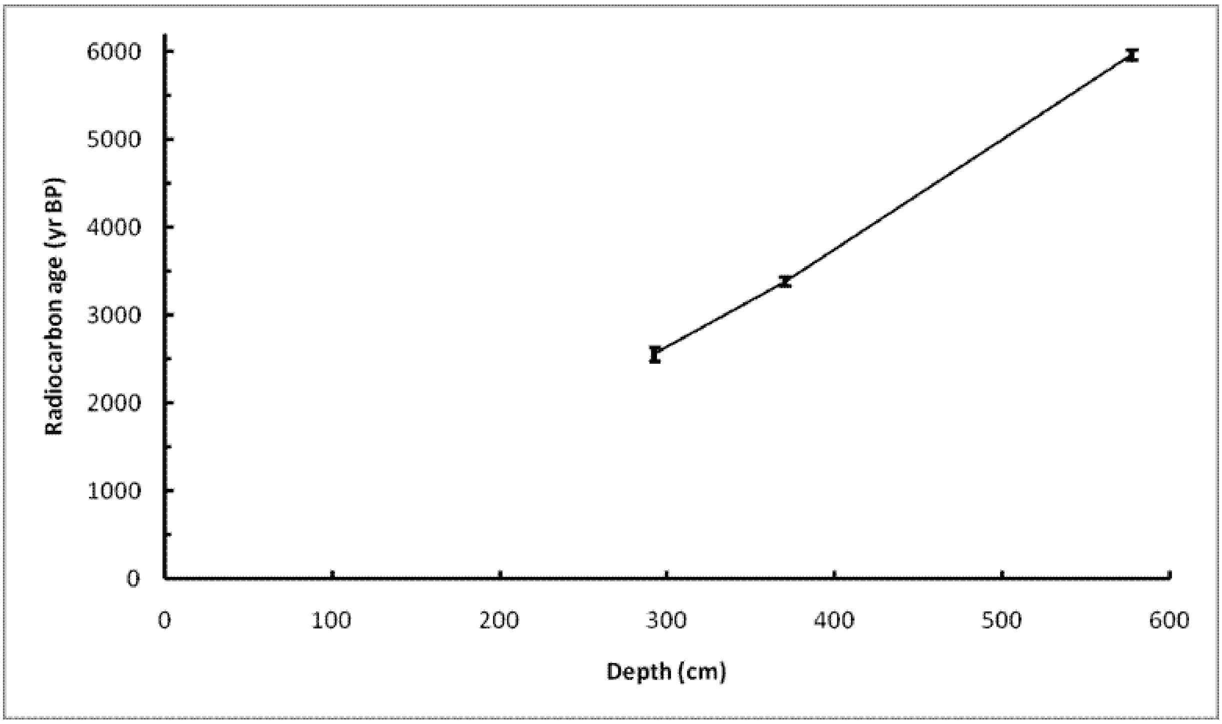
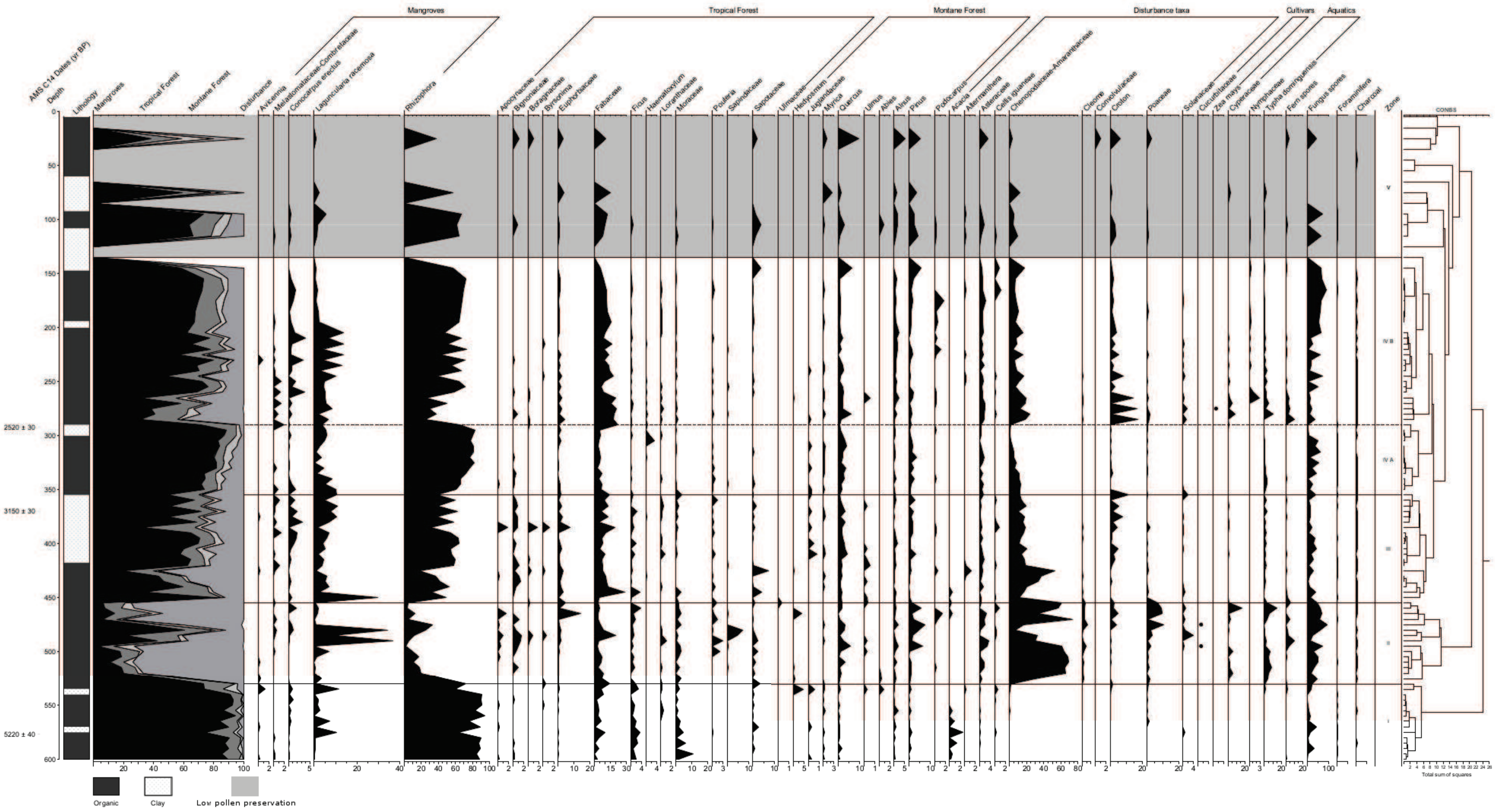

Radiocarbon age (yr BP)
6000
5000
4000
3000
2000
1000
0
0
100
200
300
400
500
600
Depth (cm)

Figure 3


Mangroves
Tropical Forest
Montane Forest
Disturbance taxa
Cultivars
Aquatics
AMS C14 Dates (yr BP)
Depth
Lithology
Mangroves
Tropical Forest
Montane Forest
Disturbance
Avicennia
Melastomataceae-Combretaceae
Conocarpus erectus
Laguncularia racemosa
Rhizophora
Apocynaceae
Bignoniaceae
Boraginaceae
Byrsonima
Euphorbiaceae
Fabaceae
Ficus
Haematoxylum
Loranthaceae
Moraceae
Pouteria
Sapindaceae
Sapotaceae
Ulmaceae
Hedyosmum
Juglandaceae
Myrica
Quercus
Ulmus
Abies
Alnus
Pinus
Podocarpus
Acacia
Alternanthera
Asteraceae
Celtis iguanaea
Chenopodiaceae-Amaranthaceae
Cleome
Convolvulaceae
Croton
Poaceae
Solanaceae
Cucurbitaceae
Zea mays
Cyperaceae
Nymphaceae
Typha domingensis
Fern spores
Fungus spores
Foraminifera
Charcoal
Zone
CONISS
2520 ± 30
3150 ± 30
5220 ± 40
V
IV B
IV A
III
II
I
Total sum of squares
Organic
Clay
Low pollen preservation

Conclusiones finales

El análisis palinológico del núcleo CERRITOS02 permitió la reconstrucción de la historia ambiental de los manglares de la costa de Chiapas durante los últimos 6000 años. Altas tasas de sedimentación y poca interferencia de actividades humanas en los manglares de la llanura costera de Chiapas y Guatemala (Neff et al., 2006a) favorecieron la alta resolución de muestreo obtenida en este estudio.

Polen fósil perteneciente a 62 taxa, agrupados en seis grupos ecológicos (Anexo), permitió el reconocimiento de cambios en la vegetación a diferentes escalas espaciales y temporales como consecuencia de eventos climáticos. El análisis de foraminíferos y partículas de carbón presentes en las muestras fue de gran apoyo en la interpretación de cambios en el nivel del mar y actividades humanas, respectivamente.

Durante el Holoceno medio, el gran desarrollo de bosques de Rhizophora indica la fase de mayor temperatura y precipitación de los últimos 6000 años (6200 – 5400 años AP), relacionada con altas tasas de aumento de nivel del mar. A partir de 5400 años AP, se observa un cambio de la vegetación de manglar por vegetación secundaria, como resultado de condiciones secas y disminuciones abruptas en las tasas de aumento del nivel del mar.

El paso hacia el Holoceno tardío está caracterizado por la recuperación de los manglares y ausencia de cambios importantes en la composición taxonómica del polen a partir de 4400 años AP, lo que sugiere condiciones húmedas y el establecimiento de la línea de costa actual; apoyado por cambios en las tasas de sedimentación. A 3200 años AP se registra una ligera y estable sequía que permitió mayor influencia de agua marina y el desarrollo de un ambiente salobre. El área de estudio presenta evidencia de actividades agrícolas del 2500 a 1800 años AP facilitadas por condiciones húmedas.

Condiciones secas típicas del Holoceno tardío se observan en el periodo 1800 – 1000 años AP.

A lo largo del registro polínico se logran observar cambios rápidos en el régimen de precipitación (aproximadamente de 50 años). Estos eventos se presentan con menor intensidad y mayor frecuencia hacia el final del Holoceno, por lo que podrían relacionarse con eventos ENSO (Moy et al., 2002). Condiciones tan cambiantes pudieron haber limitado el establecimiento de poblaciones humanas (Neff et al., 2006b).

Las condiciones físicas y ambientales actuales en el sitio de muestreo son similares a las del resto de la costa de Chiapas. Por lo tanto, los cambios climáticos inferidos en este estudio pueden ser extrapolados a toda la región.

Altas concentraciones de silicatos observadas en los últimos 900 años de nuestro registro impiden hacer inferencias acerca de los cambios en la vegetación ocurridas en este periodo. Sin embargo, Kennett et al. (2010) reportan actividades agrícolas intensivas para los últimos 1000 años en un área cercana a nuestra zona de estudio, lo que podría explicar los fuertes cambios en la sedimentación observados. Por lo tanto, proponemos llevar a cabo estudios multi-proxies de alta resolución para corroborar nuestros resultados y descifrar nuevos eventos climáticos a diferentes escalas, así como para identificar actividades humanas en la cuenca alta. Del mismo modo, se requieren estudios de lluvia de polen en la región para mejorar las interpretaciones sobre los tipos de vegetación en diferentes condiciones ambientales.

Referencias

Anderson, D.G., Goudie, A.S., Parker, A.G., 2007. Global Environment through the Quaternary. Oxford University Press, Oxford, 392 pp.

Aragón-Moreno, A.A., Islebe, G.A., Torrescano-Valle, N., 2012. A ~ 3800-yr, high-resolution record of vegetation and climate change on the north coast of the Yucatan Peninsula. Review of Palaeobotany and Palynology 178, 35–42.

Bradley, R.S., 1999. Paleoclimatology: reconstructing climates of the quaternary. Academic Press, San Diego, California, xiv, 613 pp.

Carrillo-Bastos, A., Islebe, G.A., Torrescano-Valle, N., González, N.E., 2010. Holocene vegetation and climate history of central Quintana Roo, Yucatán Península, Mexico. Review of Palaeobotany and Palynology 160, 189–196, doi:10.1016/j.revpalbo.2010.02.013.

Cronin, T.M., 1999. Principles of Paleoclimatology. Columbia University Press, New York, 560 pp.

Domínguez-Vázquez, G., Islebe, G.A., 2007. Protracted drought during the late Holocene in the Lacandon rain forest, Mexico. Vegetation History and Archaeobotany 17, 327–333.

Ellison, J.C., 2008. Long-term retrospection on mangrove development using sediment cores and pollen analysis: A review. Aquatic Botany 89, 93–104.

El Niño and La Niña, 2004. Geoscience animations [online] Disponible en: <http://esminfo.prenhall.com/science/geoanimations/animations/26_NinoNina.html> [Accesado 2 de abril, 2012].

Faegri, K., Johs, I., Kaland, P.E., Krzywinski, K., 1989. Textbook of Pollen Analysis. John Wiley and Sons, 328 pp.

Fritz, S.C., 2005. Lacustrine Perspective on Holocene Climate. In: Mackay, A., Battarbee, R., Birks, J., Oldfield, F. (Eds.), Global change in the Holocene. Hodder Education, Londres, pp. 227–241.

Gilman, E.L., Ellison, J., Duke, N.C., Field, C., 2008. Threats to mangroves from climate change and adaptation options: A review. Aquatic Botany 89, 237–250.

González, C., Urrego, L.E., Martínez, J.I., 2006. Late Quaternary vegetation and climate change in the Panama Basin: Palynological evidence from marine cores ODP 677B and TR 163-38. Palaeogeography, Palaeoclimatology, Palaeoecology 234, 62–80.

Gutiérrez-Ayala, L.V., Torrescano-Valle, N., Islebe, G.A., 2012. Reconstrucción paleoambiental del Holoceno Tardío de la reserva Los Petenes, Península de Yucatán, México. Revista Mexicana de Ciencias Geológicas México 29, 749 – 763.

Haug, G.H., Hughen, K. a, Sigman, D.M., Peterson, L.C., Röhl, U., 2001. Southward migration of the intertropical convergence zone through the Holocene. Science 293, 1304–8.

INE, 1999. Programa de Manejo. Reserva de la Biósfera La Encrucijada. Instituto Nacional Ecología, México, 184 pp.

Islebe, G.A., 1998. Vegetación de Quintana Roo. In: Xacur, J. (Ed.), Enciclopedia de Quintana Roo. , pp. 337–343.

Islebe, G.A., Hooghiemstra, H., Brenner, M., Curtis, J.H., Hodell, D.A., 1996. A Holocene vegetation history from lowland Guatemala. The Holocene 6, 265–271.

Islebe, G.A., Leyden, B.W., 2006. La vegetación de Guatemala durante el pleistoceno terminal y el holoceno. In: Cano, E. (Ed.), Biodiversidad de Guatemala. Universidad del Valle de Guatemala, Guatemala, pp. 15–24.

Islebe, G.A., Sánchez, O., 2002. History of Late Holocene vegetation at Quintana Roo , Caribbean coast of Mexico. Plant Ecology 187–192.

Kennett, D.J., Piperno, D.R., Jones, J.G., Neff, H., Voorhies, B., Walsh, M.K., Culleton, B.J., 2010. Pre-pottery farmers on the Pacific coast of southern Mexico. Journal of Archaeological Science 37, 3401–3411.

Kennett, D.J., Voorhies, B., 1996. Oxygen Isotopic Analysis of Archaeological Shells to Detect Seasonal Use of Wetlands on the Southern Pacific Coast of Mexico. Journal of Archaeological Science 23, 689–704.

Leyden, B.W., 2002. POLLEN EVIDENCE FOR CLIMATIC VARIABILITY AND CULTURAL DISTURBANCE IN THE MAYA LOWLANDS. Ancient Mesoamerica 13, 85–101.

López Portillo, J., y Ezcurra, E. 2002. Los manglares de México: una revisión. Madera y Bosques, Número especial, 27–51.

Marshall, J.S., 2007. Geomorphology and Physiographic Provinces of Central America. In: Bundschuh, J., Alvarado, G. (Eds.), Central America: Geology, Resources, and Hazards. Taylor & Francis, London, pp. 75 – 122.

Monacci, N.M., Meier-Grünhagen, U., Finney, B.P., Behling, H., Wooller, M.J., 2011. Paleoecology of mangroves along the Sibun River, Belize. Quaternary Research 76, 220–228.

Moore, P.D., Webb, J.A., Collinson, M.E., 1991. Pollen Analysis. Blackwell Scientific Publications, Oxford, 216 pp.

Mueller, A.D., Islebe, G.A., Hillesheim, M.B., Grzesik, D.A., Anselmetti, F.S., Ariztegui, D., Brenner, M., Curtis, J.H., Hodell, D. a., Venz, K. a., 2009. Climate drying and associated forest decline in the lowlands of northern Guatemala during the late Holocene. Quaternary Research 71, 133–141.

Neff, H., Bove, F.J., Genovez, J. V., 2006a. El clima y la naturaleza de la ocupación del Postclásico en la Costa Sur de Guatemala. In: Laporte, J.P., Arroyo, Bárbara, Mejía, H. (Eds.), XIX Simposio de Investigaciones Arqueológicas en Guatemala, 2005. Museo Nacional de Arqueología y Etnología, Guatemala, pp. 149–155.

Neff, H., Pearsall, D.M., Jones, J.G., Arroyo, B., Collins, S.K., Freidel, D.E., 2006b. Early Maya Adaptive Patterns: Mid-Late Holocene Paleoenvironmental Evidence from Pacific Guatemala. Latin American Antiquity 17, 287–315.

Neff, H., Pearsall, D.M., Jones, J.G., Arroyo de Pieters, B., Freidel, D.E., 2006c. Climate change and population history in the Pacific Lowlands of Southern Mesoamerica. Quaternary Research 65, 390–400.

Oldfield, F., 2005. Introduction: The Holocene, a special time. In: Mackay, A., Battarbee, R., Birks, J., Oldfield, F. (Eds.), Global change in the Holocene. Hodder Education, Londres, pp. 1–9.

Popenoe de Hatch, M., 2004. Un paso más en entender los inicios de tak´alik ab´aj. In: Laporte, J.P., Arroyo, B., Escobedo, H., Mejía, H. (Eds.), XVII Simpsosio de Investigaciones arqueológicas en Guatemala, 2003. Museo Nacional de Arqueología y Etnología, Guatemala, pp. 415–425.

Roberts, N., 1998. The Holocene: an environmental history. Blackwell Publishers Inc, Malden, Massachussetts, E.U.A., 332 pp.

Schoonmaker, P.K., Foster, D.R., 1991. Some implications of paleoecology for contemporary ecology. The Botanical Review 57, 204–245.

Tomlinson, P.B., 1986. The botany of mangroves. Cambridge University, Cambridge, 419 pp.

Torrescano-Valle, N., Islebe, G.A., 2012. Mangroves of Southeastern Mexico : Palaeoecology and Conservation. The Open Geography Journal 5, 6–15.

Toth, L.T., Aronson, R.B., Vollmer, S. V, Hobbs, J.W., Urrego, D.H., Cheng, H., Enochs, I.C., Combosch, D.J., Van Woesik, R., Macintyre, I.G., 2012. ENSO drove 2500-year collapse of Eastern Pacific coral reefs. Science 336, 81–84.

Tovilla-Hernández, C., Aguilar-López, E., Gordillo-Solís, O.G., Rojas-García, J., Vázquez-Lule, A.D., 2009. Caracterización del sitio de manglar La Encrucijada. In:

(CONABIO), C.N. para el C. y U. de la B. (Ed.), Sitios de manglar con relevancia biológica y con necesidades de rehabilitación ecológica. CONABIO, México, pp. 1–15.

Traverse, A., 2007. Paleopalynology. Springer Netherlands, Dordrecht, 813 pp.

Anexo

Principales tipos de polen identificados en las muestras. 1) Manglar: A, *Rhizophora;* B, *Laguncularia racemosa*; C, *Conocarpus erectus*. 2) Bosque tropical: A, Fabaceae; B, Sapotaceae; C, Moraceae; D, *Ficus*. 3) Bosque montano: A, *Pinus*; B, *Alnus*; C, *Quercus*; D, *Myrica.* 4) Perturbación: A, Chenopoidiaceae; B, Asteraceae; C, Poaceae; D, *Croton*. 5) Acuáticas: A, *Typha dominguensis*; B, Cyperaceae; C, *Nymphaea ampla.*