

The Paleanthropocene of the Yucatán Peninsula: palynological evidence of environmental change

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ABSTRACT

Human activities have changed and shaped landscape conditions of the Yucatán Peninsula for more than 4000 years. Several paleoecological studies showed the oldest pollen record of corn-based agriculture is from northern Belize, with an estimated age of 3300 BC.

Several other studies report maize between 1500 and 3000 BC from northern Guatemala and the Mexican part of the Yucatán Peninsula. After 3500 cal yr BP several paleoecological studies showed a marked tendency to drier climatic conditions. In pollen records, increased drought is expressed as a reduced presence of fossil arboreal pollen. Pollen records with the presence of *Zea mays* also show other taxa, which are indicators of disturbance in different vegetation types.

Keywords: Paleanthropocene, Holocene, Yucatán Peninsula, fossil pollen, *Zea mays*.

RESUMEN

*Las actividades humanas han influenciado sobre los paisajes de la península de Yucatán desde más de 4000 años. Varios estudios paleoecológicos muestran actividades de agricultura, el registro polínico más antiguo de maíz (*Zea mays* L.) proviene del norte de Belice, con una edad aproximada de 3300 BC. Otros estudios paleoecológicos del norte de Guatemala y de la porción mexicana de la península de Yucatán muestran registros de maíz fósil con rangos de edad desde 1500 a 3000 A.C. La mayoría de los registros muestran una marcada tendencia a condiciones de mayor sequía después de los 3500 A.C. Estas tendencias de sequía se registran como reducción del polen fósil arbóreo. El registro polínico de *Z. mays* está acompañado de taxa que indican diferentes grados de perturbación en la vegetación natural.*

Palabras clave: Paleanthropoceno, Holoceno, península de Yucatán, polen fósil, *Zea mays*.

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1. Introduction

The Yucatán Peninsula has a long history of human impact and use, starting in the middle Holocene until the present, or *Anthropocene*. The interaction of human with natural forces has shaped the landscape of the Yucatán Peninsula on different scales and therefore offers a valuable opportunity of understanding past and present sustainability (DeClerk *et al.*, 2010; Douglas *et al.*, 2016; Ford and Nigh, 2016). The term *Anthropocene* was introduced by Crutzen and Stoermer (2000) to highlight the human influence on the environment and some researchers even proposed the term *Palaeoanthropocene* as the period of first anthropogenic change until the early industrial revolution (Foley *et al.*, 2013). More specific to the area occupied by Maya culture and their influence on the environment, the term *Mayacene* was proposed to describe the period for the last 3000 years (Beach *et al.*, 2015).

In this paper we expand the idea of the *Paleoanthropocene* to the last 4000 years, as human impact on natural resources is evident in southern Mexico and Mesoamerica (Voorhies, 1996; Leyden, 2002) from this environmentally influential period. The human-environment-climate interaction goes back at least 4000 years, when early settlers became established and agriculture began transforming the landscape during the Archaic period. Abandonment of cities is strongly but not exclusively linked to climatic variability (Fedick, 2010; McNeil *et al.*, 2010; Dunning *et al.*, 2012, 2015; McNeil, 2012; Douglas *et al.*, 2016), and several studies have highlighted Maya cultural development related to climatic events and environmental conditions using different proxies like isotope chemistry, sediment geochemistry and pollen (Hodell *et al.*, 1995; Islebe *et al.*, 1996; Kennett *et al.*, 2012; Medina-Elizalde and Rohling, 2012). Opposing views on geographical determinism are ongoing in scholarly discussions, and it seems clear as a general consensus that the rise and fall of Maya culture is multifactorial. The periods of Maya cultural development are based on archaeology and are usually divided into Archaic (7000–2000 before Christ [BC];

Voorhies, 1996), Preclassic (2000 BC–250 AD), Classic (250–900 AD), and Postclassic and Contact periods (900–1500 AD; Coe, 1993; Webster, 2002; Dunning *et al.*, 2015). This subdivision does not necessarily reflect environmental or climatic change in each period.

Influence of Maya culture on the environment was reflected mainly in land cover changes, including deforestation in a broad sense, although there is ongoing discussion on the extent and relevance leading to culture demise and political breakdown (Aimers, 2007). This discussion includes different views, ranging from widespread forest reduction causing increasing aridity (Oglesby *et al.*, 2010; Cook *et al.*, 2012) to minimal forest cover loss due to adequate forest management (Ford and Nigh, 2009, 2016) and regional limited deforestation (Carrillo-Bastos *et al.*, 2012), depending on the cultural period and climatic conditions. Climate variability is a key factor, mainly helping to explain precipitation variability in the Maya lowlands (Hodell *et al.*, 1995; Dahlin, 2002; Medina-Elizalde and Rohling, 2012; Carrillo-Bastos *et al.*, 2013; Douglas *et al.*, 2016). The ancient Maya culture had profound knowledge of agriculture and forest management, and archaeological studies (Fedick, 2003) have shown transformation of wetlands for agricultural purposes with specific drainage channels. Others studies described the construction of terraces to reduce erosion and foster agricultural production (Dunning and Beach, 2000). Forest recovery after agricultural practices and climatic impact have shown that primary vegetation has a cycle of nearly 80 years (Mueller *et al.*, 2010), and ancient Maya had a well-developed agroforestry system (Ford and Nigh, 2009).

In this paper we summarize available published data on fossil maize (*Zea mays* L.) in pollen records from the Yucatán Peninsula, showing the first use of maize in agriculture, and the relationship with environmental and climatic change. Fossil pollen of corn (*Z. mays*) is an excellent proxy for human impact, as its presence provides a direct link between Maya culture and agricultural activities (Islebe and Leyden, 2006; Holst *et al.*, 2007).

2. Environmental setting

2.1. CLIMATE

The climate of the Yucatán Peninsula is of a seasonal nature. There are mainly two distinct seasons. The rainy season between May and November and the dry season between December and April define the annual precipitation distribution. During the winter months (December – March) arctic air incursions known locally as *nortes* can bring additional precipitation to the Yucatán Peninsula (Torrescano-Valle and Folan, 2015). The intra-annual displacement of the Intertropical Convergence Zone determines the seasonality of the precipitation (Haug *et al.*, 2001, 2003; Méndez and Magaña, 2010). Additionally, there are differences across the region. The north zone has an annual precipitation between 600 and 900 mm, while in the south it is between 900 and 1400 mm. There is also a moisture gradient between the east and west coast, being the eastern coast of the Yucatán Peninsula influenced by jet streams providing humid air during the rainy season.

2.2. VEGETATION

The dominant vegetation type is seasonal dry tropical forest, but a variety of forest types and other vegetation types exist on the Yucatán Peninsula, such as mangroves, among other (Miranda, 1958). Seasonal dry tropical forest is the dominant vegetation type. High evergreen forest, with canopy greater than 30 m, can be found in the southern Yucatán Peninsula, northern Guatemala, and Belize.

3. Methods

Published results on *Zea mays* (corn) occurrence in the Yucatán Peninsula were reviewed. A complete list of sites, with their respective radiocarbon age, and calibrated ages are listed in Table 1. Original calibrated ages from cited studies were accepted. A map was elaborated of sediment cores where *Z. mays* was found (Figure 1). Seven sites with a total of 57 samples of *Zea mays* of the Yucatán Peninsula were used to summarize pollen and ancient Maya cultural periods (Figure 2).

Table 1. List of sites recording *Zea mays* in Belize, Guatemala and México. Dates are original data.

	Site	Oldest recorded date
México		
Carrillo-Bastos <i>et al.</i> 2010	Tzib	3500 cal yr BP
Aragón-Moreno <i>et al.</i> 2012	Ría Lagartos	3600 cal yr BP
Gutiérrez-Ayala <i>et al.</i> 2012	Petenes	2079 cal yr BP
Carrillo-Bastos <i>et al.</i> 2013	Ría Lagartos	3840 cal yr BP
Torrescano-Valle and Islebe, 2015	Silvituc	4100 cal yr BP
Leyden <i>et al.</i> 1998	Cobá	2850 cal yr BP
Leyden <i>et al.</i> 1996	San José Chulchacá	1180 AD
Guatemala		
Islebe <i>et al.</i> 1996	Petén Itzá	2000 cal yr BP
Mueller <i>et al.</i> 2009	Petén Itzá	3000 cal yr BP
Wahl <i>et al.</i> 2014	Puerto Arturo	4600 cal yr BP
Wahl <i>et al.</i> 2013	Holmul	3330 cal yr BP
Wahl <i>et al.</i> 2007	El Mirador	4650 cal yr BP
Belize		
Jones <i>et al.</i> 1994	Colha	4500 cal yr BP
Pohl <i>et al.</i> 1996	Cobweb	5000 cal yr BP
Rushton <i>et al.</i> 2012	Lamanai	3650 cal yr BP

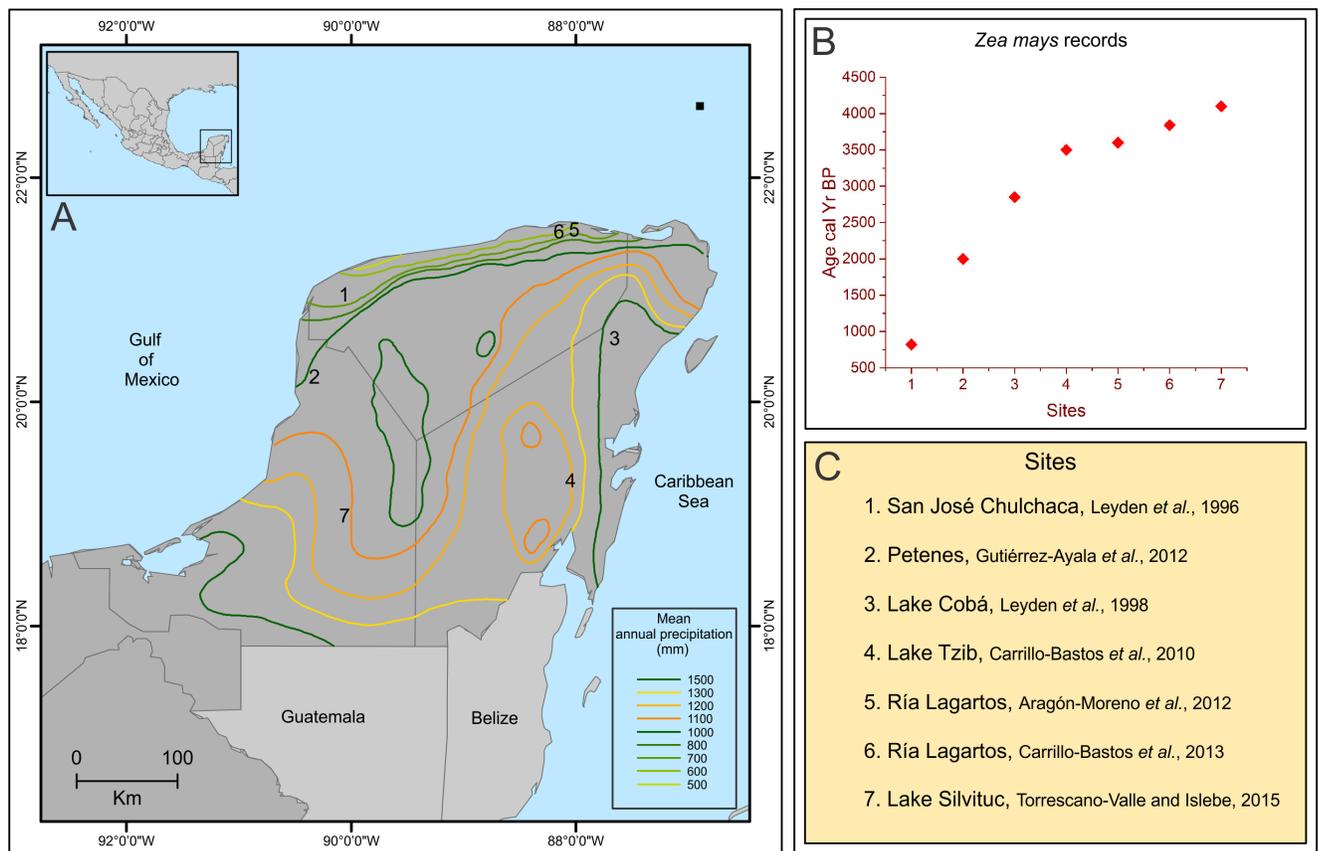


Figure 1 A) Geographical position of the Yucatán Peninsula with localities of sites. B) *Zea mays* records related to age and sites. C) Numbered sites with name and authors.

4. Results and discussion

For the Yucatán Peninsula, the oldest maize pollen grain comes from Cob swamp (Belize), and is dated at 3360 BC (Pohl *et al.*, 1996). From northern Guatemala, Wahl *et al.* (2006, 2013, 2014) gave ages of first maize pollen between 2600 and 2300 BC. From the Mexican part of Yucatán Peninsula the oldest maize pollen evidence comes from Lake Silvituc and is dated at 2100 BC (Torrescano-Valle and Islebe, 2015). From the northern part of the Yucatán Peninsula, the first recorded corn pollen has an estimated age of 1800 BC (Aragón-Moreno *et al.*, 2012; Carrillo-Bastos *et al.*, 2013). From the central region of the Yucatán Peninsula, *Z. mays* pollen is dated at 1500 BC (Carrillo-Bastos

et al., 2010). From Lamanai, in northern Belize, an estimated age of 1600 BC was given by Rushton *et al.* (2013) for first *Z. mays* appearance. Different studies have made relevant contributions on the origin and domestication of corn (Matsuoka *et al.*, 2002; Doebley, 2004; Sluyter and Domínguez, 2006; Piperno *et al.*, 2009). Paleoecological and genetic evidence have identified *teosinte* (*Zea mays* ssp. *parviglumis* and ssp. *mexicana*) as the most important ancestor of corn. This allowed detection of the highlands of Oaxaca and Guerrero (Holst *et al.*, 2007) as the center of domestication, although pollen grain size might be insufficient to separate teosinte from corn. Evidence of early fossils of domesticated maize was presented by Piperno *et al.* (2009) with starch grains of phytoliths in the Rio Balsas valley between 9000 and 8600 calibrated years Before Present (cal yr BP). After maize

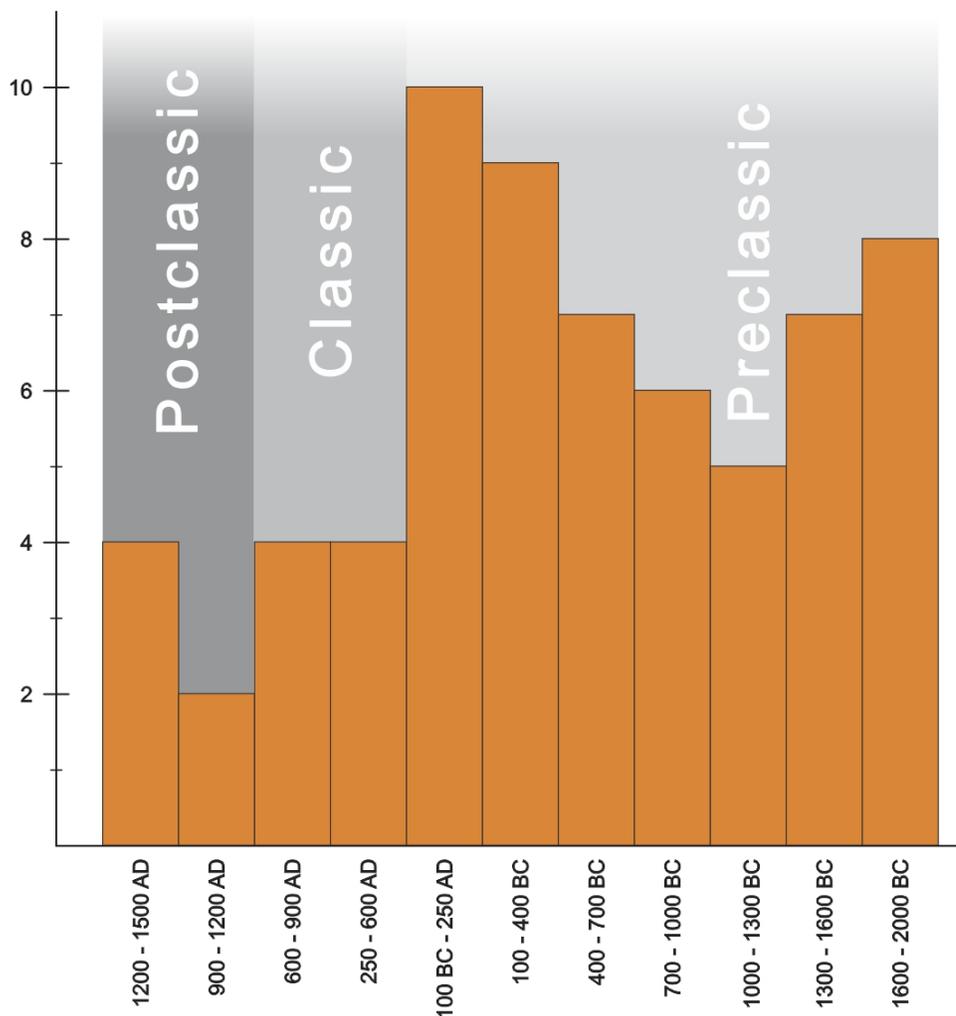


Figure 2 *Zea mays* presence in pollen records of the Yucatán Peninsula grouped according to Maya cultural periods.

was domesticated it spread into Central America around 7800 cal yr BP (Piperno, 2011). The presence of fossil corn pollen in southern Mexico (Voorhies, 1996) is direct evidence of the use of corn since 4000 BC. For additional information on the geographical spread of corn we refer to Staller *et al.* (2009).

4.1. IMPACT ON LANDSCAPE

Reduction of forest cover combined with increase taxa indicating disturbance, and the presence of *Zea mays* pollen, has been used as an indicator of

change in the landscape and/or induced change by climatic factors (Wiseman, 1978; Leyden, 2002). Other research included the importance of wetlands as suitable habitat for agriculture (Beach *et al.*, 2008; Luzzadder-Beach *et al.*, 2012). Other indicative pollen taxa that imply change in vegetation cover include Poaceae, Asteraceae, Cucurbitaceae, and Malvaceae, among others disturbance taxa (Wiseman, 1978; Islebe *et al.*, 1996; Leyden *et al.*, 1998), which generally appear before and after corn pollen records in many pollen diagrams. Slash and burn agriculture, different forms of agroforestry, and forestry harvesting were main

agricultural activities. The sustainability of those activities is under academic scrutiny (Demarest, 2004; Ford and Nigh, 2009; Lentz *et al.*, 2014, 2015; Douglas *et al.*, 2016). Pohl *et al.* (1996) reported a strong deforestation around 2500 BC in northern Belize, which could also be interpreted as a regional drought signal (Torrescano-Valle and Islebe, 2006; Mueller *et al.*, 2009; Carrillo-Bastos *et al.*, 2010). The drying signal around 3500 cal yr BP reported by Mueller *et al.* (2009) agrees with large regional drying trends from Cariaco Basin, Venezuela (Haug *et al.*, 2001); Haiti (Hodell *et al.*, 1991); Lake Valencia, Venezuela (Curtis *et al.*, 1999); and from several lakes of the African tropics (Gasse, 2000). Intensified farming activities are dated between 1500 and 1300 BC with increased presence of corn in northern Belize (Pohl *et al.*, 1996; Rushton *et al.*, 2013). From the northern part of the Yucatán Peninsula, a similar pattern of climatic drying is observed after 3500 cal yr BP (Aragón-Moreno *et al.*, 2012; Gutiérrez-Ayala *et al.*, 2012). *Z. mays* was recorded in near-coastal lake sediments with an interpolated age of 1900 BC (Aragón-Moreno *et al.*, 2012; Carrillo-Bastos *et al.*, 2013). Changes in nearby coastal mangrove composition, mainly the turnover of species composition from *Rhizophora mangle* L. to dominant *Conocarpus erectus* L., with reduced pollen representation of forest taxa is indicative of a drying trend in the northern part of the Yucatán Peninsula (Aragón-Moreno *et al.*, 2012; Carrillo-Bastos *et al.*, 2013). The trend toward drier conditions had a few short phases of increased precipitation, but the terminal Preclassic period experienced increasing corn agriculture with drier climatic conditions (Figure 2). The terminal Preclassic drought and its subsequent population abandonment (150–250 AD) were strong enough to cause the end of *Z. mays* agriculture in the northern and driest parts of the Yucatán Peninsula (Carrillo-Bastos *et al.*, 2013). In the middle Classic, corn appeared again in the sedimentary records.

The intensity and geographical extension of forest reduction is under discussion, due to differences in interpretation of paleoecological proxies (Ansel-

metti *et al.*, 2007; Carrillo-Bastos *et al.*, 2012; Cook *et al.*, 2012; Taylor *et al.*, 2012; Dunning *et al.*, 2015; Douglas *et al.*, 2016).

Cook *et al.* (2012) considered that human induced deforestation led to an increased reduction in precipitation, which could have strengthened the natural drying trend during the late Classic period, and eventually led to the Maya collapse. Carrillo-Bastos *et al.* (2012), based on reconstructing the geographical distribution, its precipitation regime, and change of the most dominant vegetation type (the semi-evergreen forest) of the Yucatán Peninsula, found that deforestation was never complete. Some areas suffered from a higher deforestation rate than others, probably due to higher population densities and agricultural requirements of nearby population centers. The northern Yucatán Peninsula showed with a lower precipitation regime at 550 BC with this geographical information system approach and precipitation reduction did not affect in a uniform manner due to geographical differences of precipitation regimes. At 450 AD a widespread forest reduction can be observed, but no complete deforestation associated to intensified agriculture or amplified climatic change at this period (Carrillo-Bastos *et al.*, 2012). Many forested areas switched to a more open character, and open vegetation types were most similar to savanna type vegetation, like at present in some parts of the central peninsula. In the central Yucatán Peninsula, two records provide evidence of fossil *Z. mays*, namely in the Lake Cobá record (Leyden *et al.*, 1998) and a core from Lake Tzib (Carrillo-Bastos *et al.*, 2010). Fossil pollen of corn was found at Cobá at 850 BC, and at Lake Tzib around 1500 BC. Anselmetti *et al.* (2007), based on a soil erosion study of Lake Salpetén, northern Guatemala, found that intense soil erosion layers (like Maya clay) occurred after initial land clearance in the early Preclassic and later (Rosenmeier *et al.*, 2002), while in lakes from the Yucatán Peninsula, conspicuous erosion horizons are not observed. Figure 2 summarizes the number of sites with corn and its relative variation with cultural periods. Fossil pollen data agree with

paleocological records and the cultural decline of ancient Maya culture (900–1200 AD) is shown by less fossil corn presence.

4.2. ASSOCIATED TAXA TO *Zea mays* IN POLLEN RECORDS

Other fossil pollen taxa that appear together with *Zea mays* in sediment cores mainly indicate forest disturbance caused by human activity or natural catastrophic events, like hurricanes or extensive fires (Islebe *et al.*, 2001; Mueller *et al.*, 2009). Other economical taxa that are recorded include *Cucurbita* (Pohl *et al.*, 1996) and *Gossypium* (Wendel *et al.*, 2010), which has been domesticated in the Yucatán Peninsula. Several paleoecological studies have shown similar results of taxa indicating disturbance due to land use change, mostly *Cecropia peltata* L., *Croton* sp., *Acacia* sp., Asteraceae, Solanaceae (*Capsicum*), Convolvulaceae, Malvaceae, Poaceae, and Chenopodiaceae-Amaranthaceae (Torrescano-Valle and Islebe, 2015). Species of the previously mentioned taxa include weeds (*e.g.*, Chenopodiaceae-Amaranthaceae), fast growing herbaceous species (like Asteraceae, Convolvulaceae, Malvaceae). And pioneer trees and shrubs of early successional stages after forest disturbance (like *Cecropia*, *Croton*, Solanaceae, *Acacia*, and other members of the legume family) described by Nigh (2008), and Varela Scherrer and Trabaniño (2016). Additionally, charred particles increase in pollen records with the presence of *Z. mays* (Aragón-Moreno *et al.*, 2012).

5. Conclusions

The research line we have adopted offers relevant information on the establishment of early agriculture in the Yucatán Peninsula. The relevance goes beyond the oldest record. Multiproxy environmental studies and interdisciplinary research aim at consistent chronologies of fossil evidence, and to include robust quantitative tools to establish a clear concept about the relation human and environment.

The concepts of *Paleoanthropocene* or *Mayacene* (Beach *et al.*, 2015) seem attractive for the Yucatán Peninsula and northern Mesoamerica, considering the strong link between, climate, and environment and ancient Maya culture. The oldest corn record comes from northern Belize and is dated at 3300 BC. Several pollen records from Belize, Guatemala, and the Yucatán Peninsula present early fossil corn records between 1500 and 3000 BC. Temporal variability of corn appearance is due to different occupational histories of the area, different water availability, and differential fossil pollen preservation. Climate driven deforestation can be observed in many records around 3500 cal yr BP, with a clear reduction of arboreal taxa and increase of taxa indicating disturbance or land use change. Human driven deforestation is related in some areas to Maya agriculture, shown by high soil erosion rates in some areas, although not recorded in most lakes of the Yucatán Peninsula. Finally, we conclude that *Z. mays* is an excellent indicator and proxy of the beginning of the (paleo) *Anthropocene* in the Yucatán Peninsula.

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