Ancient Mesoamerica (2025), 1–17
doi:10.1017/S0956536125000045

CAMBRIDGE UNIVERSITY PRESS

Research Article

On the absence of a millennial population rebound in the central Maya lowlands

Elizaveta C Lyons[1] and B L Turner II[2]

[1]Department of Anthropology, University of Pennsylvania, Philadelphia, PA, USA and [2]School of Geographical Sciences and Urban Planning & School of Sustainability, Arizona State University, Tempe, AZ, USA

Abstract

The central Maya lowlands (CML) display an uncommon demographic history—the absence of a millennial population rebound from its former occupational peak, about 800 CE. Here we postulate why the loss of a well-populated CML during the Late Classic-Terminal Classic periods failed to regain substantial occupation during the subsequent 700-800 years before the Spanish conquest of the Maya realm. Updating the narrative of stressful human-environmental conditions, shifts in trade routes, and long-term paucity of occupation in the CML, we examine push-pull factors that affected Postclassic Maya population geography. These factors include population pressures, environmental hazards, resource conditions, and livelihood standards that existed in the Postclassic Period between northern and coastal lowlands and the CML. The advantages that the CML maintained before Postclassic times, foremost regaining superior environmental conditions for agriculture, were insufficient pull factors given the low levels of push factors in the northern and coastal lowlands. We draw attention to the under-treated problem—the failure of a population rebound in the CML—and encourage improvements in systematic data and analytics to address it, including consideration of non-material, socio-cultural factors.

Resumen

Las tierras bajas mayas centrales (LMC) muestran una historia demográfica poco común: la ausencia de una recuperación poblacional después de un milenio desde su antiguo pico de ocupación, alrededor del 700–900 d.C. Aquí postulamos por qué la pérdida de una LMC bien poblada durante los períodos Clásico Tardío-Clásico Terminal no logró recuperar una población sustancial durante los 500–600 años posteriores antes de la conquista española del reino maya. Siguiendo la tesis del colapso urbano y político y la despoblación de la LMC postulada por Turner y Sabloff, entre otros, exploramos los factores de empuje y atracción que podrían haber afectado a los mayas del Postclásico para regresar a la LMC en gran número. Nuestra evaluación reitera brevemente la evidencia de las condiciones del Clásico Tardío en la LMC, los cambios en las rutas comerciales desde este momento hasta el Período Postclásico y la ocupación Postclásico de la LMC. Estas tres evaluaciones contrarrestan los desafíos y proporcionan un contexto para nuestra evaluación de empuje y atracción.

Desde hace mucho tiempo se sabe que en el LMC había una gran mezcla de entidades políticas con grandes poblaciones durante el período Clásico Tardío, evidencia de lo cual se ha confirmado con los avances en los datos Lidar que identifican la ocupación concurrida. La intensidad de la sequía climática y la retroalimentación ambiental de las transformaciones del paisaje maya en el LMC durante los períodos Clásico Tardío y Clásico Terminal crearon tensiones significativas en el sistema humano-ambiental, especialmente en relación con el agua potable. La capacidad para contrarrestar estas tensiones se vio disminuida por una economía que perdió su control del comercio este-oeste a través del reino maya a medida que las rutas se volvían cada vez más marítimas, eludiendo la península de Yucatán. Si bien las causas de esta pérdida siguen siendo inciertas, los cambios en las rutas comerciales fueron sin duda un elemento interactivo en la despoblación del LMC.

La economía política emergente de los mayas en el norte y a lo largo de las costas oriental y occidental de la península creó medios de vida sostenibles respaldados por el comercio de la sal y otros productos y, significativamente, el acceso al agua subterránea. Los datos paleodemográficos parecen respaldar tales afirmaciones. Hubo episodios de sequía y hambruna, pero fueron seguidos por recuperación poblacional que no alcanzaron las densidades ocupacionales que existían en la LMC durante el Período Clásico Tardío.

Corresponding Author: B L Turner II; Email: Billie.L.Turner@asu.edu

This work has not been published elsewhere, fully or in part, or submitted to any other journal for consideration of publication.

The content of this work involved no externally sponsored funding.

Cite this article: Lyons, Elizaveta C and B L Turner II 2025 On the absence of a millennial population rebound in the central Maya lowlands. *Ancient Mesoamerica* 1–17. https://doi.org/10.1017/S0956536125000045.

Mucho antes de la conquista española de Yucatán a mediados del siglo XVI, el bosque y el suelo de la LMC se habían recuperado en gran medida de sus pasados usos a largo plazo. Si bien la CML experimentó los episodios de sequía de la península en general, sufrió menos exposición a los daños de los huracanes que las zonas ocupadas del Posclásico. Sin embargo, la LMC estuvo escasamente poblada durante el Período Posclásico como lo indican diversos datos, salvo por niveles modestos de ocupación en la zona central del lago Petén.
Los factores de empuje y atracción (presión poblacional, peligros ambientales, condiciones de los recursos y niveles de vida) no favorecieron a la reocupación de la LMC del Posclásico. Los entornos construidos de las zonas de ocupación, sobre todo su infraestructura de asentamiento y redes comerciales, y los usos generales de la tierra predominantes apuntan a condiciones que, durante períodos prolongados, no sirvieron para empujar o atraer poblaciones hacia los espacios renaturalizados y agrícolas favorecidos de la LMC. Más bien, la LMC sirvió como una frontera forestal para aquellos mayas que evitaban conflictos en el norte de Yucatán, ya sea entre ellos o con el control de los españoles. Sin embargo, dicha reocupación de la LMC fue mínima en comparación con las poblaciones pico del Período Clásico de la LMC.
Si bien otros factores de empuje y atracción merecen consideración en el futuro, especialmente factores no materiales, la dinámica poblacional poco común de la LMC plantea preguntas importantes sobre la historia ocupacional maya de la península de Yucatán.Por ejemplo, ¿por qué la LMC estuvo tan poblada y fue tan poderosa desde el punto de vista socioeconómico durante el Período Clásico?

Comparative examinations of societal stability and resilience point to long-term, regional oscillations in population (Riris et al. 2024; Scheffer et al. 2023). Turchin (2005, 2009) calculated such oscillations for past agrarian state-level societies, holding the occupied area constant, as two centuries in length for a full growth-decline-growth cycle. Whitmore and colleagues (1990) gauged that multiple century-level oscillations or millennial-level cycles also existed in such circumstances, in which shorter-term oscillations were evident but not addressed. If demographic oscillations were common for the societies in question, the case of the central Maya lowlands (CML), once home to a substantial population, stands as an exception. A millennium has passed since this rich and powerful portion of the Maya domain was densely occupied. Today, much of the CML remains a settlement frontier within and surrounding a biosphere reserve.

The greater Yucatán peninsular region has been home to lowland Maya peoples for at least four millennia. During the Late Classic period (ca. 550–830 C.E.; Table 1) of their occupation, the lands of, and adjacent to, the elevated interior (Dunning et al. 2012), especially the CML, reached a peak in population numbers, supported by a large and complex built environment and extensive trade networks (Figure 1). The elevated interior constitutes a hilly limestone plateau (ca. 150–900 m above LMSL, local mean sea level), replete with seasonally inundated *bajos*, or sinks, extending about 400 km from the Puuc Hills in northern Yucatán to the central lakes of the Petén, Guatemala (Dunning et al. 2012). The CML, in contrast, covers the southern and more moist part of the elevated interior, extending about 225 km north to south from southern Campeche and Quintana Roo, Mexico to the central Petén lakes (Turner and Sabloff 2012).

Significant population abandonment of the CML and other interior parts of the lowland Maya realm took place during the Terminal and Early Postclassic periods (ca. 830–1200 C.E.). A seasonal tropical forest overgrew the extensive infrastructural landscape that had sustained occupation of the CML for more than a millennium. The socioeconomic and political power of the lowland Maya moved with the population throughout the Terminal and Early Postclassic periods to the northern plains (e.g., Sabloff 2007) and the eastern and western coastal lands (e.g., Ek 2014) of the peninsula. The elevated interior, foremost the CML, has subsequently remained sparsely populated and significantly rewilded, even to this day, compared to its conditions in the Classic period. This demographic history, including the absence of a population rebound, is as puzzling as has been the social, economic, and political collapse of the Classic-period Maya.

Improved understanding of the prolonged occupational decline of the CML may provide important insights about the prehispanic Maya (Turner 2010). For example, why was the CML so densely populated with powerful city-states before the Terminal Classic period, given its subsequent occupational history? What advantages or disadvantages did the CML maintain during its occupational ascendancy that were maintained or lost? Were these factors largely environmental and material in kind (e.g., trade), or were they embedded in societal structures or cultural features?

Specific attention to the rebound topic is slim to our knowledge. A Google Scholar title search using different key phrases signaling long-term abandonment and rebound of the central and southern Maya lowlands or elevated interior revealed only one publication—Turner and Sabloff (2012)—which posed the rebound (or its absence) question but did not address it. The literature explicitly directed to the causes of this reoccupation failure but not captured in our key phrases, such as that by Demarest (2013), also appears to be sparse. That dealing with systematic comparisons of the evidence between the major areas of Maya occupation and the lightly settled CML during the Postclassic period is sparser.

In contrast, extensive research on various facets of the human-environmental conditions of the Maya realm yields evidence and interpretations that are relevant to the rebound and related questions. We draw on this research to examine a set of push–pull, demographic factors operative during the Postclassic period for the northern and coastal occupational zones and the CML. These factors are those that have historically operated across agrarian societies: population pressures, environmental hazards, and resources. To these we add "infrastructure" or the willingness to rebuild the CML to the material standards of the areas from which Postclassic Maya would have emigrated. We compare these factors based on evidence that is quantifiable and likely to

https://doi.org/10.1017/S0956536125000045 Published online by Cambridge University Press

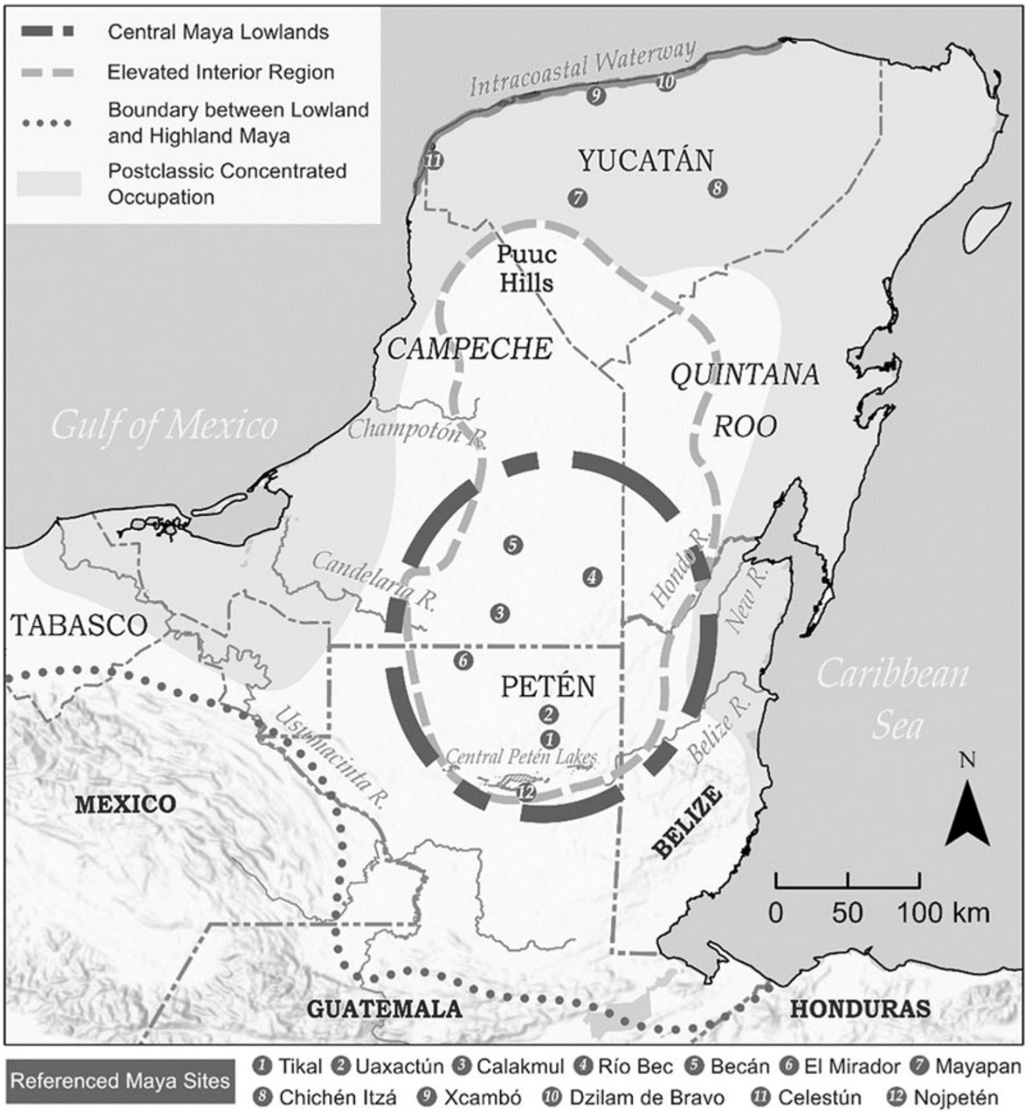

Figure 1. The central Maya lowlands and entities referenced in the text (after Turner and Sabloff 2012).

increase in detail and rigor in the near-term owing to ongoing Maya research. Unfortunately, we do not believe that the evidence is currently sufficient to warrant tests or models of their explanatory power. Rather, our effort points to some of the push–pull factors that should be included in future considerations of the problem.

We frame our effort by way of the human-environmental conditions that existed in the CML during the Late Classic period and interpretations of the drivers of the Maya societal collapse and depopulation that took place as articulated by Turner and Sabloff (2012) and others (e.g., Arnauld 2024; Griffin et al. 2014; Kennett and Beach 2013; Kennett et al. 2012; Luzzadder-Beach et al. 2012). It involves: (1) the stressful conditions of the built environment of the CML during a time of intensive drought, urban collapse, and depopulation; (2) the evidence of changes in commercial trading routes that may have constrained the occupants of the CML to respond to the environmental changes underway; and (3) the low levels of population in the CML during the Postclassic period. This brief review, which may otherwise constitute the obvious for some experts, is warranted for at least two reasons. It provides updated information about the three CML issues noted, serving as a backdrop for our push–pull assessment, and counters persistent challenges about population dynamics and agrarian landscapes in the CML. Finally, we examine the possible push–pull factors that prevented the Postclassic Maya population of the northern and coastal plains of the Yucatán peninsular area from substantially reoccupying the CML during the 700–800 years between the abandonment of the CML and the Spanish takeover of the region beginning in 1539. This last part of a millennial long-wave cycle—from the middle 16th century to the present—constitutes a qualitatively distinct set of conditions that is not included in our assessment.

The central maya lowlands in the classic period

The CML covers a large swath of southern Quintana Roo and Campeche, Mexico, northwestern Belize, and northern Guatemala from the central Petén lakes to the border with Mexico (Figure 1; as demarcated, the CML is about 59,000 km^2). The elevated interior commonly rises about 100 m

https://doi.org/10.1017/S0956536125000045 Published online by Cambridge University Press

LMSL from the peninsular coastal plains, ascending to 500 m LMSL in parts of the interior. Surface water is sparse, especially in the winter dry season, save for the deep, central Petén lakes and perennial wetlands, a few springs mostly situated along the western edge of the CML, and the headwaters of several rivers in the southern part of the peninsula that flow to the Caribbean Sea and Gulf of Mexico (Figure 1). The water table tends to be deep (>100 m; Bauer-Gottwein et al. 2011; Dunning et al. 2022; Moreno-Gómez et al. 2019) compared to the much shallower depth (<10 m) in the northern and coastal plains. As such, ground water in the CML was not readily accessible for the ancestral Maya (e.g., Lagomasino et al. 2015). In addition, sulfates residing in a gypsum-rich stratigraphy in the more northerly part of the CML can contaminate the groundwater (Perry et al. 2019).

Aguadas, or small-sized, usually seasonal pools of surface water exist throughout the CML, commonly located at the edges of wetlands where shallow sinks in the bedrock occur (Hansen et al. 2002). The Maya modified existing and constructed new *aguadas* and urban reservoirs to capture and store wet-season precipitation (Akpinar Ferrand et al. 2012), perhaps reducing percolation to groundwater (Perry et al. 2019). Maya attention to water-storage infrastructure makes the identification of individual *aguadas* as natural or constructed, or a combination thereof, difficult to determine in some cases (Ensley et al. 2021). Reservoirs, in contrast, were part of the urban infrastructure, complete with systems draining surface water to them (Matheny 1976; Scarborough 1992).

The environmental conditions of the CML for cultivation excelled compared to lands in the north and to the non-riverine lands of the coastal plains. Precipitation, both average annual amounts (ca. 1,150–2,600 mm in the CML; Luzzadder-Beach et al. 2016) and the length of the summer wet season, increases southward from the north coast of the peninsula, attested by the decreasing dry-season deciduousness of the upland forests. Mollisols, up to one meter in depth, support this vegetation, constituting a superior medium for cultivation within the tropical world (Labaz et al. 2024). Abundant wetlands (Ensley et al. 2021), commonly large depressions or *bajos*, inundate during the wet season and maintain clay-rich vertisols that serve cultivation well with soil moisture management (Wubie 2015). This soil may even have been moved to upslope terraces to enhance agricultural productivity (Hansen et al. 2002).

The CML and Maya lowlands in general have entertained large swings in climatic conditions over the millennia (Medina-Elizalde et al. 2010), including multi-decadal droughts at the end of the Preclassic period (200–300 C.E.; Figure 2), influencing the collapse of important city-states. Rural settlements likely survived (Ebert et al. 2017), however, as they did with city-state collapses in the northern lowlands during subsequent drought conditions (Masson et al. 2024). The CML population recovered and grew from the Preclassic aridity, focused on different polities and locations. Another aridity trend began in the Early Classic (690 C.E.), generating multi-decadal droughts beginning about 820 C.E. with spikes in drought throughout the Terminal Classic and Early Postclassic periods (Figure 2). Intensive aridity occurred in 870 and 920–940 C.E., and there was a longstanding, extremely intense drought from 1000–1100 C.E. (Kennett et al. 2012). These climatic conditions were associated with social, political, and demographic changes, foremost in the CML (Kennett et al. 2012), leading to a political collapse from 800–820 C.E., urban collapse from 900–1000 C.E., and a demographic collapse from 1000–1200 C.E. (Arnauld 2024).

This simplification of environmental conditions in the CML provides a rudimentary base on which to examine its occupancy in the Late Classic to Early Postclassic periods (ca. 550–1200 C.E.), a time in which the number and density of population reached significant levels and subsequently declined precipitously, if varied by location (Arnauld et al. 2024). The CML was home to abundant city-states, including those large in area, monumental architecture, and population: Tikal, Uaxactún, Calakmul, Río Bec, Becan, and others. These sites reached the tens of thousands in population (Arnauld et al. 2024; Webster 2018), perhaps with muted occupational density (Isendahl 2012). Significantly, the villages and hamlets of the urban hinterlands were well occupied (Canuto and Auld-Thomas 2024; Hutson et al. 2021) and the infrastructure of their cultivated lands (i.e., landesque capital) was substantial, save for patches of managed forests. Travel route systems connected urban sites, including the use of *sacbes* or elevated causeways, especially useful for crossing wetlands. Many known *sacbes* date to the Preclassic period (Hansen et al. 2023), but their links to Classic-period settlements (LaRocque et al. 2022) suggest their sustained maintenance.

Over the last 30 years individual site and area estimates for the Maya realm or parts of it during the Late Classic period have signaled large populations and high densities (e.g., Hutson 2024). Those for the CML at large have reached more than 150 people per square kilometer, but with lower ranges beginning at 80 people per square kilometer (e.g., Canuto et al. 2018; Hutson et al. 2021; Turner 1990). Webster (2018) cautions that the total populations derived from such densities are excessive, at least as applied over extensive areas. He significantly reduces the higher population densities proposed by others to as low as about seven people per square kilometer for a large area (one million people spread over 150,000 km^2) that includes the CML. Webster recognizes that patches supportive of high levels of occupation existed, such as Tikal with densities of 127 to 175 people per square kilometer, owing to "productive" land, presumably the uplands as opposed to wetlands. The frequency of such zones would appear to be large, however, as indicated by the massive amount of landscape infrastructure (i.e., temples to terraces) identified throughout the CML by Lidar (Beach et al. 2019; Canuto et al. 2018; Chase et al. 2024; Golden et al. 2016; Hansen et al. 2023; Hutson et al. 2021; Schroder et al. 2020; Stanton et al. 2024), much, if not most, of which relates to the Classic period, and the increasing evidence of wetland uses throughout the Maya realm (Fedick et al. 2023; Luzzadder-Beach et al. 2012). Lidar data have led to estimates of 70 to 120 persons per square kilometer for the entirety of a Petén zone, encompassing urban and rural settlements across 60,000 km^2 (Canuto and Auld-Thomas 2024), that includes the southern half of the CML as defined here.

The critical issue for our discussion is not the precise density of the CML during Late Classic to Terminal

https://doi.org/10.1017/S0956536125000045 Published online by Cambridge University Press

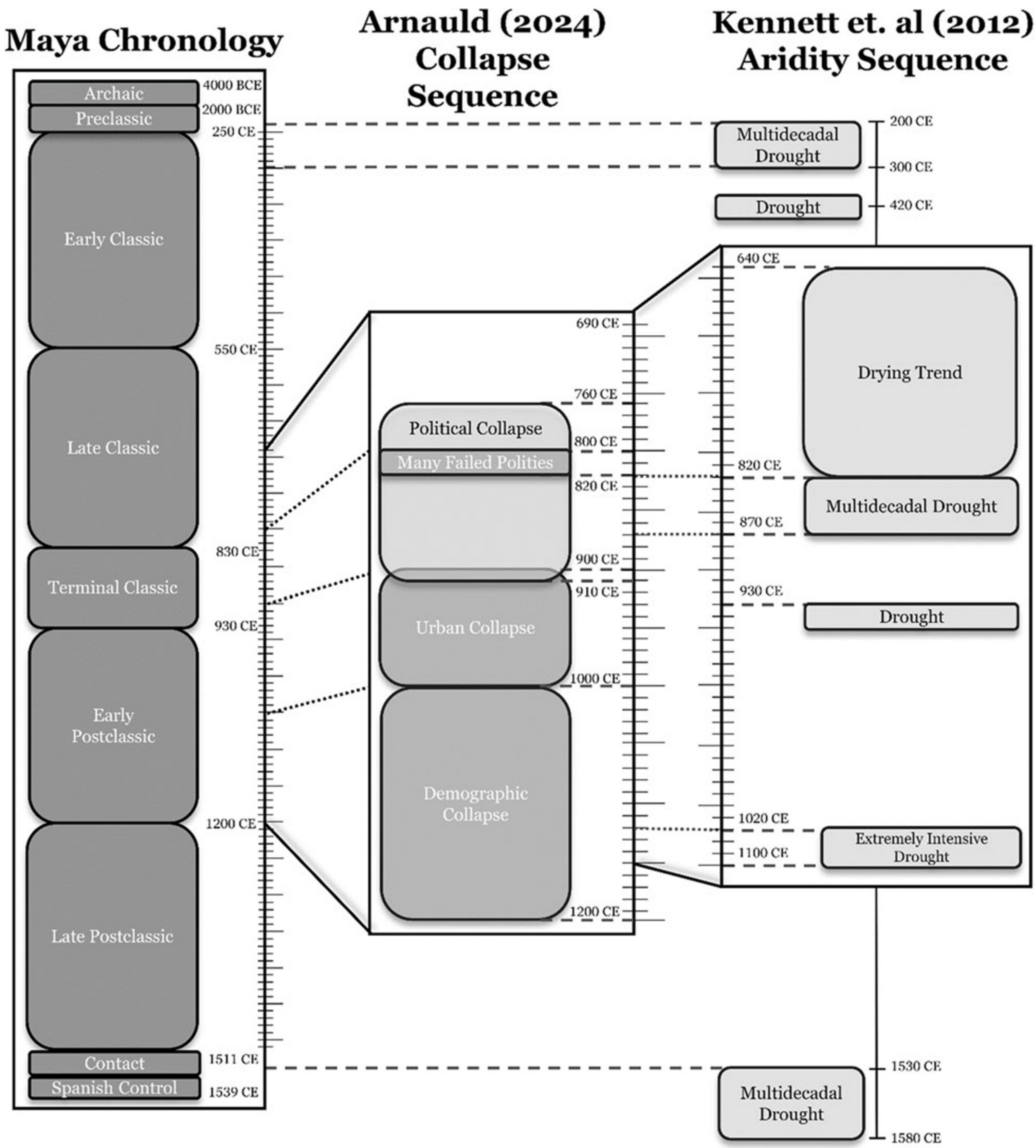

Figure 2. Chronologies of prehispanic occupation and climatic aridity episodes in the Maya lowlands and societal collapse and depopulation of the central Maya lowlands (following Arnauld 2024; Kennett et al. 2012).

Classic periods before the urban collapse (ca. 900–1000 C.E.; Table 1). Rather, it is the range of densities known to be associated with the scale of occupational and landesque infrastructure present in the CML during that time. The abundance of monumental features, residential abodes, reservoirs, terraces, wetland fields, orchard gardens, and causeways (increasingly revealed by Lidar data), as well as paleodemographic evidence (Olga Hernández Espinosa and Morfin 2015), points to elevated levels of population pressures or densities, even accounting for household movements between urban and rural residences (Arnauld et al. 2024), if such movements were significant. Evidence of landesque capital among contemporary, self-producing communities (Turner et al. 1977) strongly suggests that the relic Maya infrastructure implies population densities no lower than 50 people per square kilometer throughout the CML and over the century mark for specific areas. This evidence also points to an environmentally transformed CML—not just urban infrastructure—managing to supply water and agricultural goods, not one primarily engaged in forest-based production

https://doi.org/10.1017/S0956536125000045 Published online by Cambridge University Press

systems (Ford 2015), although managed forests existed. The surface transformation in question was so intensive that it affected the base karst geomorphosystems (Lebedeva et al. 2017).

The paleoenvironmental data within the CML and elsewhere in the Maya domain support this transformation and its population inferences (Beach et al. 2015; Luzzadder-Beach et al. 2012; Paine and Freter 1996; Turner and Sabloff 2012). With a few variations (Emery and Thorton 2008; Ford 2022; McNeil et al. 2010), this record includes: a loss in arboreal pollen by an order of magnitude approaching 90 percent (e.g., Battistel et al. 2018; Wahl et al. 2006); huge increases in vegetative disturbance indicators (Wahl et al. 2007; Wahl et al. 2013); significant decline in large-tree timber for construction at major sites, such as Tikal and Calakmul (Lentz and Hockaday 2009; Lentz et al. 2014); and a major decline in the apparent consumption of white-tailed deer (Emery 2007), indicative of various environmental stressors, including major deforestation.

Landscape ingenuity supported the Maya through earlier drought periods (e.g., in the Late Preclassic and Early Classic periods; Kennett et al. 2012; Figure 2). The overall trend in aridity from the mid-Late Classic to the latter Early Postclassic (Figure 2), and the accompanied multi-decadal drought phases over that time span, amplified by the scale of landscape changes undertaken by the Maya, extended and heightened the intensity of aridity from 1020 C.E. to 1100 C.E. (Turner and Sabloff 2012). Such land-atmospheric dynamics, or the consequences of them, were likely novel to the Maya experience, and should be understood as complementary to but superseding the case of Late Classic land degradation and the inability to supply cultivated foods, proposed fifty-years past (e.g., Culbert 1973).

The desiccation evidence is so extensive and robust that it need not be reiterated here (Douglas et al. 2015; Douglas et al. 2016; Evans et al. 2018; Gill 2000; Hoggarth et al. 2017; Kennett and Beach 2013; Luzzadder-Beach et al. 2012). The critical point is that the aridity and size of population created major societal and environmental stressors that surely served as drivers, if partial in kind, of a condition akin to a tipping point and regime shift of the human-environmental systems in the CML (Arnauld 2024; Kennett et al. 2012; Lentz et al. 2014; Lucero 2002; Turner and Sabloff 2012). The CML witnessed a slow erosion of its occupants (Chase et al. 2008), such that by the beginning of the Late Postclassic (ca. 1200 C.E.) it held a shadow of its former population. Unlike the documented cases of severe drought and famine among the colonial-period Maya in the northern lowlands, the CML population did not rebound (Hoggarth et al. 2017).

Challenges to the desiccation role (e.g., Iannone et al. 2014) focus on its primacy as the cause of the 800–1200 C.E. political, urban, and demographic collapses noted above (Figure 2; Arnauld 2024). Considering the entire Maya lowlands, for example, city-state collapses and drought do not necessarily correlate synchronously (Iannone et al. 2014), leading some researchers to conclude that drought served as a driver only in the later stages the collapse dynamics and only for certain lowland regions (Demarest 2013). Other causes, therefore, were at play. This argument is consistent with historical data from elsewhere (Butzer 2012; Haldon et al. 2018) indicating that climate aridity alone rarely explains societal collapse and depopulation (e.g., Griffin et al. 2014; Masson 2012). Rather, stressors creating societal collapses and depopulation commonly involve multiple, complex factors with which climate drivers interact. Among such interactions, Turner and Sabloff (2012), among others, suggested that significant shifts in commercial trade routes may have served as an additional factor in collapse and depopulation of the CML (also, Demarest 2013).

Postclassic trade-route shifts

Half a century ago, Rathje and Sabloff (1973; also, Sabloff and Rathje, 1975; Sabloff 2007) argued that the Postclassic Maya, influenced by the Putún or Chontol Maya from the southwestern part of the peninsula (Ek 2014), altered the political economy of the lowland Maya realm from that which existed previously in the CML and interior area at large. Occupying the northern plains and coastal zones of the peninsular region, the Postclassic Maya were more mercantile than those of the Classic-period elite, "... interested in keeping ... capital liquid and in finding ways, such as mass production, to increase the volume, extent, and efficiency of long-distance exchange" (Sabloff 2007:17), including that of bulk goods. Salt, cacao, cotton, honey, obsidian, copper, gold, and henequen were major goods of trade (Andrews 1980; Bianco et al. 2017; Hutson and Dahlin 2017; Meyers 2017; Sabloff 2007). Commercial networks facilitated trade (Andrews 2020; Sabloff 2007) in which cacao beans, cotton textiles, copper objects and, perhaps, salt cakes served as monetized mediums (Baron 2018; McKillop 2021; Sampeck 2021).

Commercial trade was not novel to the Postclassic Maya, however. It was well established long before the Postclassic period (e.g., Chase and Chase 2014; Masson et al. 2020), in which merchants and markets were foundational to the economy (King 2015; Masson and Freidel 2012). For example, several major exchange systems in the CML traded cotton. One exchange linked the Tabasco lowlands to Calakmul, and another connected Honduras to Tikal (Reents-Budet and Bishop 2020), consistent with interpretations that Tikal controlled trade with the Maya highlands (Woodfill and Andrieu 2012).

The Postclassic shift in political economy identified by Rathje and Sabloff (1973) resided not in the existence of trade per se (e.g., implied in Eppich 2020) but in the transition from a Classic-period market system apparently controlled by the political elite (Arnauld 2024) to a mercantile system in the Postclassic period with its accompanying commercial class (Masson and Freidel 2012), which may have penetrated the non-elite classes (Hutson and Dahlin 2017). This shift in political economy was marked by a major flow of trade in which sea routes overwhelming prevailed during the Postclassic period compared to land routes (Arden and Lowry 2011; Glover et al. 2018; McKillop 1996; Rosenswig and Masson 2002), even for short and medium hauls (e.g., McKillop 2010). Commerce circumnavigated the peninsula, which was ringed by ports and saltworks and included an inland coastal waterway along its northwestern-northern coastline (Figure 1) (Andrews 2020; Ardren and Lowry 2011; Demarest 2013; Glover et al. 2011; McKillop 2005, 2010).

https://doi.org/10.1017/S0956536125000045 Published online by Cambridge University Press

Coastal routes existed early in Maya history (e.g., Andrews 2020; Robles Castellanos et al. 2020), however, as did the inland coastal waterway and the use of the north–south trending Usumacinta River to the west of the CML. Yet, overland routes were highly active in the CML before the Postclassic period, as documented for trade in obsidian (Golitko et al. 2012). A major flow of goods was routed either way from the Caribbean to the Gulf of Mexico across the lands of the elevated interior, facilitated by riverine routing linking the coasts to the inland elevated terrain: the New, Hondo, and Belize rivers on the eastern and Candelaria, Champotón, and Usumacinta rivers on the western coasts of the peninsula, respectively (Figure 1). At least one assessment generates three least-cost transport routes crossing the CML and serving its urban centers (Volta et al. 2020). These routes appear to have become inactive or significantly less active during Postclassic times.

Demonstrations of the sequencing and causes of the decline of the interior CML routing and the subsequent dominance of a coastal one entering the Postclassic period are sparse. The depopulation of the CML would have severely reduced trade needs, relationships, and routing across the interior, favoring sea routes. Alternatively, such routing shifts in tandem with other stressors would have disrupted the economies of the CML polities (Lucero 2002) and destabilized city-state alliances (Martin 2020), affecting trade. Chaos among CML city-states following the defeat of Calakmul by Tikal, for instance, may have enhanced sea routing (Volta et al. 2020). Loss of trade within the CML, in turn, would have reduced the capacity of polities to address the mounting human-environmental stresses of the Terminal and Early Postclassic periods, especially regarding agriculture. The level of polity investment, if any, given to agrarian infrastructure and management is not clear. The indirect negative impacts on farming systems among the urban hinterlands, however, would have increased as city-state commerce decreased. The specifics of our argument notwithstanding, Golitko and colleagues (2012) concur that a significant shift from interior to seagoing trade routes emerged before the urban decline of the CML (and elevated interior at large) and served as a direct causal factor for the societal collapse and depopulation of the CML. While such claims require more evidence, it is safe to assume that strong interactions existed among the trade-route shift, the demise of the CML, and the resulting long-term occupation of the northern Maya and coastal plains.

Postclassic period depopulation of the central maya lowlands

Specifying the Postclassic population density of CML at large, or at least establishing a range of densities, is useful for comparisons of the demographic pressures of the northern and coastal lowlands with the CML. Deriving such estimates has proven difficult, however, despite the general understanding of sparse settlement in the CML at large at that time (e.g., Demarest 2013). Generating occupational densities is dampened by the variations in settlements over the length of the Postclassic (ca. 950 C.E. to 1539 C.E.), the occupation of the Petén lake zone at the turn of the Terminal-Early Postclassic periods versus the Late Postclassic Itza entry, and the paucity of evidence for the remainder of the CML (Arnauld 2024).

Recognizing these problems, the archaeological record fails to indicate reoccupation of the Classic-period urban sites or the development of new settlements with substantial construction in the CML beyond the lake zone (e.g., Dunning et al. 2013). Evidence of the use of significant agricultural infrastructure in the CML does not exist for this time either (e.g., Luzzadder-Beach et al. 2012), a strong indicator that Postclassic land pressures were much lower than those existing before the depopulation. Spanish accounts also indicate the paucity of population in the CML at contact times (Clendinnen 2003; Scholes and Roys 1968). Following one such account of a village population and the largely vacant area surrounding it in the northeastern portion of the CML, Thompson (1966) proposed a density of only two people per square kilometer.

Even the occupation of the central Petén lake zone does not signal substantial population densities. Occupational losses in the Early Postclassic period, for instance, resulted in an underpopulated condition in which local conflicts generated a consolidation of peoples at several sites (Rice et al. 1998; also, Schwarz 2009). The Kowoj were present north of the lake zone, and the Yalain east of the zone (Rice and Rice 2018b; but see Rice et al. 2005). The Kejache were present farther north of the lake zone, extending toward the modern-day border between Guatemala and Campeche. By early colonial times, the evidence of settlements in this part of the CML is slim. Late Postclassic immigration added people and polities to the lake zone (Jones 1998; Rice 2019; Rice and Rice 2018a), such as that of the Itza, who arrived in either the 1200s or the 1400s, taking over the western part of the lake zone (Jones 1998; Rice and Rice 2005). The fact that the Itza and other Maya peoples could settle, even in the more occupied portions of the CML, is indicative of open or sparsely used lands.

The paleoenvironmental data also support sparse Postclassic occupancy of the CML. They indicate a major reduction in disturbance taxa and a return of forest cover beginning about 850 to 1000 C.E. (e.g., Battistel et al. 2018; Curtis et al. 1998) and, about 300 to 500 years before the Spaniards arrived, the forests and soils of the CML had regenerated in the Petén lake zone (Mueller et al. 2010) and throughout the CML. A second transformation or rewilding had taken place (Wahl et al. 2006, 2007), despite the polities anchored in the lake zone. The massive forests of the CML confronted a Cortez-led expedition, which struggled to traverse them en route to Honduras, encountering nonexistent and overgrown trails and a paucity of settlements to supply food until arriving among the Itza (Cerwin 1963). Subsequent Spanish ventures in the late 1600s from northern Yucatán into the CML also recorded the massive forests and sparse occupation (Scholes and Roys 1968).

Given this record, the estimate by Whitmore and associates (1990) of a Postclassic maximum occupancy of the CML of 20–25 people per square kilometer seems excessive. If such densities existed, they were limited to parts of the central lake zone. The population density of the CML at large was surely in the single digits.

Absence of a millennial population rebound

We began by noting that large population collapses among past agrarian societies, especially those occupying sizable areas, tended to rebound over centuries to millennia, especially. Such a rebound did not take place in the CML during the more than half a millennium between the Terminal Classic period and the beginning of the colonial era, and has not taken place to this day, more than a millennium from the initial population decline. Many, if not most, Maya experts would concur with this assessment in its broad strokes, if not necessarily with the details and interpretations provided here.

Given a return to more humid precipitation regimes, the forest and soils of the CML regenerated in the latter part of Early Postclassic period (1000–1200 C.E.), taking no more than 260 to 280 years, respectively, to recover after the depopulation of the region (Mueller et al. 2010; also Read and Lawrence 2003). This recovery involved strong legacy effects, however. The Maya altered the composition of tree species and disturbed soil surfaces (Brokaw et al. 2025), foremost those maintaining decayed limestone infrastructure. Soil nutrients and moisture were regained, however. Why, then, did the population of the CML fail to rebound over the centuries that passed before Spanish conquest halted Maya control over their realm, especially given the agricultural qualities of the CML compared to the northern Maya lowlands? The answer to this question, which may seem intuitive to Maya scholars, is lacking in terms of empirical assessments or modeling exercises that examine the demographic push–pull factors of the northern and coastal plains versus the CML. Given this circumstance, we briefly entertain those push–pull factors common to migration studies of agrarian communities and for which a modicum of numerical evidence can be advanced: population pressures, environmental hazards, resources, and infrastructure.

Population pressures

The population density of the CML throughout the Postclassic period was small, surely in the low single digits as noted above, providing large areas for occupation. That for the northern lowlands, however, does not appear to have been sufficiently severe to trigger the need for migrations. Recent assessments point to a maximum population of 800,000 in the northern lowland during the Late Postclassic period (Hoggarth et al. 2017; Masson et al. 2024). This population was scattered across numerous settlements of diverse sizes in which the largest was Mayapan with 12,300 to 21,500 occupying its core and periphery, respectively (Masson and Peraza Lope 2014). Webster's (2018) high-end population for the northern lowlands also resides at 800,000. Using that figure, and accounting for the 350 by 150 km swath across the whole terrain of the northern plains of the Yucatán Peninsula (ca. 52,000 km^2)—from east to west coasts and from the north coast to the Puuc Hills—yields a population density of 15 people per square kilometer, rising to 19 people per square kilometer if the population is one million. Considered alone, such densities are not levels indicative of high population pressures by way of comparisons to other agrarian societies (Turner et al. 1977; Webster 2018: table 2), suggesting that this potential push factor in the northern lowlands was not strong.

Population or land pressures for agrarian societies, however, are a product of the density of the population relative to the agricultural qualities of the environment occupied, a factor that we address below. Despite the less than high quality environmental conditions in the northern lowlands and much of the coastal zones, the absence of a spillover of population from the occupied zone into the CML suggests that land pressures were not extreme in the Postclassic occupational areas. Indeed, this is a major rationale for our conclusion that the population densities for the coastal zones were not excessive, given the paucity of demographic evidence for the entirety of the eastern and western coastal zones.

Environmental hazards

The entire Yucatán peninsular region suffers from drought episodes and hurricanes. Drought is recurrent in the paleorecord throughout the Maya lowlands (Figure 2), with intensity levels varying locationally by episode. Fine-tuned spatiotemporal evidence (1981–2011) demonstrates annual droughts about every four years, on average, somewhere in the peninsular area (De la Barreda et al. 2020). Periods of aridity affected the northern lowlands in the Postclassic period and subsequently (Kennett et al. 2012; Masson and Peraza Lope 2014), with Spanish documented impacts indicative of food hardships in colonial times (Hoggarth et al. 2017). The Terminal-Postclassic demise of Chichén Itzá (Andrews et al. 2003), for example, may have been associated with intensive aridity between 1000 and 1100 C.E. (Figure 2), and conflicts among polities in the Postclassic period were associated with drought episodes (Kennett et al. 2022). Yet, the abundant rural settlements in the north persisted (Masson et al. 2024), and the resiliency of the Maya at a regional level of assessment persisted into contact times (Kennett et al. 2022). Importantly, the Postclassic droughts in question were likely experienced in the CML, if varying in intensity. Neither the northern coastal lowlands nor the CML, therefore, had a major advantage regarding hazards of aridity.

The synchronous character of drought across the Maya realm is not well matched by hurricane frequency and damage severity, as historically recorded. Hurricanes track across the entire peninsular area, invariably slamming the eastern coastline but reducing in strength inland and on the western coastline, lowering the damage to crops and landscapes. Their frequency and intensity, however, trend from the north-northeastern part of the peninsula southward along the Caribbean coast into Belize. One hurricane event occurs every four to ten years by location in the northeastern zone, but only about every 30 years for the CML (Boose et al. 2003; Romero and León-Cruz 2024). If such patterns of frequencies existed in the past, and we are aware of no evidence that they did not, the CML would have been a more friendly location for occupation. No evidence exists, however, of hurricane-induced migrations during the Postclassic period from the more hazardous locations in the north-northeast lowlands leading to permanent occupation of the CML. Reduced hurricane damage in the CML, therefore, appears to have constituted a low pull factor.

https://doi.org/10.1017/S0956536125000045 Published online by Cambridge University Press

Resources

Major distinctions exist between the northern and coastal lowlands and the CML in terms of natural capital and the environmental (ecosystem) services that followed from them during the Postclassic period. This capital—precipitation, soil, and potable water, all critical resources for agrarian societies (Arnauld 2024), as well as lands suitable for salt production and access to marine and riverine foods—varied differentially among the areas examined.

The immediate coastal zone of the northwestern peninsula currently averages 600–800 mm of annual precipitation. Inland, however, where the preponderance of northern Postclassic Maya settlements existed, the land receives 1,000–1,200 mm. In contrast, the CML maintains average annual precipitation ranging up to 2,500–2,600 mm (Luzzadder-Beach et al. 2016). The amount of precipitation also equates to the length of the principal growing season, which is longer in the CML than in the northern lowlands. The east and west coastal lands mimic this north-to-south increase in humidity and growing seasons.

The northern lowlands maintain a variety of cultivation micro-niches (Munro-Stasuik et al. 2014) and soil types, although rendzinas are common. All upland soils are shallow in depth, often exceptionally so, and scattered among surface limestone bedrock (Beach 1998; Sedov et al. 2023). Small, shallow cavities in the underlying bedrock provide more soil depth, although the soil moisture retention proves to be problematic. Seasonally inundated wetlands with shallow soils (e.g., calcisols) are present near the coastline. While adequate for cultivation (Leonard et al. 2019; Sedov et al. 2023), the soils of the northern lowlands are not of the same quality as those in the CML. The upland mollisols, mostly troporendolls, of the CML are deeper and of higher quality for cultivation (Liu et al. 2012) than the northern rendzinas. In addition, the clay-rich vertisols of the CML wetlands may also serve cultivation well if managed properly. Similar to Indigenous peoples throughout the Western Hemisphere, the Maya long maintained these management skills (Beach et al. 2019). The Classic-period population size and the abundance of landesque capital in the CML attests to the advantages of soils, precipitation, and growing season there (e.g., Turner and Sabloff 2012).

Underserved cultivation-wise compared to the CML, the northern lowlands and the coastal zones maintain distinctive advantages in access to potable groundwater through abundant cenotes (sinks) and caves that reach the water table (Luzzadder-Beach et al. 2016; Kennett and Hodell 2017), although cenotes penetrating the freshwater lens may encounter saline water (Socki et al. 2002). A few shallow lakes also exist in karstic depressions, and reservoirs were constructed into the Early Postclassic period in the Puuc region (Isendahl 2011). The more southerly coastal plains also had access to fresh water from rivers along those portions secure from seawater intrusion. Given the long-term persistence of drought periods, access to potable water that could serve substantial populations was a distinctive asset (pull factor) for the northern and coastal lowlands, matched in the CML only by the central Petén lakes zone.

The coastal zones of the peninsula also had the advantage of topographic conditions and seawater for salt production, the output of which was part of long-distance trade among the Maya (above) and beyond, even perhaps to the Caribbean Islands (Glover et al. 2011; McKillop 2010). Coastal lagoons and marshes favored modification for salt production by way of solar evaporation (Robles Castellanos et al. 2020), although "salt kitchens" existed, especially in coastal Belize, where brine spring water and salty soil were cooked to create salt cakes (McKillop and Sills 2025). The scale of the Maya salt trade and the economic advantages of it were profound (Andrews 1980; McKillop 2021; Robles Castellanos et al. 2020), creating a pull factor for occupation in proximity to the waters surrounding the peninsula.

Coastal zones also favored access to sea and riverine food stocks. Seafood helped to supply Postclassic food demands inland in the northern lowlands, as evidenced by fish consumption at Mayapan, about 80 km from the coast (Kennett et al. 2016). The settlements in the coastal plains of the Champotón watershed on the western side of the peninsula consumed seafoods (Ek 2014), and the wetlands along the Candelaria River maintained fish farms (Gunn et al. 2019). In addition, extensive fish-trapping infrastructure exists along the rivers of the coastal plains to the east of the CML dating to early Maya occupation of the lowlands (Harrison-Buck et al. 2024). It would not be surprising, however, to find that such activities existed throughout Maya occupation (Palka 2024). Salted fish was traded inland (Alsgaard 2020; McKillop and Aoyama 2018), surely serving the CML during its occupation. Nevertheless, lands below the elevated interior and adjacent to the coastlines maintained the advantage of fish commerce, and their populations may have survived physiological stress better than those in the elevated interior (White et al. 2006).

Infrastructure

Throughout the Postclassic period, the northern and coastal lowlands sustained settlements, trade and transport, and food production infrastructure that supported a material lifestyle which had long deteriorated in the CML. Among other facilities, a 215 km coastal waterway extended from about Celestún on the northeastern shores of the peninsula to Dzilam de Bravo on the northern shores (Figure 1). This transport use was operative long before, but continued, into the Postclassic period and beyond (Robles Castellanos et al. 2020).

In contrast, the sparsely occupied Postclassic CML contained the remnants of its former infrastructure, settlements to landesque capital, and massive forests to be cleared. Reoccupation consistent with a millennium-scale population rebound mimicking the material conditions in the northern and coastal lowlands would have required substantial labor costs. Following Abrams' (1994) construction energetics, creating CML residential structures only for an occupancy of 25 people per square kilometer (five persons per abode; 5 percent improved or elite structures), yields 126 million labor-days. This figure, however, does not include the substantial costs of constructing monumental architecture, reservoirs, *aguadas, sacbes*, terraces, and wetland fields, as well as clearing the forest and producing subsistence during the infrastructure rebuild (e.g., Beach et al. 2019; Bhattacharya et al.

2023; Castanet et al. 2024; Lucero 2023; Palka 2024; Tankersley et al. 2020). Redevelopment over multiple years, however, would have reduced annual labor costs (Webster and Kirker 1995), and refurbishing decayed landesque capital may have lowered the total labor. The critical push–pull point, however, is the willingness of an emigrant population to give up its existing material lifestyle for a lesser one or for an extended period while creating the infrastructure to provide the material conditions left in the north or along the coasts. Intuitively, this consideration would lead to a low push and low pull for the northern and coastal lowlands and the CML, respectively.

This observation, however, warrants caution. Maya populations had abandoned lands and moved within and into the CML before the Postclassic period (Arnauld et al. 2017). For example, some urban sites in the CML, such as El Mirador (Wahl et al. 2007), were abandoned near the end of the Preclassic period. Presumably, a sizable portion of these urban folks moved elsewhere in the CML, signaling the need for new or refurbished infrastructural costs. The Itza, of course, migrated from the northern lowlands to Lake Petén Itzá in the Postclassic, constructing Nojpetén as a facsimile of the settlements from which they came (Rice and Rice 2018b). Unfortunately, in both of these cases—CML urban abandonment and the Itza arrival—the time it took to create the amount and quality of infrastructure that was abandoned and the role that this consideration might have played in decisions to move, if any, are not clear.

Comparing factors

The strongest pull factor for substantial immigration into the CML during the Postclassic era would appear to be its superior agricultural conditions—higher quality soils, increased average annual precipitation, and longer growing (wet) season—compared to the northern lowlands and coastal areas, excepting the riverine locations. In addition, the CML incurred fewer intensive tropical storms and possessed substantial amounts of land to be settled. These potential pull factors, however, were insufficient to outweigh the comparative disadvantages of the CML or the low push factors beyond the CML, foremost access to potable water, especially during times of severe drought, and its distance from the critical seagoing commerce.

Critically, the land pressures among Postclassic Maya on the northern plains and, likely, the coastal zones, were not exceptionally high, averaging below 20 people per square kilometer and capable of recovering from environmental hazards. Documented population rebounds invariably followed drought-induced mortality among the northern Maya in the colonial era (Hoggarth et al. 2017). Such rebounds, we suspect, were consistent throughout the Postclassic period. Access to marine and riverine foods surely played a role in this rebound.

In addition to the material conditions examined here, the Postclassic shift to mercantilism and the dominance of seagoing trade provided a huge pull for Maya areas below the elevated interior and in proximity to the coast. Dispersed networks of northern city-states tended to maintain few restrictions on trade, facilitating commercial networks over larger regions (Masson and Freidel 2020 ; Volta et al. 2020). By the thirteenth century, the independent settlements and polities in the north permitted the movement of residents among the settlements (Kennett et al. 2022). Together, these conditions provided safety nets to confront environmental hazards and helped to stabilize occupancy in the northern lowlands.

Expressing it differently from our argument, Demarest (2013) proposed that alternative occupational locations—the northern and coastal lowlands—and their conditions were causal factors in the absence of a Postclassic population rebound elsewhere in the greater Yucatán peninsular region, including the CML. This proposal is consistent with the Postclassic push–pull factors examined in our assessment. Granting causality to the presence of alternative occupation zones raises a conundrum, however, as follows. Long before the Postclassic period, the lowland Maya occupied the entire peninsular region, although the population and power levels of the CML were at the apex of the Maya realm. A change in the political economy and shift in trade-route dominance during the Postclassic would understandably lead to occupational shifts consistent with the new conditions. Not so understandable, however, is the radical level of occupation shifts, leaving a nearly vacant CML. Metaphorically, the occupation of Maya realm, not just the CML, from the Classic to Postclassic periods is that of a glass completely full to a glass half empty.

This problem notwithstanding, the archaeological and historical records indicate at least one push factor from the occupied lands to the CML. Major social conflicts triggered migration to the CML and elevated interior at large. Internal Maya conflicts in the northern lowlands pushed the Itza to migrate permanently to the CML (Rice and Rice 2018b), as noted above, incurring the costs of recreating the necessary infrastructure for their occupation. Notably, this level of reoccupation involved an entire lineage returning to its ancestral homelands, pointing to the nuances involved in the migration to and sustained occupation of the CML. Somewhat similarly, Spanish–Maya disagreements and conflicts in the colonial era prompted the flight into, if not permanent occupation of, the elevated interior (Farriss 1984; Jones 1990, 1998), perhaps reaching the CML. In either case, the CML offered large amounts of unoccupied or sparsely occupied lands and extensive tracts of forests that served as protection from other polities and, eventually, the Spaniards in the north. For those escaping Spanish control, the upland forests provided suitable short-term habitats for occupation with their rested soils and abundant useful tree species, a product of former Maya orchard gardens and managed forests (e.g., Atran et al. 1993; Brokaw et al. 2025; Fedick 2020; Fedick et al. 2023; Ford 2015; Gómez-Pompa et al. 1987; Ross 2011; Wyatt 2020). Most of the Maya involved in such escape episodes did not remain in the CML, however.

Summary and observations

Evidence of the diversity and complexity of human-environmental relationships in the ancient Maya lowlands continues to increase. Recognizing various challenges to the interpretation of that evidence, the literature is replete with

https://doi.org/10.1017/S0956536125000045 Published online by Cambridge University Press

the following narrative. Owing to extreme land pressures and persistent climatic drought during the Late Classic–Terminal Classic periods, the societal conditions of the Maya of the CML, as well as the elevated interior at large, had difficulties maintaining food and water services. Interactive with and amplifying these difficulties was the diminution of economic activities by way of regional trade networks, which overwhelmingly shifted to coastal seafaring. These conditions assisted in a human-environmental transformation—a socio-political collapse, substantial population losses, and a subsequently degraded infrastructural or built environment. Essentially, this transformation mimics the characteristics of a regime shift associated with crossing the tipping point of a system.

The Postclassic demographic focus of the lowland Maya shifted to the northern plains and the Caribbean and Gulf coasts of the peninsular region, those possessing access to drought-resistant water sources. The emergence of a mercantile economy, dominated by seafaring trade, supported a materially prosperous population. Postclassic population pressures, muted by agricultural constraints and drought interludes, apparently did not reach the levels obtained in the CML before its depopulation. The ability of people to move among the occupied polities may have ameliorated societal drought impacts and pressures to move beyond the occupied zones.

We surmise that these dynamics—the conditions leading to the significantly depopulated CML and those of the Postclassic occupied zones—provide insights into the unusual, long-term demographic history of the CML. The pull factors of the environmentally restored and agriculturally superior CML were insufficient to attract major reoccupation, given the low levels of push factors in the Postclassic northern and coastal zones. The immense forests of CML remained primarily intact throughout the Postclassic period, except for the areas immediate to the central Petén lakes. Spanish impacts during the colonial era, including the conquest of the Itza, would continue the low occupancy of the CML, which has extended into the twenty-first century.

The demographic distinctiveness of the CML—the lack of a population rebound, at either two centuries or a millennium—constitutes one of the more unique characteristics of the prehispanic Maya. The evidence of the absence of this rebound has stood the test of time, in contrast to other unique interpretations or claims about the ancient Maya relative to other past agrarian societies. Given this uncommon demographic history, we reiterate our initial question: why has direct research attention to this history been so sparse?

Our attempt to address the topic considers those push–pull factors for which evidence resides in the literature, if not directed to the topic per se. We focused on material factors because the evidence permits quantitative data comparisons, if at a rudimentary level, between the northern and coastal lowlands and the CML. This exercise indicates the need for more robust, fine-tuned analyses based on improved levels of data specification, especially for the Postclassic areas of occupation. Examples include population pressures, which involve more than raw population densities, agricultural output for different soils and management strategies, water access for settlements in which groundwater-cenotes and -caves and river access did not exist, and fine-tuned, locational intensities of drought and hurricane impacts. With sufficient specification, these and other factors may improve our understanding of the topic by way of various modeling approaches, with attention to the use of geographically weighted regressions to account for the role of location in push–pull factors.

Finally, our attention to nonmaterial push–pull factors has been sparse. We briefly addressed the willingness of the populations of the well-developed Postclassic occupational areas to give up their material lifestyle to migrate to the forested CML and recreate it through infrastructure development. We also recognized the transformation of the political economy from the Classic to Postclassic periods, but did not pursue why such a change would alter the occupation of the Maya realm so fundamentally. Why would the political and economic structures before the Postclassic period produce occupation throughout the entirety of the Maya realm, whereas those during the Postclassic period lead to large areas with minimal population? More sophisticated assessments of these and other nonmaterial factors, such as sociocultural dimensions and power dynamics among the Maya, are warranted. We encourage those steeped in these dimensions and dynamics of Maya studies to add them to future assessments.

Improved understanding of the uncommon demographic history of the CML should provide insights into other important queries that require the attention of the research community. Paramount among these is the reason for the prosperity and power of the CML before the Terminal Classic period, given its subsequent status. Did it reside in the favorable agricultural base of the CML, the social dynamics of its inhabitants, the legacy and lock-ins of its abandonment, or other human-environmental conditions?

Acknowledgements. We think Jeremy Sabloff for comments on earlier drafts of this paper, and Timothy Beach and Arlen Chase for providing access to various literatures. The reviewers of the initial submission of this paper provide critical insight that directed alterations. The authors are responsible for the content of the paper, however. The Gilbert F. White Professorship, Arizona State University provided financial support for the publication. We thank Shea Lemar and Yueling Li for the preparation of Figure 1.

References

Abrams, Elliot M.
1994 *How the Maya Build Their World: Energetics and Ancient Architecture*. University of Texas Press, Austin.
Akpinar Ferrand, Ezgi, Nicholas P. Dunning, David L. Lentz, and John G. Jones
2012 Use of Aguadas as Water Management Sources in Two Southern Maya Lowland Sites. *Ancient Mesoamerica* 23:85–101. https://doi.org/10.1017/S0956536112000065.
Alsgaard, Asia V.
2020 A Meta-Analysis Approach to Understanding Maya Fish Use on the Yucatán Peninsula. *Journal of Ethnobiology* 40:499–518.
Andrews, Anthony P.
1980 *Salt-Making, Merchants and Markets: The Role of a Critical Resource in the Development of Maya Civilization*. University of Arizona Press, Tucson.
Andrews, Anthony P.

2020 Ancient Maya Ports, Port Facilities, and Navigation. In *The Maya World*, edited by Scott R. Hutson and Traci Ardren, pp. 269–286. Routledge, London.
Andrews, Anthony P., E. Wyllys Andrews, and Fernando Robles Castellanos
2003 The Northern Maya Collapse and Its Aftermath. *Ancient Mesoamerica* 14:151–156. https://doi.org/10.1017/S095653610314103X.
Ardren, Traci, and Justin Lowry
2011 The Travels of Maya Merchants in the Ninth and Tenth Centuries AD: Investigations at Xuenkal and the Greater Cupul Province, Yucatan, Mexico. *World Archaeology* 43:428–443.
Arnauld, M. Charlotte
2024 The Why and How: Causality Research in Maya Archaeology of Climate Change (800–1100 CE). *IdéAs* 24. https://doi.org/10.4000/12hsb.
Arnauld, M. Charlotte, Chloé Andrieu, and Mélanie Forné
2017 "In the Days of My Life." Elite Activity and Interactions in the Maya Lowlands from Classic to Early Postclassic Times (the Long Ninth Century, AD 760–920). In "Maya Times," edited by Valentina Vapnarsky, Fabienne de Pierrebourg, and Dominique Michelet. Special issue, *Journal de la Société des Américanistes*. https://doi.org/10.4000/jsa.15362.
Arnauld, M. Charlotte, Eva Lemonnier, and Julien Hiquet
2024 Classic Maya Population History as Seen from Río Bec, Campeche, Mexico. In *Mesoamerican Population History: Urbanism, Social Complexity and Change*, edited by Adrian S.Z. Chase, Arlen F. Chase, and Diane Z. Chase, pp. 161–192, University of Arizona Press, Tucson.
Atran, Scott, Arlen F. Chase, Scott L. Fedick, Gregory Knapp, Heather McKillop, Joyce Marcus, Norman B. Schwartz, and Malcolm C. Webb
1993 Itza Maya Tropical Agro-Forestry. *Current Anthropology* 34:633–700.
Baron, Joanne P.
2018 Ancient Monetization: The Case of Classic Maya Textiles. *Journal of Anthropological Archaeology* 49:100–113.
Battistel, D., Marco Roman, Andrea Marchetti, Natalie M. Kehrwald, Marta Radaelli, Eleonora Balliana, Giuseppe Toscano, and Carlo Barbante
2018 Anthropogenic Impact in the Maya Lowlands of Petén, Guatemala, during the Last 5500 Years. *Journal of Quaternary Science* 33:166–176.
Bauer-Gottwein, Peter, Bibi R. N. Gondwe, Guillame Charvet, Luis Marín, Mario Rebolledo-Vieyra, and Gonzalo Merediz-Alonso
2011 Review: The Yucatán Peninsular Karst Aquifer, Mexico. *Hydrology Journal* 19:507–524.
Beach, Timothy
1998 Soil Constraints on Northwest Yucatan, Mexico: Pedoarchaeology and Maya Subsistence at Chunchucmil. *Geoarchaeology* 13:759–791.
Beach, Timothy, Sheryl Luzzadder-Beach, Duncan Cook, Nicholas Dunning, Douglas J. Kennett, Samantha Krause, Richard Terry, Debora Trein, and Fred Valdez
2015 Ancient Maya Impacts on the Earth's Surface: An Early Anthropocene Analog? *Quaternary Science Reviews* 124:1–30.
Beach, Timothy, Sheryl Luzzadder-Beach, Samantha Krause, Tom Guderjan, Fred Valdez Jr., Juan C. Fernandez-Diaz, Sara Eshleman, and Colin Doyle
2019 Ancient Maya Wetland Fields Revealed under Tropical Forest Canopy from Laser Scanning and Multiproxy Evidence. *Proceedings of the National Academy of Sciences* 116:21469–21477.
Bhattacharya, Tripti, Samantha Krause, Dan Penny, and David Wahl
2023 Drought and Water Management in Ancient Maya Society. *Progress in Physical Geography: Earth and Environment* 47:189–204.
Bianco, Bre, Rani Alexander, and Gary Rayson
2017 Beekeeping Practices in Modern and Ancient Yucatán: Going from Known to Unknown. In *The Value of Things. Prehistoric to Contemporary Commodities in the Maya Region*, edited by Jennifer P. Mathews, and Thomas H. Guderjan, pp. 87–103. University of Arizona Press, Tucson.
Boose, Emery R., David R. Foster, A. Barker Plotkin, and Brian Hall
2003 Geographical and Historical Variation in Hurricanes across the Yucatan Peninsula. In *The Lowland Maya Area: Three Millennia at the Human-Wildland Interface*, edited by Scott Fedick, Michael Allen, and A. Gomez-Pompa, pp. 495–516. Haworth Press, New York.
Brokaw, Nicholas, Sheila E. Ward, Timothy Beach, Sheryl Luzzadder-Beach, Stanley Walling, Marisol Cortes-Rincon, and Fred Valdez
2025 The Ancient Maya and the Modern Forest. *Biotropica* 57(1):e13370.
Butzer, Karl W.
2012 Collapse, Environment, and Society. *Proceedings of the National Academy of Sciences* 109:3632–3639.
Canuto, Marcello A., and Luke Auld-Thomas
2024 Greater than the Sum of Its Surveyed Parts: Reconstructing the Population of Late Classic Peten with Updated Methods and New Data. In *Mesoamerican Population History: Urbanism, Social Complexity and Change*, edited by Adrian S. Z. Chase, Arlen F. Chase, and Diane Z. Chase, pp. 215–267, University of Arizona Press, Tucson.
Canuto, Marcello A., Francisco Estrada-Belli, Thomas G. Garrison, Stephen D. Houston, Mary Jane Acuña, Milan Kováč, Damien Marken, Philippe Nondédéo, Luke Auld-Thomas, Cyril Castanet, David Chatelain, Carlos R. Chiriboga, Tomáš Drápela, Timor Lieskovský, Alexandre Tokovinine, Antolín Velasquez, Juan C. Fernández-Díaz, and Ramesh Shrestha
2018 Ancient Lowland Maya Complexity as Revealed by Airborne Laser Scanning of Northern Guatemala. *Science* 36:1313–1314.
Castanet, Cyril, Amaury Fernandes, Fatima Mokadem, Christine Hatté, Caroline Gauthier, Anne-Lise Develle-Vincent, Julien Cavero, Hugo Dru, Clément Virmoux, Gyorgy Sipos, Lydie Dussol, and Philippe Nondédéo
2024 Wetland Landscapes in the Southern Maya Lowlands (Naachtun, Guatemala) from the Ancient Agroecosystems to the Tropical Biosphere Reserve: Ecology, Exploitation and Management of Water and Soil Resources, and Heritage Legacy. *Geoarchaeology* 39:530–562.
Cerwin, Herbert
1963 *Bernal Diaz—Historian of the Conquest*. University of Oklahoma Press, Norman.
Chase, Adrian S. Z., Elyse D. Z. Chase, Diane Z. Chase, and Arlen F. Chase
2024 Population History for Caracol, Belize: Numbers, Complexity, and Urbanism. In *Mesoamerican Population History: Urbanism, Social Complexity and Change*, edited by Adrian S. Z. Chase, Arlen F. Chase, and Diane Z. Chase, pp. 67–88, University of Arizona Press, Tucson.
Chase, Diane Z., and Arlen F. Chase
2014 Ancient Maya Markets and the Economic Integration of Caracol, Belize. *Ancient Mesoamerica* 25:239–250. https://doi.org/10.1017/S0956536114000145.
Chase, Diane Z., Arlen F. Chase, and John M. Morris
2008 Archaeological Myths of the Postclassic Period: Belizean Archaeology as "Dragonslayer." In *Research Reports in Belizean Archaeology*, *Vol.* 5, edited by John Morris, Sherilyne Jones, Jaime Awe, and Christophe Helmke, pp. 13–22. Institute of Archaeology, Belmopan.
Clendinnen, Inga
2003 *Ambivalent Conquests: Maya and Spaniard in Yucatan, 1517–1570*, 2nd ed. Cambridge University Press, Cambridge.
Culbert, T. Patrick,
ed. 1973 *The Classic Maya Collapse*. University of New Mexico Press, Albuquerque.
Curtis, Jason H., Mark Brenner, David A. Hodell, Richard A. Balser, Gerard A. Islebe, and Henry Hooghiemstra
1998 A Multi-Proxy Study of Holocene Environmental Change in the Maya Lowlands of Peten, Guatemala. *Journal of Paleolimnology* 19:139–159.

De la Barreda, Betsabé, Sarah E. Metcalfe, and Doreen S. Boyd
2020 Precipitation Regionalization, Anomalies and Drought Occurrence in the Yucatan Peninsula, Mexico. *International Journal of Climatology* 40:4541–4555.

Demarest, Arthur A.
2013 The Collapse of the Classic Maya Kingdoms of the Southwestern Petén: Implications for the End of the Maya Civilization. In *Millenary Maya Societies: Past Crises and Resilience*, edited by M.-Charlotte Arnauld and Alain Breton, pp. 22–48. www.mesoweb.com/publications/MMS/MMS.pdf, accessed April 3, 2025.

Douglas, Peter M. J., Arthur A. Demarest, Mark Brenner, and Marcello A. Canuto
2016 Impacts of Climate Change on the Collapse of Lowland Maya Civilization. *Annual Review of Earth and Planetary Sciences* 44: 613–645.

Douglas, Peter M. J., Mark Pagani, Marcello A. Canuto, Mark Brenner, David A. Hodell, Timothy I. Eglinton, and Jason H. Curtis
2015 Drought, Agricultural Adaptation, and Sociopolitical Collapse in the Maya Lowlands. *Proceedings of the National Academy of Sciences* 112:5607–5612.

Dunning, Nicholas, Jeffrey Brewer, Christopher Carr, Armando Anaya Hernández, Timothy Beach, Jennifer Chmilar, Liwy Grazioso Sierra, Robert Griffin, David Lentz, Sheryl Luzzadder-Beach, Katheryn Reese-Taylor, William Saturno, Vernon Scarborough, Michael Smyth, and Fred Valdez Jr.
2022 Harvesting Ha: Ancient Water Collection and Storage in the Elevated Interior Region of the Maya Lowlands. In *Sustainability and Water Management in the Maya World and Beyond*, edited by Jean T. Larmon, Lisa J. Lucero, and Fred, Valdez Jr., pp. 13–52. University Press of Colorado, Boulder.

Dunning, Nicholas P., Timothy Beach, Liwy Grazioso Sierra, John G. Jones, David L. Lentz, Sheryl Luzzadder-Beach, Vernon L. Scarborough, and Michael P. Smyth
2013 A Tale of Two Collapses: Environmental Variability and Cultural Disruption in the Maya Lowlands. *Diálogo Andino-Revista de Historia, Geografía y Cultura Andina* 41:171–183.

Dunning, Nicholas P., Timothy P. Beach, and Sheryl Luzzadder-Beach
2012 Kax and Kol: Collapse and Resilience in Lowland Maya Civilization. *Proceedings of the National Academy of Sciences* 109:3652–3657.

Ebert, Claire E., Nancy Peniche May, Brendan J. Culleton, Jaime J. Awe, and Douglas J. Kennett
2017 Regional Response to Drought during the Formation and Decline of Preclassic Maya Societies. *Quaternary Science Reviews* 173: 211–235.

Ek, Jerald
2014 The Political and Economic Organization of Late Classic States in the Peninsular Gulf Coast: The View from Champoton, Campeche. In *The Ancient Maya of Mexico: Reinterpreting the Past of the Northern Maya Lowlands*, edited by Geoffrey Braswell, pp. 157–183. Routledge, New York.

Emery, Kitty F.
2007 Assessing the Impact of Ancient Maya Animal Use. *Journal for Nature Conservation*, 15:184–195.

Emery, Kitty F., and Erin K. Thornton
2008 A Regional Perspective on Biotic Change during the Classic Maya Occupation Using Zooarchaeological Isotopic Chemistry. *Quaternary International* 191:131–143.

Ensley, Ross, Richard D. Hansen, Carlos Morales-Aguilar, and Josie Thompson
2021 Geomorphology of the Mirador-Calakmul Karst Basin: A GIS-Based Approach to Hydrogeologic Mapping. *PLoS One*, 16:e0255496.

Eppich, Keith
2020 Commerce, Redistribution, Autarky, and Barter. In *The Real Business of Ancient Maya Economies: From Farmer's Field to Rulers' Realms*, edited by Marilyn A. Masson, David A. Freidel, Arthur A. Demarest, Arlen F. Chase, and Diane Z. Chase, pp. 150–171. University of Florida Press, Tallahassee.

Evans, Nicholas P., Thomas K. Bauska, Fernando Gazquez-Sanchez, Mark Brenner, Jason H. Curtis, and David A. Hodell
2018 Quantification of Drought during the Collapse of the Classic Maya Civilization. *Science* 361:498–501.

Farriss, Nancy M.
1984 *Maya Society under Colonial Rule: The Collective Enterprise of Survival*. Princeton University Press, Princeton.

Fedick, Scott L.
2020 Maya Cornucopia: Indigenous Food Plants of the Maya Lowlands. In *The Real Business of Ancient Maya Economies: From Farmer's Field to Rulers' Realms*, edited by Marilyn A. Masson, David A. Freidel, Arthur A. Demarest, Arlen F. Chase, and Diane Z. Chase, pp. 224–237. University of Florida Press, Tallahassee.

Fedick, Scott L., Shanti Morell-Hart, and Lydie Dussol
2023 Agriculture in the Ancient Maya Lowlands (Part 2): Landesque Capital and Long-Term Resource Management Strategies. *Journal of Archaeological Research* 32:103–154.

Ford, Anabel
2015 *The Maya Forest Garden*. Routledge, New York.

Ford, Anabel
2022 Scrutinizing the Paleoecological Record of the Maya Forest. *Frontiers in Ecology and Evolution* 10:868660.

Gill, Richardson B.
2000 *The Great Maya Droughts: Water, Life, and Death*. University of New Mexico Press, Albuquerque.

Glover, Jeffrey B., Zachary X. Hruby, Dominique Rissolo, Joseph W. Ball, Michael D. Glascock, and M. Steven Shackley
2018 Interregional Interaction in Terminal Classic Yucatan: Recent Obsidian and Ceramic Data from Vista Alegre, Quintana Roo, Mexico. *Latin American Antiquity* 29:475–494.

Glover, Jeffrey B., Dominique Rissolo, and Jennifer P. Mathews
2011 The Hidden World of the Maritime Maya: Lost Landscapes along the North Coast of Quintana Roo, Mexico. In *The Archaeology of Maritime Landscapes*, edited by Ben Ford, pp. 195–216, Springer, New York.

Golden, Charles, Timothy Murtha, Bruce Cook, Derek S. Shaffer, Whittaker Schroder, Elijah J. Hermitt, Omar Alcover Firpi, and Andrew K. Scherer
2016 Reanalyzing Environmental Lidar Data for Archaeology: Mesoamerican Applications and Implications. *Journal of Archaeological Science: Reports* 9:293–308.

Golitko, Mark, James Meierhoff, Gary M. Feinman, and Patrick R. Williams
2012 Complexities of Collapse: The Evidence of Maya Obsidian as Revealed by Social Network Graphical Analysis. *Antiquity* 86:507–523.

Gómez-Pompa, Arturo, J. Salvador Flores, and Victoria Sosa
1987 The "Pet Kot": A Man-Made Tropical Forest of the Maya. *Interciencia* 12(1):10–15.

Griffin, Robert, Robert Oglesby, Thomas Sever, and Udaysankar Nair
2014 Agricultural Landscapes, Deforestation and Drought Severity. In *The Great Maya Drought in Cultural Context: Case Studies in Resilience and Vulnerability*, edited by Gyles Iannone, pp. 71–86, University Press of Colorado, Boulder.

Gunn, Joel D., William J. Folan, Nuria Torrescano-Valle, Betty B. Faust, Helga Z. Geovannini-Acuña, and Alfred H. Siemens
2019 From Calakmul to the Sea: The Historical Ecology of a Classic Maya City That Controlled the Candelaria/Champoton Watersheds. In *The Holocene and Anthropocene Environmental History of Mexico: A Paleoecological Approach on Mesoamerica*, edited by Nuria Torrescano-Valle, Gerald A. Islebe, and Priyadarsi D. Roy, pp. 209–248. Springer, Cham.

Haldon, John, Lee Mordechai, Timothy P. Newfield, Arlen F. Chase, Adam Izdebski, Piotr Guzowski, Inga Labuhn, and Neil Roberts
2018 History Meets Paleoscience: Consilience and Collaboration in Studying Past Societal Responses to Environmental Change. *Proceedings of the National Academy of Sciences* 115:3210–3218.

Hansen, Richard D., Steven Bozarth, John Jacob, David Wahl, and Thomas Schreiner

https://doi.org/10.1017/S0956536125000045 Published online by Cambridge University Press

2002 Climatic and Environmental Variability in the Rise of Maya Civilization: A Preliminary Perspective from Northern Petén. *Ancient Mesoamerica* 13:273–295. https://doi.org/10.1017/S0956536102132093.

Hansen, Richard D., Carlos Morales-Aguilar, Josephine Thompson, Ross Ensley, Enrique Hernandez, Thomas Schreiner, Edgar Suyuc-Ley, and Gustavo Martinez
2023 LiDAR Analyses in the Contiguous Mirador-Calakmul Karst Basin, Guatemala: An Introduction to New Perspectives on Regional Early Maya Socioeconomic and Political Organization. *Ancient Mesoamerica* 34:587–626. https://doi.org/10.1017/S0956536122000244.

Harrison-Buck, Eleanor, Samantha M. Krause, Marieka Brouwer Burg, Mark Willis, Angelina Perrotti, and Katie Bailey
2024 Late Archaic Large-Scale Fisheries in the Wetlands of the Pre-Columbian Maya Lowlands. *Science Advances* 10:eadq1444.

Hoggarth, Julie A., Matthew Restall, James W. Wood, and Douglas J. Kennett
2017 Drought and Its Demographic Effects in the Maya Lowlands. *Current Anthropology* 58:82–113.

Hutson, Scott R.
2024 Population Estimates and Population Movement in Northwestern Yucatan, Mexico. In *Mesoamerican Population History: Urbanism, Social Complexity and Change*, edited by Adrian S. Z. Chase, Arlen F. Chase, and Diane Z. Chase, pp. 129–160. University of Arizona Press, Tucson.

Hutson, Scott R., and Bruce H. Dahlin
2017 Introduction: The Long Road to Maya Markets. In *Ancient Maya Commerce: Multidisciplinary Research at Chunchucmil*, edited by Scott R. Hutson, pp. 3–26, University Press of Colorado, Boulder.

Hutson, Scott R., Nicholas P. Dunning, Bruce Cook, Thomas Ruhl, Nicolas C. Barth, and Daniel Conley
2021 Ancient Maya Rural Settlement Patterns, Household Cooperation, and Regional Subsistence Interdependency in the Río Bec Area: Contributions from G-LiHT. *Journal of Anthropological Research* 77:550–579.

Iannone, Gyles, Jason Yeager, and David Hodell
2014 Assessing the Great Droughts: Some Critical Issues. In *The Great Maya Drought in Cultural Context: Case Studies in Resilience and Vulnerability*, edited by Gyles Iannone, pp. 51–70, University Press of Colorado, Boulder.

Isendahl, Christian
2011 The Weight of Water: A New Look at Pre-Hispanic Puuc Maya Water Reservoirs. *Ancient Mesoamerica* 22:185–197. https://doi.org/10.1017/S0956536111000149.

Isendahl, Christian
2012 Agro-Urban Landscapes: The Example of Maya Lowland Cities. *Antiquity* 86:1112–1125.

Jones, Grant D.
1990 *Maya Resistance to Spanish Rule: Time and History on a Colonial Frontier*. University of New Mexico Press, Albuquerque.

Jones, Grant D.
1998 *The Conquest of the Last Maya Kingdom*. Stanford University Press, Stanford.

Kennett, Douglas J., and Timothy P. Beach
2013 Archeological and Environmental Lessons for the Anthropocene from the Classic Maya Collapse. *Anthropocene* 4: 88–100.

Kennett, Douglas J., Sebastian F. M. Breitenbach, Valorie V. Aquino, Yemane Asmerom, Jaime Awe, James U. L. Baldini, Patrick Bartlein, Brendan J. Culleton, Claire Ebert, Christopher Jazwa, Martha J. Macri, Norbert Marwan, Victor Polyak, Keith M. Prufer, Harriet E. Rifley, Harald Sodemann, Bruce Winterhalder, and Gerald H. Haug
2012 Development and Disintegration of Maya Political Systems in Response to Climate Change. *Science* 338:788–791.

Kennett, Douglas J., and David A. Hodell
2017 AD 750–1100 Climate Change and Critical Transitions in Classic Maya Sociopolitical Networks. In *Megadrought and Collapse: From Early Agriculture to Angkor*, edited by Harvey Weiss, pp. 205–230. Oxford University Press, Oxford.

Kennett, Douglas J., Marilyn Masson, Carlos P. Lope, Stanley Serafin, Richard J. George, Tom C. Spencer, Julie A. Hoggarth, Brendan J. Culleton, Thomas K. Harper, Keith M. Prufer, Susan Milbrath, Bradley W. Russell, Eunice Uc Gonzalez, Weston C. McCool, Valorie W. Aquino, Elizabeth H. Paris, Jason H. Curtis, Norbert Marwan, Mingua Zhang, Yemane Asmerom, Victor J. Polyak, Stacy A. Carolin, Daniel H. James, Andrew J. Mason, Gideon M. Henderson, Mark Brenner, James U. L. Baldini, Sebastian F. M. Breitenbach, and David A. Hodell
2022 Drought-Induced Civil Conflict among the Ancient Maya. *Nature Communications* 13:3911.

Kennett, Douglas J., Marilyn Masson, Stanley Serafin, Brendan J. Culleton, and Carlos P. Lope
2016 War and Food Production at the Postclassic Maya City of Mayapán. In *The Archaeology of Food and Warfare: Food Insecurity in Prehistory*, edited by Amber M. VanDerwarker and Gregory D. Wilson, pp. 161–192. Springer, New York.

King, Eleanor M.,
ed. 2015 *The Ancient Maya Marketplace: The Archaeology of Transient Space*. University of Arizona Press, Tucson.

Labaz, Beata, Alfred E. Hartemink, Yakun Zhang, Annalisa Stevenson, and Cezary Kabała
2024 Organic Carbon in Mollisols of the World—A Review. *Geoderma* 447:116937.

Lagomasino, David, René M. Price, Jorge Herrera-Silveira, Fernando Miralles-Wilhelm, Gonzalo Merediz-Alonso, and Yadira Gomez-Hernandez
2015 Connecting Groundwater and Surface Water Sources in Groundwater-Dependent Coastal Wetlands and Estuaries: Sian Ka'an Biosphere Reserve, Quintana Roo, Mexico. *Estuaries and Coasts* 38:1744–1763.

LaRocque, Armand, Brigitte Leblon, Gerald Ek, and William J. Folan
2022 Detection of Maya Sacbeob (Sacbes) Using Optical and SAR Imagery in Northern Petén, Mexico. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences* 43:633–639.

Lebedeva, E. V., D. V. Mikhalev, and L. A. Nekrasova
2017 Evolutionary Stages of the Karst-Anthropogenic System of the Yucatán Peninsula. *Geography and Natural Resources* 38:303–311.

Lentz, David L., Nicholas P. Dunning, Vernon L. Scarborough, Kevin S. Magee, Kim M. Thompson, Eric Weaver, Christopher Carr, Richard E. Terry, Gerald Islebe, Kenneth B. Tankersley, Liwy Grazioso Sierra, John G. Jones, Palma Buttles, Fred Valdez, and Carmen E. Ramos Hernandez
2014 Forests, Fields, and the Edge of Sustainability at the Ancient Maya City of Tikal. *Proceedings of the National Academy of Sciences* 111:18513–18518.

Lentz, David L., and Brian Hockaday
2009 Tikal Timbers and Temples: Ancient Maya Agroforestry and the End of Time. *Journal of Archaeological Science* 36:1342–1353.

Leonard, Daniel, Sergey Sedov, Elizabeth Solleiro-Rebolledo, Scott L. Fedick, and Jaime Diaz
2019 Ancient Mayan Use of Hidden Soilscapes in the Yalahau Wetlands, Northern Quintana Roo, Mexico. *Boletín de la Sociedad Geológica Mexicana* 71:93–119.

Liu, Xiaobing, Charles Lee Burras, Yuri S. Kravchenko, Artigas Duran, Ted Huffman, Hector Morras, Guillermo Studdert, Xingyi Zhang, Richard M. Cruse, and Xiaohui Yuan
2012 Overview of Mollisols in the World: Distribution, Land Use and Management. *Canadian Journal of Soil Science* 92:383–402.

Lucero, Lisa J.
2002 The Collapse of the Classic Maya: A Case for the Role of Water Control. *American Anthropologist* 104:814–826.

Lucero, Lisa J.
2023 Ancient Maya Reservoirs, Constructed Wetlands, and Future Water Needs. *Proceedings of the National Academy of Sciences* 120:e2306870120.

Luzzadder-Beach, Sheryl, Timothy Beach, Scott Hutson, and Samantha Krause
2016 Sky-Earth, Lake-Sea: Climate and Water in Maya History and Landscape. *Antiquity* 90:426–442.
Luzzadder-Beach, Sheryl, Timothy P. Beach, and Nicholas P. Dunning
2012 Wetland Fields as Mirrors of Drought and the Maya Abandonment. *Proceedings of the National Academy of Sciences* 109:3646–3651.
Martin, Simon
2020 *Ancient Maya Politics: A Political Anthropology of the Classic Period 150–900 CE*. Cambridge University Press, Cambridge.
Masson, Marilyn A.
2012 Maya Collapse Cycles. *Proceedings of the National Academy of Sciences* 109:18237–18238.
Masson, Marilyn A., and David A. Freidel,
eds. 2002 *Ancient Maya Political Economies*. Rowman Altamira, 2002.
Masson, Marilyn A., and David A. Freidel
2012 An Argument for Classic Era Maya Market Exchange. *Journal of Anthropological Archaeology* 31:455–484.
Masson, Marilyn A., David A. Freidel, Arthur A. Demarest, Arlen F. Chase, and Diane Z. Chase,
eds. 2020 *The Real Business of Ancient Maya Economies: From Farmer's Field to Rulers' Realms*. University of Florida Press, Tallahassee.
Masson, Marilyn A., Timothy S. Hare, Carlos Peraza Lope, Douglas J. Kennett, Walter R. T. Witschey, Bradley W. Russell, Stanley Serafin, Richard James George, Luis Flores Cobá, Pedro Delgado Kú, Bárbara Escamilla Ojeda, and Wilberth Cruz Alvarado
2024 Postclassic Maya Population Recovery and Rural Resilience in the Aftermath of Collapse in Northern Yucatan. *Journal of Anthropological Archaeology* 76:101610.
Masson, Marilyn A., and Carlos Peraza Lope,
eds. 2014 *Kukulcan's Realm: Urban Life in Ancient Mayapán*. University, Boulder.
Matheny, Ray T. M.
1976 Maya Lowland Hydraulic Systems: Reservoirs, Canals, Drains, and other Water Controls Were Important in Development of Maya Civilization. *Science* 193:639–646.
McKillop, Heather
1996 Ancient Maya Trading Ports and the Integration of Long-Distance and Regional Economies: Wild Cane Cay in South-Coastal Belize. *Ancient Mesoamerica* 7:49–62. https://doi.org/10.1017/S0956536100001280.
McKillop, Heather
2005 *In Search of Maya Sea Traders*. Texas A&M Press, College Station.
McKillop, Heather
2010 Ancient Maya Canoe Navigation and Its Implications for Classic to Postclassic Maya Economy and Sea Trade: A View from the South Coast of Belize. In "Mobility and Exchange from a Pan-Caribbean Perspective," edited by Corinne L. Hofman and Alistair J. Bright. *Journal of Caribbean Archaeology* Special Publication 3: 93–105.
McKillop, Heather
2021 Salt as a Commodity or Money in the Classic Maya Economy. *Journal of Anthropological Archaeology* 62:101277.
McKillop, Heather, and Kazuo Aoyama
2018 Salt and Marine Products in the Classic Maya Economy from Use-Wear Study of Stone Tools. *Proceedings of the National Academy of Sciences* 115:10948–10952.
McKillop, Heather, and E. Cory Sills
2025 Earliest Ancient Maya Salt Production in Southern Belize: Excavations at Jay-yi Nah. *Antiquity* 99:187–202. https://doi.org/10.15184/aqy.2024.186.
McNeil, Cameron L., David A. Burney, and Lida P. Burney
2010 Evidence Disputing Deforestation as the Cause for the Collapse of the Ancient Maya Polity of Copan, Honduras. *Proceedings of the National Academy of Sciences* 107:1017–1022.
Medina-Elizalde, Martin, Stephen J. Burns, David W. Lea, Yemane Asmerom, Lucien Von Gunten, Victor Polyak, Mathias Vuille, and Ambarish Karmalkar
2010 High Resolution Stalagmite Climate Record from the Yucatán Peninsula Spanning the Maya Terminal Classic Period. *Earth and Planetary Science Letters* 298:255–262.
Meyers, Allan D.
2017 Prerevolutionary Henequen Landscapes of Northwestern Yucatán. In *The Value of Things: Prehistoric to Contemporary Commodities in the Maya Region*, edited by Jennifer P. Mathews and Thomas H. Guderjan, pp 124–143, University of Arizona Press, Tucson.
Moreno-Gómez, Miguel, Carolina Martínez-Salvador, Ahmed-Walid Moulahoum, Rudolf Liedl, Catalin Stefan, and Julia Pacheco
2019 First Steps into an Integrated Karst Aquifer Vulnerability Approach (IKAV). Intrinsic Groundwater Vulnerability Analysis of the Yucatan Karst, Mexico. *Water* 11:1610.
Mueller, Andreas D., Gerald Islebe, Flavio Anselmetti, Daniel Ariztegui, Mark Brenner, David A. Hodell, Irka Hadjas, Yvonne Hamann, Gerald H. Haug, and Douglas J. Kennett
2010 Recovery of the Forest Ecosystem in the Tropical Lowlands of Northern Guatemala after Disintegration of Classic Maya Polities. *Geology* 38:523–526.
Munro-Stasiuk, Mandy J., T. Kam Manahan, Trent Stockton, and Traci Ardren
2014 Spatial and Physical Characteristics of Rejolladas in Northern Yucatan, Mexico: Implications for Ancient Maya Agriculture and Settlement Patterns. *Geoarchaeology* 29:156–172.
Olga Hernández Espinoza, Patricia, and Lourdes Marquez Morfin
2015 Maya Paleodemographics: What Do We Know? *American Journal of Human Biology* 27:747–757.
Paine, Richard R., and AnnCorinne Freter
1996 Environmental Degradation and the Classic Maya Collapse at Copan, Honduras (A.D. 600–1250): Evidence from Studies of Household Survival. *Ancient Mesoamerica* 7:37–47. https://doi.org/10.1017/S0956536100001279.
Palka, Joel W.
2024 Ancestral Maya Domesticated Waterscapes, Ecological Aquaculture, and Integrated Subsistence. *Ancient Mesoamerica* 35:208–236. https://doi.org/10.1017/S0956536122000402.
Perry, Eugene C., Gudalupe Velazquez-Oliman, Rosa M. Leal-Bautista, and Nicholas P. Dunning
2019 The Icaiche Formation: Major Contributor to the Stratigraphy, Hydrochemistry and Geomorphology of the Northern Yucatán Peninsula, Mexico. *Boletín de la Geológica Mexicana* 71: 741–760.
Rathje, William L., and Jeremy A. Sabloff
1973 Ancient Maya Commercial Systems: A Research Design for the Island of Cozumel, Mexico. *World Archaeology* 5:221–231.
Read, Larissa, and Deborah Lawrence
2003 Recovery of Biomass Following Shifting Cultivation in Dry Tropical Forests of the Yucatan. *Ecological Applications* 13:85–97.
Reents-Budet, Dorie, and Ronald L. Bishop
2020 Classic Maya Interaction Networks and the Production and Consumption of Cotton Fiber and Textiles. In *The Real Business of Ancient Maya Economies: From Farmer's Field to Rulers' Realms*, edited by Marilyn A. Masson, David A. Freidel, Arthur A. Demarest, Arlen F. Chase, and Diane Z. Chase, pp. 340–351. University of Florida Press, Tallahassee.
Rice, Don S., Prudence M. Rice, Susan Kepecs, and Rani T. Alexander
2005 Sixteenth-and Seventeenth-Century Maya Political Geography in Central Petén, Guatemala. In *The Postclassic to Spanish-Era Transition in Mesoamerica: Archaeological Perspectives*, edited by Susan Kepecs and Rani T. Alexander, pp. 139–160, University of New Mexico Press, Albuquerque.
Rice, Don S., Prudence M. Rice, and Timothy Pugh
1998 Settlement Continuity and Change in the Central Petén Lakes Region: The Case of Zacpetén. In *Anatomía de una Civilización: Aproximaciones Interdisciplinarias a la Cultura Maya*, edited by Maria Yolanda Fernández Marquínez and José Miguel García Campillo, pp. 207–252. Universidad Nacional Autónoma de México; Sociedad Española de Estudios Mayas, Madrid.

https://doi.org/10.1017/S0956536125000045 Published online by Cambridge University Press

Rice, Prudence M.
2019 Late Maya Factionalism and Alliances: The Case of Contact-Period Central Peten, Guatemala. *Journal of Anthropological Archaeology* 56:101083.
Rice, Prudence M., and Don S. Rice
2005 Central Petén, Guatemala, 1450–1700 CE. In *Untaming the Frontier in Anthropology, Archaeology, and History*, edited by Bradley J. Parker and Lars Rodseth, pp. 147–173, University of Arizona Press, Tucson.
Rice, Prudence M., and Don S. Rice
2018a Classic-to-Contact-Period Continuities in Maya Governance in Central Petén, Guatemala. *Ethnohistory* 65:25–50.
Rice, Prudence M., and Don S. Rice,
eds. 2018b *Historical and Archaeological Perspectives on the Itzas of Petén, Guatemala*. University Press of Colorado.
Riris, Philip, Fabio Silva, Enrico Crema, Alessio Palmisano, Erick Robinson, Peter E. Siegel, Jennifer C. French, Erlend Kirkeng Jørgensen, Shira Yoshi Maezumi, Steinar Solheim, Jennifer Bates, Benjamin Davies, Yongje Oh, and Xiaolin Ren
2024 Frequent Disturbances Enhanced the Resilience of Past Human Populations. *Nature* 629:837–842.
Robles Castellanos, Fernando, Anthony P. Andrews, and Rubén Chuc Aguilar
2020 Intercoastal Waterway and Trading Port Systems in Prehispanic Northwest Yucatán, Mexico. In *The Real Business of Ancient Maya Economies: From Farmer's Field to Rulers' Realms*, edited by Marilyn A. Masson, David A. Freidel, Arthur A. Demarest, Arlen F. Chase, and Diane Z. Chase, pp. 368–386, University of Florida Press, Tallahassee.
Romero, David, and José Francisco León-Cruz
2024 Spatiotemporal Changes in Hurricane-Force Wind Risk Assessment in the Yucatan Peninsula, Mexico. *Natural Hazards* 120:4675–4698.
Rosenswig, Robert M., and Marilyn A. Masson
2002 Transformation of the Terminal Classic to Postclassic Architectural Landscape at Caye Coco, Belize. *Ancient Mesoamerica* 13:213–235. https://doi.org/10.1017/S0956536102132123.
Ross, Nanci J.
2011 Modern Tree Species Composition Reflects Ancient Maya "Forest Gardens" in Northwest Belize. *Ecological Applications* 21:75–84.
Sabloff, Jeremy A.
2007 It Depends on How We Look at Things: New Perspectives on the Postclassic Period in the Northern Maya Lowlands. *Proceedings of the American Philosophical Society* 151:11–26.
Sabloff, Jeremy A., and William L. Rathje
1975 The Rise of a Maya Merchant Class. *Scientific American* 23:72–83.
Sampeck, Kathryn E.
2021 A Constitutional Approach to Cacao Money. *Journal of Anthropological Archaeology* 61:101257.
Scarborough, Vernon L.
1992 Flow of Power: Water Reservoirs Controlled the Rise and Fall of the Ancient Maya. *The Sciences* 32:38–43.
Scheffer, Marten, Egbert Van Nes, Luke Kemp, Timothy A. Kohler, Timothy M. Lenton, and Chi Xu
2023 The Vulnerability of Aging States: A Survival Analysis across Premodern Societies. *Proceedings of the National Academy of Sciences* 120:e2218834120.
Scholes, France V., and Ralph L. Roys
1968 *The Maya Chontal Indians of Acalan-Tixchel: A Contribution to the History and Ethnography of the Yucatán Peninsula*. University of Oklahoma Press, Norman.
Schroder, Whittaker, Timothy Murtha, Charles Golden, Armando Anaya Hernández, Andrew Scherer, Shanti Morell-Hart, Angélica Almeyda Zambrano, Eben Broadbent, and Madeline Brown
2020 The Lowland Maya Settlement Landscape: Environmental LiDAR and Ecology. *Journal of Archaeological Science: Reports* 33:102543.
Schwarz, Kevin R.
2009 Eckixil: Understanding the Classic to Postclassic Survival and Transformation of a Peten Maya Village. *Latin American Antiquity* 20:413–441.
Sedov, Sergey, M. Yazmin Rivera-Uria, Georgina Ibarra-Arzave, Pamela García-Ramírez, Elizabeth Solleiro-Rebolledo, Héctor V. Cabadas-Báez, Daisy Valera-Fernández, Jaime Díaz-Ortega, Karla A. Guillén-Domínguez, Sol de Jesús Moreno-Roso, Scott L. Fedick, Daniel Leonard, Charles Golden, Shanti Morell-Hart, and Rodrigo R. Liendo-Stuardo
2023 Soil Toposequences, Soil Erosion, and Ancient Maya Land Use Adaptations to Pedodiversity in the Tropical Karstic Landscapes of Southern Mexico. *Frontiers in Earth Science* 11:1239301.
Socki, Richard A., Eugene Jr. C.Perry, and Christopher S. Romanek
2002 Stable Isotope Systematics of Two Cenotes from the Northern Yucatan Peninsula, Mexico. *Limnology and Oceanography* 47:1808–1818.
Stanton, Travis W., Scott R. Hutson, and Traci Ardren
2024 People, Pixels, and Points Per Square Meter: Using Lidar to Estimate Population at Coba, Quintana Roo. In *Mesoamerican Population History: Urbanism, Social Complexity and Change*, edited by Adrian S. Z. Chase, Arlen F. Chase, and Diane Z. Chase, pp. 89–159, University of Arizona Press, Tucson.
Tankersley, Kenneth B., Nicholas P. Dunning, Christopher Carr, David L. Lentz, and Vernon L. Scarborough
2020 Zeolite Water Purification at Tikal, an Ancient Maya City in Guatemala. *Scientific Reports* 10:18021.
Thompson, John E. S.
1966 The Maya Central Area at the Spanish Conquest and Later: A Problem in Demography. *Proceedings of the Royal Anthropological Institute of Great Britain and Ireland* 1966:23–73.
Turchin, Peter
2005 Dynamical Feedbacks between Population Growth and Sociopolitical Instability in Agrarian States. *Structure and Dynamics* 1(1). https://doi.org/10.5070/SD911003259.
Turchin, Peter
2009 Long-Term Population Cycles in Human Societies. *Annals of the New York Academy of Sciences* 1162:1–17.
Turner, B. L. II
1990 Population Reconstructions of the CML: 1000 BC to AD 1500. In *Precolumbian Population History in the Maya Lowlands*, edited by T. Patrick Culbert and Don S. Rice, pp. 301–324. University of New Mexico Press, Albuquerque.
Turner, B. L.II
2010 Unlocking the Ancient Maya and Their Environment: Paleo-Evidence and Dating Resolution. *Geology* 38:575–576.
Turner, B. L. II, and Jeremy A. Sabloff
2012 Classic Period Collapse of the Central Maya Lowlands: Insights about Human–Environment Relationships for Sustainability. *Proceedings of the National Academy of Sciences* 109: 13908–13914.
Turner, B. L. II, Robert Q. Hanham, and Anthony V. Portararo
1977 Population Pressure and Agricultural Intensity. *Annals of the Association of American Geographers* 67:384–396.
Volta, Beniamino, Joel D. Gunn, Lynda F. Folan, William J. Folan, and Geoffrey E. Braswell
2020 The Political Geography of Long-Distance Exchange in the Elevated Interior Region of the Yucatán Peninsula. In *The Real Business of Ancient Maya Economies: From Farmer's Field to Rulers' Realms*, edited by Marilyn A. Masson, David A. Freidel, Arthur A. Demarest, Arlen F. Chase, and Diane Z. Chase, pp. 352–367, University of Florida Press, Tallahassee.
Wahl, David, Francisco Estrada-Belli, and Lysanna Anderson
2013 A 3400-Year Paleolimnological Record of Prehispanic Human–Environment Interactions in the Holmul Region of the Southern Maya Lowlands. *Palaeogeography, Palaeoclimatology, Palaeoecology* 379:17–31.
Wahl, David, Roger Byrne, Thomas Schreiner, and Richard Hansen
2006 Holocene Vegetation Change in the Northern Peten and Its Implications for Maya Prehistory. *Quaternary Research* 65:380–389.
Wahl, David, Roger Byrne, Thomas Schreiner, and Richard Hansen
2007 Paleolimnological Evidence of Late-Holocene Settlement and Abandonment in the Mirador Basin, Peten, Guatemala. *Holocene* 17:813–820.

Webster, David
2018 *The Population of Tikal: Implications for Maya Demography*. Paris Monographs for American Archaeology 49. Access Archaeology, Oxford.
Webster, D., and J. Kirker
1995 Too Many Maya, Too Few Buildings: Investigating Construction Potential at Copan, Honduras. *Journal of Anthropological Research* 51:363–387.
White, Christine, Jay Maxwell, Alexis Dolphin, Jocelyn Williams, and Fred Longstaffe
2006 Pathoecology and Paleodiet in Postclassic: Historic Maya from Northern Coastal Belize. *Memórias do Instituto Oswaldo Cruz* 101:35–42.
Whitmore, Thomas M., B. L. Turner II, Douglas L. Johnson, Robert W. Kates, and Thomas R. Gottschang
1990 Long-Term Population Change. In *The Earth as Transformed by Human Action*, edited by B. L. Turner II, William C. Clark, Robert W. Kates, John F. Richards, Jessica T. Mathews, and William B. Meyer, pp. 25–39. Cambridge University Press, Cambridge.
Woodfill, Brent K. S., and Chloé Andrieu
2012 Tikal's Early Classic Domination of the Great Western Trade Route: Ceramic, Lithic, and Iconographic Evidence. *Ancient Mesoamerica* 23:189–209. https://doi.org/10.1017/S0956536112000156.
Wubie, Amare Aleminew
2015 Review on Vertisol Management for the Improvement of Crop Productivity in Ethiopia. *Journal of Biology, Agriculture and Healthcare* 5:92–03.
Wyatt, Andrew R.
2020 Gardens of the Maya. In *The Real Business of Ancient Maya Economies: From Farmer's Field to Rulers' Realms*, edited by Marilyn A. Masson, David A. Freidel, Arthur A. Demarest, Arlen F. Chase, and Diane Z. Chase, pp. 187–209. University of Florida Press, Tallahassee.