# Kax and kol: Collapse and resilience in lowland Maya civilization

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**Episodes of population loss and cultural change, including the famous Classic Collapse, punctuated the long course of Maya civilization. In many cases, these downturns in the fortunes of individual sites and entire regions included significant environmental components such as droughts or anthropogenic environmental degradation. Some afflicted areas remained depopulated for long periods, whereas others recovered more quickly. We examine the dynamics of growth and decline in several areas in the Maya Lowlands in terms of both environmental and cultural resilience and with a focus on downturns that occurred in the Terminal Preclassic (second century Common Era) and Terminal Classic (9th and 10th centuries CE) periods. This examination of available data indicates that the elevated interior areas of the Yucatán Peninsula were more susceptible to system collapse and less suitable for resilient recovery than adjacent lower-lying areas.**

Mesoamerica | archaeology | climate change | deforestation

For millennia, the forest has waxed and waned across the Yucatán Peninsula in multifarious forms. For the past 3 millennia in particular, humans have been the dominant driver of ecological change, which sometimes influenced the fate of ancient Maya civilization. Ancient Maya civilization has grown in the imaginations of the public and scientific community since the 19th century, and it has been associated with images of crumbling palaces and temples covered by tropical forest, which has stoked countless explanations for the fate of the Classic Period Maya. Indeed, the Classic Maya collapse has grown into a favorite allegory and warning for modern civilization (1) because of its large size, sophisticated urban culture, and completeness and persistence of abandonment in many areas. Since the early 1990s, evidence for drought has grown into an important factor for understanding the Terminal Classic collapse as well as earlier and later downturns in the course of Maya civilization (2–4). Many scholars have strongly objected to these drought causes collapse studies as reductionist and deterministic (5–7). Part of this disagreement stems from differing views of the nature of collapse and the sheer complexity of this phenomenon as it played out across time and space in the Maya Lowlands. Critics of the recent deterministic models of collapse in the Maya Lowlands view the Terminal Classic and earlier Terminal Preclassic as periods of profound transformation and transition in Maya society (8). These critics note that Maya history has few examples of rapid, apocalyptic depopulations, except perhaps at a few individual sites. In contrast, the process of multisite and regional abandonment in the Terminal Classic played out over at least 125 y. Here, we use the definition of societal collapse proffered by Joseph Tainter (9): a fundamental and pronounced decline in sociopolitical complexity taking place within two or three generations. In this sense, even those areas of the Maya Lowlands that were not abandoned in the Terminal Preclassic or Terminal Classic periods often did experience collapse, because the changes that occurred in Maya society during these periods were profound and enduring, including long-term population loss in some sizable areas.

Ancient lowland Maya civilization spanned the period roughly from 1000 before common era (BCE) to 1500 CE and encompassed a region that included the entire Yucatán Peninsula and contiguous areas of Mexico and Central America (Fig. 1). Variations in rainfall, elevation, geologic structure, and water quality and availability created a mosaic of habitats within the region (10). At the heart of the region is an area ranging from 40 to 300 m in elevation and often delimited by geologic scarps that we hereafter refer to as the elevated interior region (EIR). This region was the focus of notable periods of cultural development as expressed in monumental architecture both early on and late in the course of Maya civilization, including the Late Preclassic (BCE 300 to CE 150) apogee in the Mirador Basin and the Late/Terminal Classic (CE 700–925) florescence in the Puuc Hills. The EIR was also the focus of some of the most dramatic examples of collapse: in the 2nd century CE in the Mirador Basin and the 10th century CE in the Puuc Hills. Over the course of millennia, Maya civilization experienced multiple periods of growth and decline, often with highly different trajectories in various regions (11, 12). To understand these temporal and spatial variations, we need to explicate the complex interrelationship of Maya populations and this lowland environment.

The use of a theoretical approach based on the systemic coupling of human and environmental variables can be traced back, in part, to Julian Steward's (13) Theory of Culture Change and its culture core concept. Over the ensuing years, systems theory proved invaluable in the development of increasingly sophisticated treatments of human–environment interactions (14) and more recently, into complex coupled systems modeling (15). This orientation also underlies adaptive cycle and panarchy theory (16), which we use here to help elucidate collapse cycles in the Maya Lowlands. Based on underlying ecosystems, adaptive cycles operate at multiple scales, including the scale of the individual community. In this conceptualization, each community passes through cycles consisting of four phases: exploitation, conservation, release, and reorganization. In this model, release is a period of rapid negative change that can take the form of collapse. The degree to which the system experiences profound collapse or recovers and its rate of recovery depends in large part on three system properties: (*i*) the range of options available for change, (*ii*) the rigidity of the system (degree of interconnectedness), and (*iii*) the resilient capacity (vulnerability to unexpected perturbations). Panarchy theory expands on this model by increasing scale and looks at the interconnectedness of multiple adaptive cycles such as in a complex political economic system or network of communities. Applying this theory to the vulnerabilities and resilient capacities of ancient Maya Lowland communities, it is clear that the elevated interior portions were significantly more susceptible to collapse and faced greater

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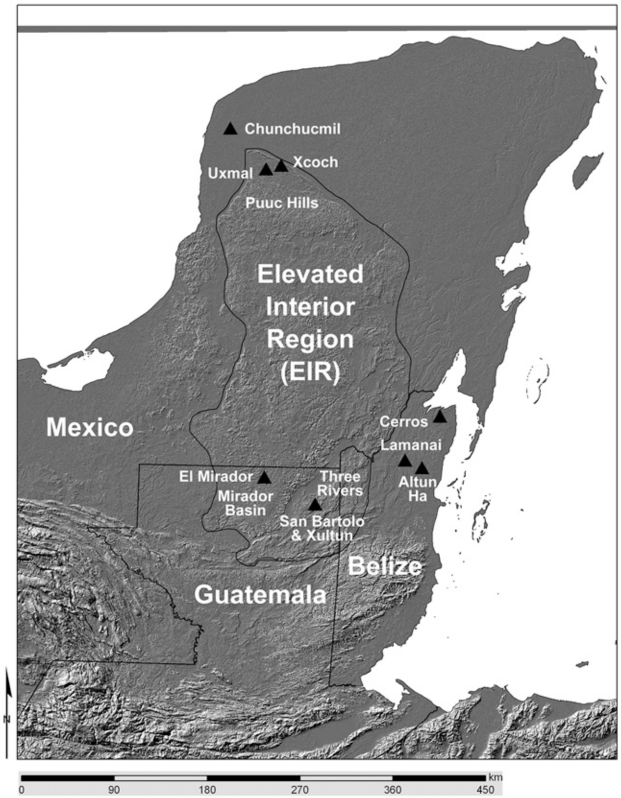


**Fig. 1.** Map of the Maya Lowlands highlighting the EIR and sites mentioned in the text.

obstacles for effective reorganization than the surrounding lower-lying areas with perennial water sources. However, even many communities in these supposedly more resilient areas succumbed to abandonment (17).

## Environment and Vulnerabilities

Much of the Maya Lowlands region lies atop the carbonate Yucatán Platform and its well-developed karst landforms (Fig. 2). Most interior areas have been uplifted into a series of plateaus and basins (the EIR). Drainage is largely internal, except along its southern periphery, where rivers with large inputs of groundwater drain the margins of the interior. Rainfall varies along a generally north to south gradient from about 1,000 to nearly 3,000 mm. Rainfall is highly seasonal, linked to the annual shift in the intertropical convergence zone (ITCZ), with about 80% falling from late May and June to November. Soils range from Entisols and Inceptisols to Mollisols and Vertisols, and they are typically calcareous with high pH status. The distribution of natural vegetation follows regional patterns of precipitation, drainage, and soils. From the north coast and its beach ridges and estuarine wetlands and savannas, vegetation grades into low, tropical deciduous forest in the northern EIR. Forest cover increases in height after increasing precipitation southward, becoming tropical moist forest in the southern EIR (18). Embedded within the southern forest are numerous wetlands, ranging from seasonal swamp forests in karst depressions (bajos) within the EIR to perennial wetlands in adjacent lower areas that receive spring discharge and stream flow (17). Much of this landscape was well-suited to the maize-based agricultural system of the ancient Maya, but settlements in the region faced significant vulnerabilities, particularly as population density increased.

Specific vulnerabilities for ancient Maya settlements included those vulnerabilities based on karst hydrology, regional climate, tropical forest ecosystem, and characteristics of the Maya sociopolitical system in many contexts. Within the EIR, perennial lakes are largely limited to a few deep structural depressions, surface drainage is poorly developed and entirely seasonal, and springs are few and far between. In contrast, many lower-lying surrounding areas had year-round access to water by springs and perennial streams in the south and sinkholes (cenotes) that breached the groundwater table in the north. In the EIR, permanent human settlement was, therefore, strongly tied to the ability to capture and store rainwater. In a region with a 4+-month-long dry season with little precipitation, such storage was a significant challenge, and the Maya developed systems ranging from large urban reservoirs to household tanks and cisterns to facilitate settlement (19–21). This lack of water would have left settlements in the EIR especially vulnerable to drought, because most groundwater was inaccessible.

Traditional Maya agriculture is highly adapted to the seasonal rhythms of regional precipitation. However, the Maya Lowlands also experienced drying trends on an apparent cycle on the scale of hundreds of years that linked to migrations in the ITCZ (22). These shifts lead to episodic increases in the frequency and severity of drought [a review of paleoclimate proxy data is in the work by Luzzadder-Beach et al. (17)]. One useful rubric used by the United Nations to assess drought states that it can be manifest in four ways: (*i*) meteorological (diminishment in precipitation), (*ii*) agricultural (diminishment in soil moisture), (*iii*) hydrological (diminishment in stream and lake levels), and (*iv*) socioeconomic (disruption of water-dependent production of goods and services) (23). In most of the Maya Lowlands, meteorological drought could quickly translate into agricultural drought because of the rainfall-dependent nature of cultivation and in turn, lead to socioeconomic perturbation if it severely curtailed food production. Some low-lying areas with spring-fed or riverine wetlands would have been less vulnerable because of higher soil moisture levels, but even these areas would have suffered if drought severity increased to the point of adversely lowering discharge rates (18). The Maya Lowlands are also subject to frequent hurricane strikes that have the capacity to destroy crops and accelerate forest fires over both local and widespread areas (24). Notably, both drought and hurricane cycles were also systemically linked to the structure and composition of lowland forest ecosystems (25, 26).

Tropical forest covered much of the Yucatán Peninsula ranging from drier, lower in the north to higher, moister variants in the south. These forests were well adapted to seasonal moisture deficits and periodic hurricane blow downs. Longer-term climate cycles induced changes in the relative openness of the forest canopy, but over the past three millennia, the extent of forest cover has mostly pulsed with human population numbers (26). While intact, the forest provided the Maya with many resources. The ancient Maya intentionally left standing patches of managed forest as well as individual valuable trees within fields (27). However, paleoecological data from throughout the Maya Lowlands document a strong correlation between rising human populations and forest decline, because timber was consumed and agricultural fields were opened.

Forest cover removal produced many interrelated, and often negative, effects on the regional environment. Declining forest cover likely translated into reduced local transpiration and eventually precipitation, potentially significantly exacerbating drought severity and persistence (28) and compromising soil moisture levels. Removal of forest cover also left sloping land vulnerable to soil loss by erosion (29). Associated sedimentation within karst depressions and stream channels had profound effects on local hydrology, reducing recharge and eutrophication of shallow water bodies (30). Reductions in tree canopy would also reduce the capture of airborne volcanic ash (a principal component of the inorganic fraction of regional soils) (31), soot,

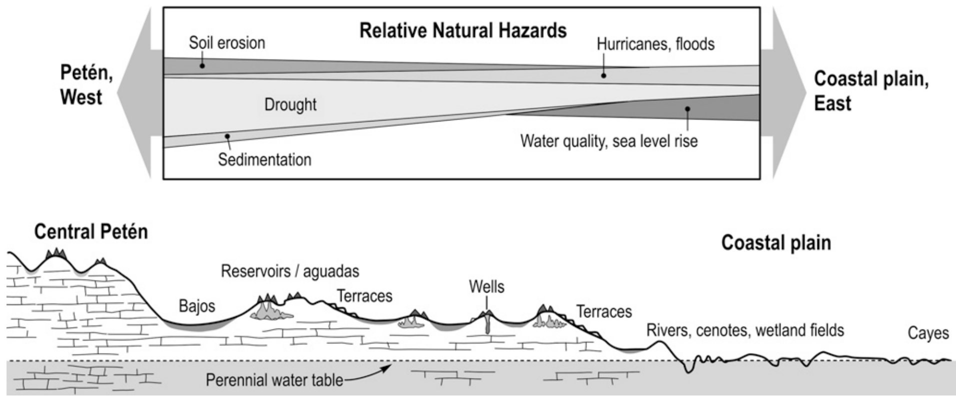


**Fig. 2.** Hypothetical cross-section from the Caribbean Sea to the EIR with associated natural hazards.

and other forms of airborne phosphorus, a nutrient already in critically low supply in regional soils (32). Reductions in forest fallowing would also likely decrease nitrogen levels by reducing inputs from leguminous *Leucaena* species, which compose a significant portion of regional forests (33). Declining soil fertility would also increase vulnerability to field invasion by weedy species (34). Cropped plants weakened by declining fertility would also be less disease-resistant, most notably to maize mosaic virus—a disease for which Maya maize land races have no natural resistance that increases dramatically as fallow periods are shortened and spacing between fields is reduced (35). In short, although the high base status soils and tropical climate of the Maya Lowlands were favorable for cultivating maize and supporting high population densities, the incremental reduction of forest for construction material, fuel, and farm land associated with population growth and urbanization would have created a risk spiral within the region, especially when coupled with other environmental and cultural risk factors.

Archaeologists have pointed out that the Classic Maya sociopolitical system should itself perhaps be considered vulnerable to collapse (8). Maya polities thrived on growth and expansion that funneled wealth to a small ruling elite topped by hereditary divine kings. Notably, “divine kingship is a double-edge sword: it carries great privilege and unlimited power but also demands that a ruler deliver munificence to their people as would a god. A string of military defeats or seasonal drought can do much to damage the credibility of a divine ruler” (ref. 5, p. 157). In the Late Classic, the stability of this system was further threatened by polygamy among rulers that spawned numerous cadet lineages and polities, fueling greater intersite competition and warfare (36). Warfare and a tribute-based status system created further pressure for rulers to agglomerate population. Data from both pre-Hispanic and Colonial times indicate that periods in which the mobility of populations was restricted either by force or because that landscape was simply full were likely to witness more dramatic demographic decline and political economic failure associated with perturbations such as drought or warfare (37, 38). In short, system rigidity and poor options for change created conditions ripe for collapse.

## Cultural and Environmental History

Our brief review of the complex and varied course of Maya civilization focuses on the northern and southern extremes of the EIR and two periods of demographic decline and cultural transition: the Terminal Preclassic (ca. 100–250 CE) and Terminal Classic (ca. 750–950 CE). For most areas, both archaeological and paleoenvironmental data are more abundant for the later period than the former period, in part because later processes and patterns often obscured earlier ones but also because scientific research has only belatedly begun to focus on earlier periods.

The east-central Yucatán Peninsula encompasses the Mirador Basin, the fractured and block-faulted eastern edge of the Petén Karst Plateau, and the coastal plains of northern Belize (39). This subregion includes abrupt gradients formed by escarpments as one moves westward from the coastal lowlands into the interior. Large and small bajos cover over 45% of the land surface in the EIR here. Many of the largest and earliest settled Maya Preclassic communities were located on the margins of these depressions, many of which once held shallow lakes or perennial wetlands (30). Around 50 CE, El Mirador alone boasted over 40 triadic pyramid groups, including some of the largest monuments ever constructed in Mesoamerica. By 150 CE, El Mirador and most larger sites within the Mirador Basin lay desolate, and most would see only light reoccupation beginning several hundred years later. Forest-shrouded El Mirador itself became a religious pilgrimage center, or perhaps a tourist destination, with an intrusive shrine complex and viewing platform erected to overlook the great abandoned center (40).

Multiple paleoenvironmental proxies indicate that the second century CE was a period with significantly increased drought frequency and severity across the Maya Lowlands and elsewhere in the Caribbean Basin (4, 41, 42). Sediments within several bajos in the Mirador Basin and a nearby lake indicate that this area experienced widespread deforestation and soil erosion. These changes were associated with land clearing and quarrying (in significant part to generate plaster for the huge pyramids) for centuries preceding regional abandonment, suggesting that anthropogenic environmental degradation was at least as important as drought in bringing about the demise of El Mirador and allied centers (43, 44). Nevertheless, forest recovery was relatively rapid after regional abandonment (45, 46).

In the Three Rivers region east of the Mirador Basin, site survival or abandonment was more sporadic (47). A telling pair of sites is San Bartolo and Xultun: only 8 km apart and in the same physiographic setting. However, the Maya abandoned San Bartolo around 150 CE, whereas Xultun grew into an important Classic center (48). Regional wetlands show evidence of both climatic drying and anthropogenic soil loss, sedimentation, and hydrologic changes. Notably, Xultun invested in a large-scale reservoir system, whereas San Bartolo did not, although it is unclear which is cause and which is effect (49). San Bartolo would not be reoccupied until around 700 CE, a process that was accompanied by the ritual reconsecration of abandoned structures (50).

In Three Rivers’ centers that persisted through the Terminal Preclassic, social upheaval is evident, with many Preclassic building complexes ritually terminated and new ones initiated and many associated with a new system of dynastic kingship (47, 51). Communities that developed into Classic urban centers in the region also typically exhibit investment in sizeable reservoirs, a phenomenon likely related to the identification of new dynastic rulers with water control (52). The ensuing Early and Late Classic periods witnessed overall population growth with widespread development of urban centers within the Three Rivers region (48). This development was hardly tranquil, because violent competition between rival polities and dynasties increased through the period (53).

Paleoenvironmental data indicate that deforestation escalated in the Late Classic as population increased and demands for timber and croplands rose (27, 54). In some areas, terracing was used to arrest soil erosion, and in other areas like Copan, it was inexplicably not used (12, 55). Beginning around 760 CE, some paleoenvironmental data indicate that the first in a series of severe droughts beset the Maya Lowlands (4, 17). Around this same time, abandonment of Late Classic sites begins, although in areas not obviously vulnerable to drought such as in the Río de la Pasión and Usumacinta drainages, among the best watered parts of the Maya Lowlands. However, these areas show evidence for little wetland agriculture and marginal soil resources; thus, it is possible that agricultural drought could have disrupted communities dependent on rain-fed cultivation. The marginal nature of land may also have meant that competition between rival dynastic centers over goods and labor became acute earlier than in other regions. Such competition was manifest in extraordinarily violent conflict, including the sacking and burning of towns until the region degenerated into a landscape of fear and desertion (36, 56). This pattern of abandonment was sometimes sudden, but sometimes, a lingering death took hold such as in the Three Rivers region and other parts of the southern and central EIR over the course of the ninth century; by 900 CE, much of the region was effectively depopulated (55–59). Paleoenvironmental data indicate that the regional forest returned to pre-Maya levels within 100–200 y after abandonment, but with the exception of a few areas such as the Central Peten Lakes lying to the south of the EIR proper, people did not (46).

The Belizean coastal plain borders the eastern edge of the EIR and connects the Maya Lowlands with the Caribbean Sea. The coastal plain consists of the southern end of the karstic Yucatán platform. On top of the Tertiary limestone are sand ridges marking former coastlines and prograded shoreline deltaic deposits (60). Elevation in the coastal plain runs from sea level to about 10 m above mean sea level. Water is available from rivers tracing a series of south- to north-running normal faults and grabens in northern Belize. Water is also available from sinkholes and wells accessing near-surface groundwater. A major hazard to settlements here is hurricane activity from the Caribbean and associated flooding (24). A number of ancient Maya settlements occupied the coastal fringe and the offshore islands and may have functioned as trade ports with inland cities (61, 62). Some coastal sites such as Cerros were abandoned in the Terminal Preclassic, perhaps as the result of sea level rise or the collapse of trade routes (63), whereas other sites show greater longevity, including continuous occupation from the Classic into the Postclassic (61). Several significant Maya sites occupied the wetlands and river valleys of the mainland coastal plain, including Lamanai (with occupation from 1500 BCE to 1500 CE) (64) and Altun Ha (with occupation from about 200 BCE to 1200 CE) (65). Although the sites had differing economic functions, the hallmark environmental change experienced by many of these sites was either the direct or secondary influence of rising sea levels, which eventually inundated some coastal sites or engendered major land transformations to adapt to rising groundwater tables, including wetland agriculture, in the evolving landscape (17, 60, 66, 67).

The Puuc region comprises the northernmost extension of the EIR (Fig. 1). On the low-lying bordering plains to the north and west, groundwater was accessible through sinkholes (cenotes) and wells, whereas in the uplifted Puuc, groundwater was obtainable only in a handful of deep caves, posing a barrier to year-round settlement. The Puuc is renowned for high-quality farm land, making such settlement desirable. Until recently, ancient settlement of the Puuc was believed to have been largely limited to the period between 700 and 950 CE when the region experienced explosive growth and cultural florescence. However, in the past 20 y, research has revealed sizeable settlements dating to 400–700 CE and 800 BCE to 150 CE (68–70). At the site of Xcoch, a large populace constructed a huge monument complex and elaborate reservoir system (71). However, despite that investment, Xcoch was apparently abandoned around 150 CE before being reoccupied ca. 400 CE.

On the adjacent low-lying plains, where groundwater is often easily accessible but soils are often poor, the Terminal Preclassic is also not well-understood (72). Although there was certainly a pattern of widespread site abandonment, the region as a whole remained largely populated. Like other parts of the Maya Lowlands, dramatic shifts in material culture and settlement patterns indicate significant social upheaval and reorganization (73).

In the Puuc Hills, the fifth through seventh centuries CE saw reoccupation proceeding at a modest pace and then unprecedented rapid growth of regional population in the eighth and early ninth centuries, with established centers expanding and new towns emerging to fill the landscape (20). The high productivity of Puuc soils underwrote this dramatic growth. However, analysis of Puuc soils and apparent cropping system indicates that maximal yields would likely have been sustainable for only about 75 y, with significant declines in fertility and yields certainly setting in after about 100 y (74). This duration is coincident with the apogee of most Terminal Classic Puuc centers (ca. 770–870 CE). After around 870 CE, many centers declined, but Uxmal grew dramatically and produced some of the most spectacular architecture in the Maya world (75). Iconography and inscriptions at Uxmal indicate that its growth may have been accomplished by preying on weakened neighbors (76). However, sometime after 910 CE, Uxmal also was largely abandoned, apparently under duress. Paleoprecipitation records gathered from speleothems indicate that the northern lowlands and Puuc experienced a similar chronological pattern of decreased rainfall, including eight apparent droughts between 806 and 935 CE (42). These droughts spanned the time of both maximal population growth and decline in the Puuc. The concentration of population in the Puuc during the Terminal Classic was accomplished through the use of both urban reservoirs and tens of thousands of household cisterns. This combination of water capture and storage systems may have allowed the Puuc Maya to withstand droughts better than in other parts of the EIR (71). However, rising population, declining forest cover, declining soil fertility, and reduced soil moisture likely produced a lethal risk spiral in the 10th century. Small numbers of people hung on in some Puuc centers into the 11th century or later, but the region was never effectively repopulated in pre-Hispanic times.

Similar to the Terminal Preclassic, the Terminal Classic period on the northern plains saw regional population decline and some site abandonment but no wholesale regional depopulation. One clear example of how no one prime mover is important in the Maya abandonment is the sprawling site of Chunchucmil, which lies just 30 km northwest of the Puuc. This site contrasts with the Puuc sites in that it diminished far before any climatic deterioration in the early part of the Late Classic (ca. seventh century CE), but unlike the Puuc, it had accessible and good water supplies but thin soils (77). Instead, reorganization is again evident, culminating in new settlement patterns and sociopolitical forms.

## Discussion

In Yukatek Maya, the term kol indicates a managed agricultural field but also space that has been sanctified and set in order (78). The term kax has multiple meanings that span a continuum from long fallow field to forest, but it denotes space that has left the established ordered realm and is returning to primeval chaos. The Maya view the forest and abandoned towns as dangerous places, disordered, unpredictable, and full of malevolent spirits (79). Taking land back from the forest was done with great care and ritual precision. Maya landscapes are, and were, patchworks of kax and kol: part of a dynamic that has played out over the centuries, and the forest waxed and waned as human populations sought to create and hold order.

Earlier, we mentioned three factors that influence the vulnerability and resilience of coupled human–environment systems: options for change, system rigidity, and resilient capacity. Ancient Maya communities on the coastal plains had more options for change and resilient capacity than those Maya in the EIR. Most importantly, plains communities had more dependable access to drinking water. In some southern coastal plains areas, wetland agriculture also offered some security against agricultural drought, although the hydrology and chemistry of the wetlands was dynamic and challenging (17). Plains communities were also more closely and easily integrated into river and maritime trade networks, an advantage that was manifest in the growth of maritime trade in the Postclassic (62, 64). Although social and political institutions collapsed on the plains, population declines were typically less severe. System rigidity posed problems for communities in all regions, especially as population levels increased and competition between rival polities escalated. As many have noted, the ruler-centric Maya political system was poorly suited to withstand environmental and economic perturbations; failures condemned the legitimacy of kings and the political system itself. To some degree, the Maya collapses were first and foremost elite and urban phenomena, with the repercussions on rural populations less clear but in some cases, more muted and delayed (80). In many areas, smaller centers survived significantly longer than in others; in some centers, the institution of divine kingship disappeared, but population remained for many years and revamped Postclassic communities emerged (81, 82).

Close examination of the Terminal Preclassic and Terminal Classic collapses reveals few apocalyptic events and no prime movers in this heterogeneous region. Rather, these collapses were typically complex, multigenerational, and asynchronous both within and outside the EIR. Decline followed from many years of growth, but growth that contained the seeds of future failure. Population growth and forest removal went hand in hand with political expansions but created a risk spiral, leading to increasing vulnerability. The Maya Lowlands and Maya society also contained numerous potential triggers to initiate system release or collapse. These triggers included droughts, hurricanes, and volcanic eruptions (capable of choking or fouling reservoirs in the EIR) (31), all of which could generate system-stressing crop failures and population movements. The political system itself also likely generated triggering events in the form of warfare spawned by interpolity competition among prestige-obsessed dynasts. Like collapses documented for other cultures, these phenomena were multicausal and characterized by cascading feedbacks (83). The great tropical civilization of the Khmer, for example, may have collapsed because of the cascading effects of an overextended irrigation system, climate change, internal political strife, and foreign invasions (84). Environmental triggers in the form of perturbations in rainfall likely even had political repercussions in ancient Egypt, where the normally dependable hydrological patterns of the Nile were altered (85).

A question that has come to the fore in current discussions of collapse in the Maya Lowlands is why some regions, notably those regions in the EIR, were slow to be effectively reoccupied or were not reoccupied at all after collapse (6). Hydrologic problems lie at the heart of this issue. Reoccupation of the EIR by sizeable populations required a system to capture and store rain water. In the Preclassic and Classic periods, such systems developed in situ within the EIR as an integral part of Maya society. After the collapse of that society in the Terminal Preclassic and Terminal Classic, these hydraulic systems were abandoned, and reoccupation by large numbers of people and urbanization required labor-intensive revitalization or replacement. Such efforts were less necessary on the coastal plains, and widespread continuity of occupation is more evident, even when political and economic structures failed. In Classic Maya polities, failure implicated both gods and rulers. Their former territories became places of ill fortune and returned to the forest. Reoccupation called for a reordering of a most profound kind.

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