Wetland fields as mirrors of drought and the Maya abandonment

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Getting at the Maya Collapse has both temporal and geographic dimensions, because it occurred over centuries and great distances. This requires a wide range of research sites and proxy records, ranging from lake cores to geomorphic evidence, such as stratigraphy and speleothems. This article synthesizes these lines of evidence, together with previously undescribed findings on Maya wetland formation and use in a key region near the heart of the central Maya Lowlands. Growing lines of evidence point to dryer periods in Maya history, which correlate to major periods of transition. The main line of evidence in this paper comes from wetland use and formation studies, which show evidence for both large-scale environmental change and human adaptation or response. Based on multiproxy studies, Maya wetland fields had a long and varied history, but most evidence indicates the start of disuse during or shortly after the Maya Terminal Classic. Hence, the pervasiveness of collapse extended into a range of wetlands, including perennial wetlands, which should have been less responsive to drought as a driver of disuse. A synthesis of the lines of evidence for canal infilling shows no attempts to reclaim them after the Classic Period.

Mesoamerica | proxies | wetland agriculture

Scholars have explored many proxy lines of evidence to understand the environmental change and timing of societal transitions in the Maya Lowlands of Mesoamerica. These proxies include lake and ocean cores; speleothems; geomorphic evidence; architecture; modeling; and, recently for Mesoamerica, tree rings. One repository of evidence we examine here comes from ancient Maya wetland field systems and their canals. Over the past decade, we have studied more than 50 of these systems, which can provide unique insights into site abandonment because their canals started to fill with sediment and proxy evidence after the Maya ceased maintaining them. We can thus date the infill of sediment and use multiple proxies to study ecological change from near the time of abandonment forward. These canals also provide the advantage of being repositories of paleoenvironmental information directly in the context of ancient Maya farming systems from and after abandonment (1). Research on wetland field systems can demonstrate the diversity and complexity of ancient human adaptations to changing environments (2, 3), and they demonstrate starkly different interactions between humans and wetlands even in similar and nearby environments (1–4).

There has been spirited debate about the importance of wetland agriculture to the ancient Maya; at the same time, evidence for ancient wetland agriculture from the broader Americas has grown and several groups have even sought to restore indigenous wetland fields as modern development projects (2–5). However, despite 4 decades of Maya wetland field research, we have much to learn about their importance, extent, crops, formation, and chronology. Recent research is also indicating that wetland systems were more abundant, and thus a more important part of ancient Maya subsistence (1).

In *Collapse* (6), Jared Diamond considers the ancient Maya as a special case of collapse. He defines Collapse as a "drastic decline in human population and/or" social systems extended over time and space (ref. 6, p. 3). *Collapse* considers the ancient Maya as one of a series of regional and historical comparative studies that tests five potential natural and human factors contributing to Collapse. Ultimately, after making cases for the impacts of drought, preferentially on areas of difficult groundwater access like the Petén, and environmental degradation, he concludes the Maya Classic Collapse resulted from a lack of leadership (6). McAnany and Negron continue this line of inquiry, including "effectiveness of divine rulership" (ref. 3, p. 145) as one of six potential collapse factors. Unlike other examples of failed societies, the Ancient Maya were a literate society, whose books endured until the Spaniards burned most of them centuries later. However, Maya inscriptions, copious iconography, and millions of descendants survive today. As J. R. McNeill (a historian) puts it: "If a people, a language, and a culture survive… is this Collapse?" (ref. 7, p. 359). McNeill notes that Diamond (a biologist) defines collapse differently, as "either human numbers or cultural complexity declined drastically" (ref. 7, p. 359). McAnany and Negron (3) also conclude that the Maya kings did not deal effectively with economic and political change but that Maya society neither succeeded nor failed: It changed in the face of these challenges. Population declined precipitously in many areas during the Maya Terminal Classic, and forest cover declined, droughts occurred, and soil was eroding both in the Late Preclassic and the Late Classic. However, the Maya were building landesque capital in their agricultural terraces, dams, reservoirs, and ditched fields while succeeding to manage and even rehabilitate their environment (4, 8, 9). Herein, we use the definition of "collapse" as enduring social, political, and economic decline for multiple human generations (10, 11). We focus on the social–ecological complex (12) of wetland field agriculture and what environmental proxies can tell us about human systems resilience through the end of the Maya Classic.

The Maya Lowlands region comprises the carbonate Yucatán Platform and contiguous areas of Mexico and Central America and includes a mosaic of habitats created by variation in precipitation, drainage, and edaphic patterns (11, 13). The east-central portion of the Yucatán Peninsula grades from low-lying coastal plains with perennial rivers westward into elevated karst uplands, where drainage is mainly internal and water is seasonally scarce. This gradient is abrupt where block faulting has created a stepped series of scarp-edged horsts and grabens. Most prominent in our study area is the 100-m-high Rio Bravo Escarpment, where the ancient Maya site of Blue Creek stands, situated near the confluence of three rivers, the Rio Bravo, Rio Azul/Blue Creek, and Booths River, which become the Rio Hondo (Fig. 1).

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This Three Rivers region of northwestern Belize (Fig. 1) lies at the interface of multiple environments and a rich diversity of resources. Most Maya monumental sites in this region occupy escarpment edges next to wetlands that are either perennially or seasonally wet (14). Numerous smaller sites lie dispersed across the broader rural and agricultural landscape, including around the high points of wetland field systems. Most wetland field systems occur closest to smaller Maya sites; thus, some have suggested wetland fields may not have been significant in Maya agriculture because we know little about their productivity, their extensiveness, and how much and how far the Maya transported food (15). This wider wetland environment with growing evidence for wetland fields does occur near numerous mid-sized sites and a few better known sites, such as Lamanai and Altun Ha. As with the Puuc in Yucatán for the North Coastal Plain (11), some scholars have suggested, without direct evidence, that cultivation in the riparian wetlands of northern Belize helped feed less resource-rich but populous interior areas to the west (e.g., 16). Although we know little about the amount of interchange of subsistence goods between the wetland-based communities of northern Belize and the peninsular interior, the coastal and riverine trade networks were clearly linked with overland trade routes and interior cities in the exchange of common items, exotic goods, and prestige items. Shifts in cross-peninsular trade routes during the course of Maya civilization affected the prosperity of major inland centers, such as El Mirador in the Preclassic and Calakmul in the Classic Period (17). The rise and fall of these powerful centers and the trade they controlled clearly influenced the linked coastal lowland centers, such as nearby Lamanai and Cerros (18, 19). However wetland systems fit into broad trade networks, Maya farmers could have managed wetland fields for a wide variety of resources, especially during the region's dry season from February into May and during its recurrent droughts. Indeed, Maya farmers potentially managed their wetland fields to provide greater resilience for their dependent communities (11).

Climate and Evidence for Drought

The Maya region has a wide range of ecosystems and quantities of rainfall, and the study region lies near the average, with circa 1,500 mm of rainfall per year. The study area also lies at the confluence of rivers and near multiple springs that maintain perennial wetlands near or around the regional sites. This is critical in a region with a severe dry season and recurrent droughts.

Discussion of the impacts of climate change on Maya Civilization goes back nearly a century to Ellsworth Huntington, who

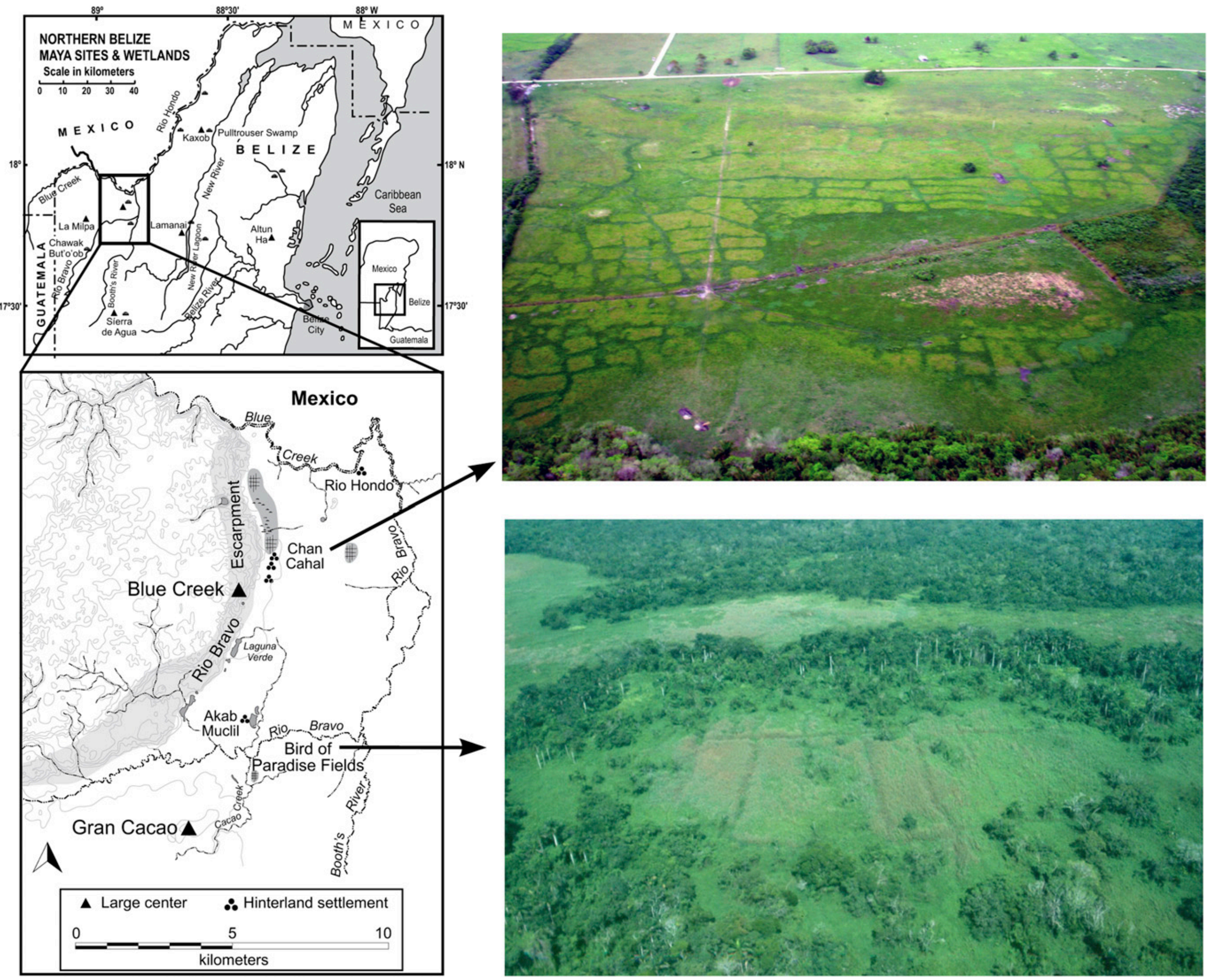

Fig. 1. Northern Belize Maya sites and wetlands. Chan Cahal site (*Upper*) and BOP site (*Lower*). (Photographs courtesy of A. Padilla, Ecological Communications Corporation, Austin, TX and S.L.-B.).

linked the Maya Terminal Classic Collapse with wetter conditions based on a suspected inverse relationship with tree rings in California (20). Scholars began to suspect the role of drought in Maya history by associating Mesoamerican with European trends (21, 22), but the first regional evidence came in the 1990s based on retrodicting the discharge of the Rio Candelaria, Mexico, with models of global insolation, atmospheric patterns, and volcanic emissions that indicated higher rainfall in the Classic Period and dryer conditions in the Terminal Classic (23, 24). Lake core studies at Chichancanab and Punta Laguna, also in the 1990s, indicated climate change in the Yucatán based on the relative abundance of sulfur (S) to calcite ($CaCO_3$) in sediments and oxygen isotope ratios ($\delta\ ^{18}O$) in benthic shells (25–28). The Chichancanab study revealed two sharp peaks in S in the Late Preclassic and Late Classic, which the $\delta\ ^{18}O$ ratios partly parallel in the Preclassic and fully parallel in the Late Classic. This research links the two peaks with drought, and $\delta\ ^{18}O$ and S and $CaCO_3$ ratios return to moister levels after the Late Classic (29). The Punta Laguna study indicates peak drought in the Terminal Classic as well (30). Laminated marine sediments from the Cariaco Basin, 2,000 km southeast of the Maya Lowlands, provide another proxy evidence of variations in sedimentary titanium (Ti) and iron from terrestrial erosion and runoff (31, 32). These sediments indicate high variability from circa 3800 to circa 2000 radiocarbon years before present [B.P.; 1850 before the Common Era (B.C.E.) to 50 Common Era (C.E.)] and stability from 2000 to 1300 B.P. (50 B.C.E. to 650 C.E.), low quantities from 1300 to 1000 B.P. (650–950 C.E.), and the lowest quantities during the Little Ice Age [500 to 200 B.P. (1450–1760 C.E.)]. The authors argue that low Ti concentrations, reflecting reduced runoff and precipitation, correspond to circa 760, 810, 860, and 910 C.E. as well as the Maya Late and Terminal Classic Periods (32). The heart of Maya Classic Civilization in the Petén of Guatemala has only produced equivocal evidence, because although $\delta\ ^{18}O$ data indicate greater evaporation in the Terminal Classic, they may indicate either hotter and dryer conditions or simply reforestation (33). Findings from speleothem studies in Belize and Yucatan provide further support. From cave laminae in southern Belize, Webster et al. (34) used color, luminescence, $\delta\ ^{13}C$, and $\delta\ ^{18}O$ as precipitation proxies to suggest Preclassic climate flux from drought to pluvial, Late Preclassic (5 B.C.E. and 141 C.E.) severe droughts, Classic Period wetter conditions sandwiching a drought in the Middle Classic (517 C.E.), and Late through Postclassic (780, 910, 1074, and 1139 C.E.) severe droughts. Some 450 km north, another speleothem sequence near the Maya Postclassic site of Mayapan shows a series of eight multiyear droughts, 3–18 y in length, that span the Terminal and Early Postclassic (35). This annually resolved record identifies eight periods of aridity in 806, 829, 842, 857, 895, 909, 921, and 935 C.E., and the authors estimate that mean rainfall decreased by 52% to 36%. In comparison, two studies (36, 37) also modeled the climate of the Maya Lowlands. Hunt and Elliot (36) indicate large drought could occur stochastically in this region, but Oglesby et al. (37) found both increased temperatures and decreased precipitation occurred from deforestation, although they modeled an unlikely, low-probability scenario of complete deforestation.

The latest proxy turns again to distant tree rings, however, in this case, in central Mexico with Montezuma bald cypress (*Taxodium mucronatum*), which has produced a Mesoamerican climate record of 1,238 y (38). This record indicates Late Classic droughts about 810 and 860 C.E. and an extended dry period from 897 to 922 C.E., but the record only partly correlates with that of the Maya Lowlands (38).

In sum, multiple overlapping lines of evidence now indicate dry conditions triangulated the Maya Lowlands during the Maya Terminal Classic and probably the Late Preclassic, which coincides with significant population losses in many areas. Although we lack evidence for the central Petén in the heart of the Maya Classic civilization, these lines of evidence triangulate drought to the region and the Maya Terminal Classic transition. One environment where we can test the human response to collapse and flesh out possible causes lies in perennial wetlands, where drought should have its least significant impacts because of the ubiquity of water.

Study Area and Background

In this study, we focus on canals in two wetland field complexes near the ancient Maya center of Blue Creek, Belize: the Chan Cahal and the Birds of Paradise (BOP) wetlands. We also include findings from recent field seasons in these and nearby wetland field complexes at Chawak But'o'ob upstream in the Rio Bravo watershed, Sierra de Agua in the Booth's River watershed, and the Barber Creek wetlands at Lamanai in the neighboring New River watershed (Fig. 1). We analyze these results in the context of two models of wetland field formation (1), with a refocus on the canals' time and environment of abandonment. These wetland agriculture field systems fall within a regional and chronological context of other ancient Mesoamerican wetland field systems, including Veracruz (Totonac agriculture dating to at least 450 C.E.) (39); Campeche, Mexico (40); and Pulltrouser Swamp, Belize (41, 42).

These fields were part of the sustaining area of ancient Blue Creek, an area estimated at about 150 km^2, which may have reached a population of about 20,000 in the Late Classic around 800 C.E. (43). The anthropogenic chronology for the wetlands region includes pollen evidence for *Zea mays* by 4800 to 4420 B.P. (circa 2800 to 2400 B.C.E.) in a nearby lake, but occupational evidence only starts a millennium later in the Middle Preclassic at the site of Chan Cahal in the midst of the densest group of wetland fields. Indeed, human uses of the Maya wetland areas, although not from Maya wetland fields, start earlier in the Archaic and last longer, with spotty evidence for Postclassic architecture (1). Regional populations and settlements expanded through the Early and Late Classic, but population declined to a few hundred in the Terminal Classic by 900 C.E. (43).

The Blue Creek chronology correlates generally with that of the bulk of earlier research 40 km northward in Northern Belize, including the site of K'axob and the nearby site of Pulltrouser Swamp, where Berry and McAnany (2) review and present artifactual evidence of wetland occupation and maintenance from the Archaic to the Late Classic. Evidence ranges from Archaic points and uniface tools in the Pulltrouser Swamp and Freshwater Creek wetland regions, to Archaic charcoal dates in the K'axob wetlands, to in situ broken and use-polished tools in Classic and Late Classic sediments in Pulltrouser Swamp. On the basis of numerous studies around northern Belize, Pohl and coworkers (44, 45) concluded that abandonment and disuse of these wetland fields occurred mostly by the Early Classic Period.

Blue Creek was a medium-sized Maya site, but it had a disproportionate quantity of jade, rivaling larger sites like Copán and Tikal. The region also had a multiplicity of agricultural environments, such as well-drained uplands, agricultural terraces, depressions with deep soils, and perennial and seasonal wetland fields (43). Terraces and perennial wetland fields appear mainly in the Late Classic as populations and new settlements were expanding, and some areas had experienced soil erosion and sedimentation (43). The region had at least 7 km^2 of wetland fields, as indicated by the rectilinear canals that show up in aerial surveys within 10 km of the Blue Creek site center (Fig. 1). These wetlands are 8–10 masl (meters above sea level) and have water tables near the surface in the wet season and 0.5–2.0 m below the surface in the dry seasons (1–4). This region, with its range from upland sites ≥100 m above the water table to perennial wetlands, allows us to test the hypothesis (6) that easy access to the water table allowed populations to persist through the Terminal Classic droughts.

We derived two models of landscape formation from field and laboratory studies regarding the Chan Cahal and BOP complexes (1). Overall, these wetland fields formed from a complex series of biophysical and anthropogenic factors, mainly during the Classic Maya Period. The Chan Cahal fields, circumscribed by ditches or canals, have formed in piecemeal, asymmetrical, spider web patterns wedged between lower, wetter, and higher points, whereas the BOP fields are more regular, with symmetrical canal systems built between the confluence of two streams (1). Both systems have long, straight canals, which are up to about 400 m long, 2 m wide, and 1–2 m deep at Chan Cahal and up to 900 m long with similar widths and depths at the BOP wetlands (Fig. 1). Both systems are aggrading, but BOP is aggrading faster on its floodplain site than is Chan Cahal on its spring-fed saddle site. BOP has aggraded by 330 cm in 1,856 y, or a mean of 0.2 cm/y, whereas Chan Cahal has aggraded by circa 200 cm maximally over at least 3,000 y, or circa 0.07 cm/y. Finally, both are Classic Period systems but have their origins in different, earlier environments and human uses.

Results

Chronology. An overview of all the wetland field radiocarbon dates demonstrates that fields formed over the following two generalized chronologies (Fig. S1). The perennial, groundwater-fed Chan Cahal wetlands formed as water tables rose and inundated formerly dry lands (1). Previous research suggests sea level rise in the Holocene drove up rivers and groundwater systems that inundated both wetlands and drylands through the Classic Period. Many sites have paleosols (Eklu'um) that date from the Archaic to Preclassic and lie buried below 1 m or more of sediment, deposited from the Preclassic through Classic Periods, representing the "field" deposits in Fig. S1. These fields formed from sedimentation from erosion and precipitation of calcium carbonate and calcium sulfate dihydrate (gypsum, $CaSO_4{\cdot}2H_2O$) from evaporating groundwater as well as sediments added to the field from ancient Maya canal excavation and maintenance (1). The Maya built the canals in the Classic Period sometime after the field areas formed and the canal sediment began to accumulate (Figs. 2 and 3). Maya farmers used the fields and canals in the Classic Period; however, in all cases, the canals began to fill during the Terminal Classic Period and through the Postclassic Period, which indicates canal disuse during these times (Fig. S1).

Tale of Two Wetlands: Analysis. Two distinct models of wetland formation and Maya water management arose from more than 50 excavations within the Chan Cahal (Fig. 2) and BOP (Fig. 3) wetlands regions. The evidence supporting these models includes stratigraphic mapping, pollen, phytoliths, charcoal, soil and water chemistry, magnetic susceptibility, micromorphology, and carbon isotope data (1, 4, 5, 46, 47) (Figs. 2 and 3). These two conceptual models demonstrate geomorphic and environmental transformations from a wet lowland (Chan Cahal) and an active floodplain (BOP), respectively, through divergent pathways to today's vestigial rectilinear patterned wetlands (1) (Fig. 1). Our main foci in these landscapes are the canal fills, which serve as anthropogenic unconformities marking the presence and absence of human manipulation of the hydrologic landscape (Figs. 2 and 3).

Chan Cahal. During the Archaic Period, circa 4000 B.P. (2050 B.C.E.), the Chan Cahal site was a slowly evolving soil surface of the coastal plain on which the ancient Maya burned and cultivated fields of *Z. mays* and a variety of trees (1) (Fig. 2). This stable soil surface is now a buried soil unit (2Ab horizon), identified as the Eklu'um Paleosol (Fig. 2). This horizon occurs in most of the excavation units and serves in the sequence as one of the time markers of unconformity. Next, the groundwater table rose, driven by relative sea level rise (4) during the Maya Preclassic, circa 2300 B.P. (350 B.C.E.). Under this waterlogged condition, peats formed over the Paleosol and a flood event deposited

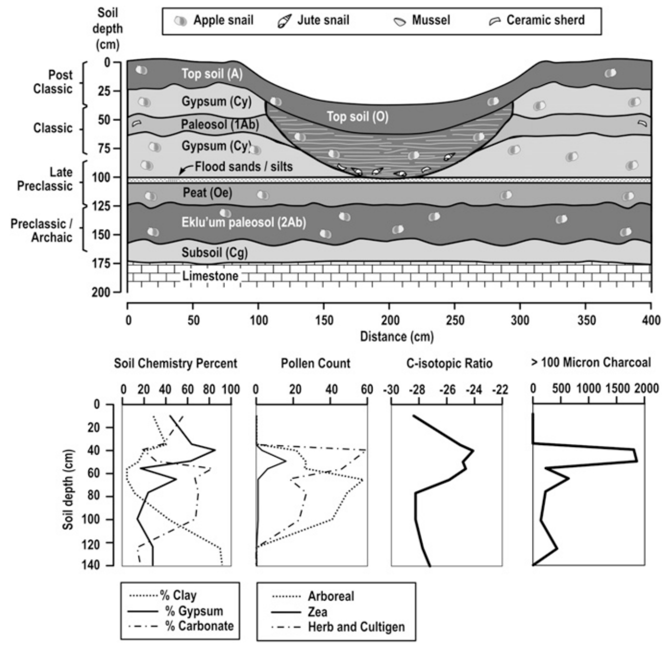

Fig. 2. Chan Cahal generalized soil profile and canal proxy evidence model. (Reprinted from Quat Sci Rev, 28, Beach T, et al., A review of human and natural changes in Maya Lowlands wetlands over the Holocene, 1710–1724, Copyright (2009), with permission from Elsevier.)

carbonate silts and sands over the peat units [circa 2000 B.P. (50 B.C.E.)] (Fig. 2). Later, in the Late Preclassic through Classic Periods [circa 2000 to 1000 B.P. (50 B.C.E. to 950 C.E.)], the groundwater table continued to rise but it began to precipitate gypsum. This precipitate accumulated in a horizon that, combined with sediment eroded from the uplands, buried the flood layer and peats by an average of 1 m. Because the upland sediment sources have lower gypsum (8–20%), we surmise that the gypsum derived from a geological unit that the groundwater encountered in the Rio Bravo fault zone as it rose to this elevation. The groundwater is at or near saturation in calcium and sulfate even today (4), and the main direction in which the minerals can migrate is from the saturated groundwater into the soil matrix, driven by adsorption, ion exchange, and evaporite formation. The latter can explain how, in a seemingly abundant hydrologic regime, drought can still play a limiting role or create a tipping point in an already chemically limited water supply. The waterlogged gypsic soil horizons and high-ion groundwater thus imposed more limits on Maya agriculture. However, the Maya overcame this challenge and reclaimed the land in the Late Preclassic Period through to the Late Classic Period [Fig. 2; circa 2000 to 1000 B.P. (50 B.C.E. to 950 C.E.)] by digging canals to drain the fields and to grow crops in the higher field zones, where naturally lower ion rainwater could assist in germinating young plants. From 60 to 100 cm deep, a higher paleosol from the Classic Period testifies to ancient agriculture with abundant charcoal and economic taxa like *Z. mays* and *Persea* (Fig. 2). Drought could interfere with wetland agriculture by lowered water tables, more ion-concentrated water, and simply less rain water. The canals (Fig. 2) cut across all the previously described units from the Archaic through recent times (Fig. S1, 2Ab1 and Ab Chan Cahal field dates), and the canal bottom contact with infilled sediments represents an unconformity (Fig. S1, Chan Cahal Canal dates). Dating the canal sediments indicates infilling back to at least 1000 B.P. (950 C.E.), or the Terminal Classic, continuing until the present (Fig. 2). The lowest canal sediments represent the last stages of canal and field maintenance, with proxies for *Z. mays*, *Persea*, other tree crops,

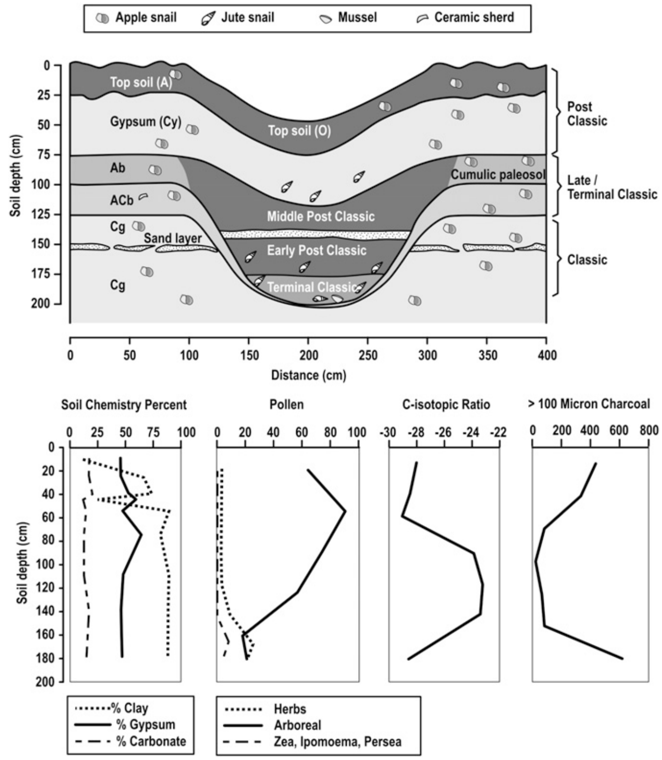

Fig. 3. BOP generalized soil profile and canal proxy evidence model (Reprinted from Quat Sci Rev, 28, Beach T, et al., A review of human and natural changes in Maya Lowlands wetlands over the Holocene, 1710–1724, Copyright (2009), with permission from Elsevier.)

abundant charcoal, and carbon isotopic ratios (δ ^{13}C) showing significant increases in C_4 species like *Z. mays* and other tropical grasses. All these change to proxies for tropical forest during or after the Terminal Classic (Fig. 2). Farmers would not reclaim the Chan Cahal wetlands again for cultivation until half a century ago. These recent pioneers started a new cycle of ditching and draining (and now laser leveling) the fields for modern cultivation of rice and cattle pasture, facing the limits imposed by high-ion groundwater and a high modern groundwater table (4, 47).

BOP. The BOP wetlands (Fig. 3) evolved differently from those at Chan Cahal, despite being only 10 km away. Although morphologically different, the ancient Maya took advantage of and managed this evolving hydrologic landscape for agriculture as well. The earliest proxy evidence for Maya agriculture in this zone dates to the Classic Period (Fig. S1, BOP fields). At BOP, the site begins as a flood plain of Cacao Creek, a tributary of the Rio Bravo, circa 1500 B.P. (Fig. 3, 450 C.E.). This is a time when the Chan Cahal site had already evolved into wetlands, the Eklu'um Paleosol and overlying peats were no longer available as planting surfaces, and groundwater was beginning to precipitate gypsum into the soil matrix. In parallel at the BOP site, gypsum was also accumulating in the soil matrix but at lower concentrations and more consistently mixed throughout the sediment profiles. Gypsum concentration was not as high as at Chan Cahal, because low calcium and sulfate runoff dilutes floodwaters in the wet season. Continued flooding aggraded the BOP area, and the Maya dug canals in these wetlands around 1200 B.P. (750 C.E.), or the Late Classic (Fig. 3). This is at or after the time of canal construction at Chan Cahal. The BOP fields have Late Classic agricultural horizons from 60–100 cm that stratigraphically connect with canal bottoms. These agricultural horizons have abundant charcoal, artifacts, and proxies for *Z. mays* and tree crops, and the Maya managed the fields and canals until disuse soon after their construction by circa 1000 B.P. (950 C.E.), or the Maya Terminal Classic (Fig. 3). Again the canal beds hold evidence for their final uses, with abundant charcoal; proxies for *Z. mays*, *Ipomaea*, and other economic species; and carbon isotopic ratios (δ ^{13}C) indicating significant increases in C_4 species. As with Chan Cahal, the canal sediments return to tropical forest indicators from the lower to upper canal fills, although they also show some Postclassic intrusions of extensive land uses like milpa farming as well as hunting and fishing. Nonetheless, the BOP fields and canals aggraded after 1000 B.P., remaining uncultivated to the present (Fig. 3) as part of the modern, undeveloped Programme for Belize Rio Bravo Conservation Area. As a testament to ancient Maya hydrologic engineering (48), the abandoned canals still function to move and distribute water throughout the BOP field system, fed by a large canal leading from Cacao Creek into the fields.

Broader Evidence for Wetland Fields. The formation chronology and proxy data suggest the Maya built the Chan Cahal and BOP canals to drain the waterlogged fields of gypsic, high-ion groundwater. Literature about other sites, however, suggests that ancient Mesoamerican canals also functioned to deliver water to fields during the dry season, thus extending agricultural productivity (e.g., 39). We have also found this to be the case in a feeder canal from Cacao Creek into the BOP wetlands. A third set of wetland fields in the Rio Bravo system also supports this hypothesis, at Chawak But'o'ob. The Chawak But'o'ob site (49) has spring- and river-fed wetland systems circa 14 km upstream (southwest) from the BOP wetlands and is similarly situated at the base of the Rio Bravo escarpment. What distinguishes Chawak from the other wetland sites in this region is its much lower ion water quality that imposes no limits for crop growth. This is in stark contrast to the Chan Cahal and BOP fields discussed above, as well as other wetlands at Sierra de Agua and Lamanai–Barber Creek (4) (Fig. 1). Thus, far in our studies, Chawak presents the only example of wetland fields without excessive gypsum in this region, and thus is potentially more productive for dry season cultivation. Nevertheless, these small-scale, irregularly shaped fields had a brief period of occupation that also came to end with the Maya Terminal Classic.

Discussion and Conclusion

Complex natural and anthropogenic processes formed ancient Maya wetland field complexes in northwestern Belize (1, 45, 50). Proxy evidence from the ancient fields and canals indicates the Late Preclassic through Late Classic Maya successfully adapted in the face of a radically changing environmental and socioeconomic landscape. However, it is clear that the Maya abandoned canal maintenance in these systems during the Terminal Classic at this time of population decline and multiple, complex socio-environmental and hydrologic challenges. Hence, this argues against the notion that nearness to the water table allowed some areas to persist through the Terminal Classic (6).

The timing of the Blue Creek wetland abandonment and population decline coincides with the dates from growing lines of evidence on drought around this region; therefore, we cannot reject the hypothesis of drought as one possible driver. Although perennial wetlands would seem resistant to drought, most of the systems we have studied are based on rainwater diluting ion-saturated water and leaching away excessive gypsum. Turner (51) argues that there is abundant evidence and growing consensus on the Maya Classic Period collapse and depopulation as a complex and asynchronous process rather than a singular event. The Terminal Classic abandonment written in the Three Rivers canal sediments concurs with this evidence. If drought drove the Maya Terminal Classic "Collapse," perennial wetland fields had the best opportunity to persist. Indeed, the Maya wetland fields at Blue Creek had been successful adaptations to large-scale environmental changes of rising water tables, and occurred during population expansion in the Classic Period. Evidence from fields and canals shows a diverse group of crops through to the Terminal Classic; however, like elsewhere, farmers left the systems in the Terminal Classic. The evidence for burning, *Z. mays*, and other economic species declined or became nonexistent.

Several drivers could have caused these agroecological systems to collapse: (*i*) the political instability caused by the collapse elsewhere overlapped into these areas via trade disruptions and interelite dependencies (16, 19); (*ii*) with the population decimated, there were no longer demands for intensive agroecological systems; and (*iii*) the systems may have succumbed to drought because these groundwater-quality limited systems were rainfall-dependent like other systems.

All these explanations show how complicated evidence for Collapse can be and how difficult it is to assign drivers based on the archaeological and paleoecological records. We know the wetland fields collapsed at the same time as regional population decline and the evidence for broader drought. However, at this time, with the limits of scientific evidence, each possible driver is too interrelated to isolate in any of our proxies. These wetlands tell a longer tale of Maya resilience and complex responses in the face of environmental change, but the Terminal Classic event ultimately affected even this most resource-rich environment (13).

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