Arising from the *Bajos*: The Evolution of a Neotropical Landscape and the Rise of Maya Civilization

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The conjunctive use of paleoecological and archaeological data to document past human-environment relationships has become a theoretical imperative in the study of ancient cultures. Geographers are playing leading roles in this scholarly effort. Synthesizing both types of data, we argue that large karst depressions known as *bajos* in the Maya Lowlands region were anthropogenically transformed from perennial wetlands and shallow lakes to seasonal swamps between 400 BC and AD 250. This environmental transformation helps answer several questions that have long puzzled scholars of Maya civilization: (1) why many of the earliest Maya cities were built on the margins of bajos, (2) why some of these early centers were abandoned between 100 BC and AD 250, and (3) why other centers constructed elaborate water storage systems and survived into the Classic period (AD 250–900). The transformation of the bajos represents one of the most significant and long-lasting anthropogenic environmental changes documented in the pre-Columbian New World. *Key Words: geoarchaeology, Latin America, neotropics, Maya archaeology, wetlands.*

Regional landscapes are the product of the long-term dynamics of human-environment interactions. Indeed, it is critical that we have a long-term perspective in order to best understand ongoing changes in today's ambient environment (Oldfield 1998; Klepeis and Turner 2001).[1] Analysis of landscape transformations can also reveal important clues about the social and environmental dynamics associated with the rise and decline of ancient civilizations. Behind such investigations there is a growing theoretical imperative for the integration of paleoecological and archaeological research in order to understand more fully the impacts of ancient societies on the environment (e.g., Butzer 1996; Fall, Lines, and Falconer 1998; Redman 1999). Geographers have played a critical role in this work, using a combination of historical, archaeological, geoarchaeological, and physical geographical approaches to help establish the time depth, spatial extent, and causation of both intentional and unintentional anthropogenic environmental change associated with pre-Columbian populations in the New World (e.g., Turner 1974, 1983; Mathewson 1984; Doolittle 1990; Butzer 1992, 1996; Denevan 1992; Dunning 1992; Sluyter and Siemens 1992; Turner and Butzer 1992; O'Hara, Street-Perrott, and Burt 1993; Dunning and Beach 1994, 2000; Beach and Dunning 1995; Turner et al. 1995; Beach 1998; Woods and McCann 1999; Whitmore and Turner 2001). In this article, we report on a profound transformation of wetland ecosystems across wide areas of the Maya Lowlands region and the apparent impacts of those changes on the course of Maya civilization. This ecological transformation represents one of the most significant and long-lasting anthropogenic environmental changes documented in the pre-Columbian New World. Our research continues a long tradition of geographical research on the ecology and use of wetlands in the pre-Hispanic Americas (e.g., West and Armillas 1950; Denevan 1970, 1982; Siemens and Puleston 1972; Turner 1974; Siemens 1978, 1983; Gliessman et al. 1983; Turner and Harrison 1983; Wilken 1987; Sluyter 1994).

Traditional models of Maya civilization posited a sequential, unilinear progression of increasing population and cultural complexity beginning in the Early Preclassic period (ca. 1000 BC) and ending dramatically in the "collapse" of Classic civilization in the Terminal Classic (ca. AD 900) (see, e.g., Coe 1966; Adams 1977). We now

Annals of the Association of American Geographers, 92(2), 2002, pp. 267–283

Published by Blackwell Publishing, 350 Main Street, Malden, MA 02148, and 108 Cowley Road, Oxford, OX4 1JF, UK.

know that Maya civilization suffered other significant perturbations prior to the Classic collapse, including the abandonment of some of the largest urban centers towards the end of the Late Preclassic period (ca. AD 150) (Hansen 1992; Grube 1995). In this article we report new evidence suggesting that both the decline of these early centers and the growth of later cities relate to anthropogenic changes in wetland environments.

Many of the largest and earliest centers of Lowland Maya civilization developed along the margins of large karst depressions known as *bajos*, a spatial relationship that has long intrigued scholars. Today many of these bajos contain seasonal wetlands, ecosystems that most Mayanists have perceived to be deficient in resources. To explain the connection between bajos and the ancient Maya, several scholars hypothesized that many of these basins were once lakes or perennial wetlands, but most have dismissed this idea because there was insufficient evidence to support it. We use paleoenvironmental and archaeological data gathered near the ancient Maya cities of La Milpa, Belize and Yaxha, Guatemala to demonstrate that at least some bajos near these centers contained much larger areas of perennial wetlands (with even some open water) prior to about AD 250. These hydrologically stable ecosystems were potentially a more attractive settlement location than the seasonal swamps

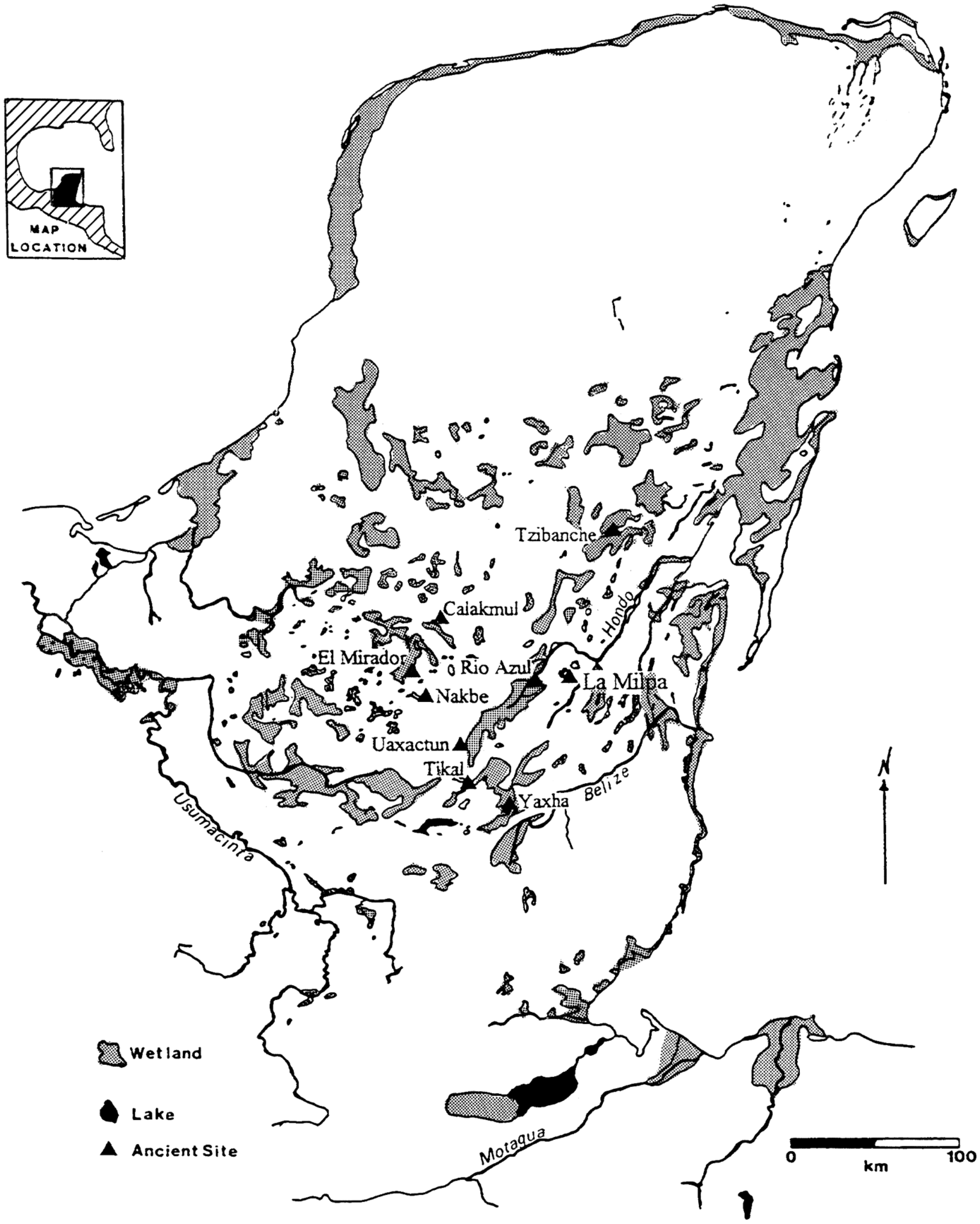


Figure 1. Map of the Maya Lowlands showing the general distribution of wetlands (after Pope and Dahlin 1989) and sites mentioned in the text.

found there today. We argue that human-induced environmental change, in tandem with climatic change, transformed at least some of these bajos between 1,700 and 3,000 years ago. These changes may help explain why some early Maya urban centers were abandoned near the end of the Late Preclassic period (400 BC–AD 150) and others adapted elaborate water-storage systems. Such environmental changes and resulting storage systems may have been important factors in the emergent political structure of Classic Maya civilization. As profound as the transformation of the bajos was, it is equally remarkable that in many areas the Maya not only successfully adapted to but flourished in the altered environment throughout the Classic period (AD 250–900).

Bajos and Wetlands in the Maya Lowlands Environment

The Maya Lowlands cultural region encompasses all of the karstic Yucatan Peninsula and adjacent low-lying areas of Mexico, Guatemala, and Belize (Figure 1). Bajos and other wetlands are a common feature across the southern and central Maya Lowlands, variably covering between 40 and 60 percent of land area across the region.[2] An east-west transect across the southern Maya Lowlands reveals significant variation in elevation and hydrology (Figure 2). The coastward or exterior margins of the Lowlands are low-lying (1–20 m above mean sea level [msl]), and many wetlands are spring-fed or riparian and typically of a perennial nature, maintaining saturated or near-saturated soil-moisture conditions throughout the year. In contrast, interior areas of the Lowlands are generally elevated 120–300 m above mean sea level, and perennial surface water of any sort is generally rare and often perched in clay layers. Bajos are very common throughout this region. The seasonal wetlands typical of interior bajos today are flooded for as many as several months and dry for the remainder of the year. The interior bajos contain a variety of vegetation communities, depending on the relative degree of inundation and desiccation characteristic of any given area (Lundell 1937; Siemens 1978; Pope and Dahlin 1989; Culbert et al. 1996). Some interior bajos today include small pockets of perennial wetlands with generally herbaceous vegetation; these pockets are known locally as *civales* (Lundell 1937; Jacob 1995). Soils in the interior bajos range from organic Histosols (peats) found in *civales* to fine clay Vertisols, a soil type that seems to characterize the most extensive areas (Simmons, Tarano, and Pinto 1959; Beach 1998). Both the Histosols and Vertisols pose significant difficulties for agriculture, and the Vertisols have large seasonal water deficits and severe cracking. These generalizations mask much greater variation within and between bajos in their hydrologies, soils, and variations (Culbert, Levi, and Cruz 1990; Brokaw and Mallory 1993; Culbert et al. 1996; Kunen et al. 2000; Dunning et al. forthcoming)

Despite 1500–2000 mm of annual rainfall, water is an especially precious resource across much of the Maya Lowlands interior because of two facts of nature. First, the region has a tropical wet/dry climate, with more than 90 percent of rainfall arriving during a late May-December wet season, leaving the landscape dry for four months. Table 1 and Figure 3 illustrate the water budget for the Chan Chich Lodge, a meteorological station recently established near La Milpa in northwestern Belize. Second, the region is largely karst, with most water quickly entering the complex groundwater system and accessible only in a few places. As ancient Maya civilization developed, adaptation to this hydrology was critical for the success or failure of individual regions, cities, and dynasties (Scarborough 1993). The idea that significant hydrologic changes may have occurred during the rise of Maya civilization enriches our understanding of the adaptive systems associated with Maya prehistory (Hodell, Curtis, and Brenner 1995; Brenner et al. 2000; Hoddell, Brenner, and Curtis 2000; Hodell, Brenner, and Guilderson 2001).

Bajos and Wetlands in the Maya Lowlands: Earlier Research

The hypothesis that the interior bajos in the Southern Maya Lowlands may have at one time contained shallow

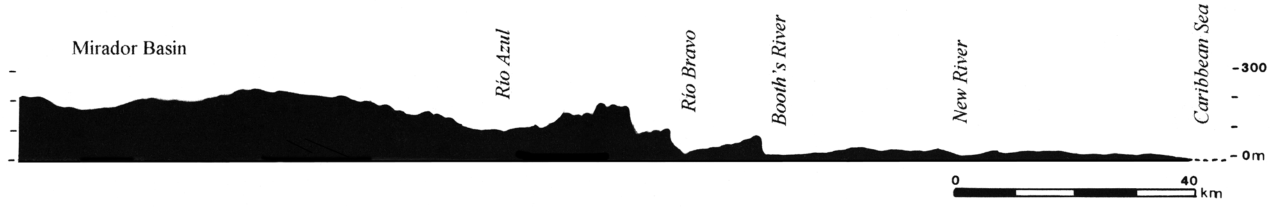


Figure 2. Elevational transect from the northern Caribbean coast of Belize to the Mirador Basin in the northern Peten (Guatemala).

Table 1. Water Budget for Chan Chich, Belize: Five-Year Average, 1991–1996

Month	Precipitation in Millimeters	Potential Evapotranspiration in Millimeters	Average Daily Temperature (Celsius)
JAN	175	75	23
FEB	100	105	25
MAR	58	143	27
APR	25	193	29
MAY	85	199	29
JUN	205	178	28
JUL	160	177	28
AUG	190	172	28
SEP	195	166	28
OCT	170	122	26
NOV	100	102	25
DEC	79	53	21

lakes has been proposed before, but proponents of this hypothesis suggested that the lakes filled with sediment during the Late Classic (AD 550–850) apogee of Maya civilization, when population levels—and presumably land disturbance—reached their maxima. This idea was first put forth in 1931 by Cooke, who suggested that *bajo* sedimentation (from agricultural intensification on adjacent uplands) had deprived the Maya of their primary water source, possibly increased mosquito populations (and mosquito-borne diseases), and triggered the abandonment of the Classic period centers of the southern Lowlands. This suggestion was furthered by Ricketson (1937), who excavated a 5.5-m-deep pit in a bajo adjacent to the ancient center of Uaxactun. He interpreted the stratigraphy to be a combination of alluvial and colluvial deposition, as indicated by a layer of water-worn pebbles and thick, dark clays believed to have been eroded off adjacent uplands. In 1957, Palerm and Wolf suggested that bajos may have been used for wetland agriculture using drained field systems similar to the *chinampas* of the Valley of Mexico, and that they played an analogous role in the centralization of political authority. This idea presaged a paradigm shift in Maya research, from a model holding that Classic Maya civilization consisted of vacant ceremonial centers with a dispersed population practicing long-fallow swidden farming to a model featuring true cities and dense populations supported by a variety of intensive agricultural practices (Turner 1993).

Harrison (1977) furthered this model by noting the strong spatial correlation between settlements and bajos in southern Quintana Roo, punctuated by the aerial observation of features in bajos believed to represent extensive wetland field systems. Subsequent ground investigations and excavations confirmed some features in the Bajo Morocoy (near the large site of Tzibanche) to be wetland fields (Gliessman et al. 1983). Wetland field systems have been more thoroughly investigated in the low-lying perennial wetlands of northern Belize. Nevertheless, controversy remains concerning the degree to which these wetland field systems are the result of natural processes or human modification and the temporal periods during which they were under cultivation (cf. Turner and Harrison 1983; Pope and Dahlin 1989, 1993; Harrison 1990, 1996; Pohl, Bloom, and Pope 1990; Jacob 1995; Pohl et al. 1996; Pope, Pohl, and Jacob 1996).

There has been an equal amount of contention about the degree to which the bajos of the elevated interior portions of the Maya Lowlands were a valuable resource for agriculture or other uses. Soil investigations in bajos near the large ancient cities of Tikal and El Mirador seemingly refuted earlier assertions that these depressions had once contained lakes. However, the oft-cited Cowgill and Hutchinson (1963) only excavated two deep soil pits in the huge Bajo de Santa Fe, 3.5 km east of

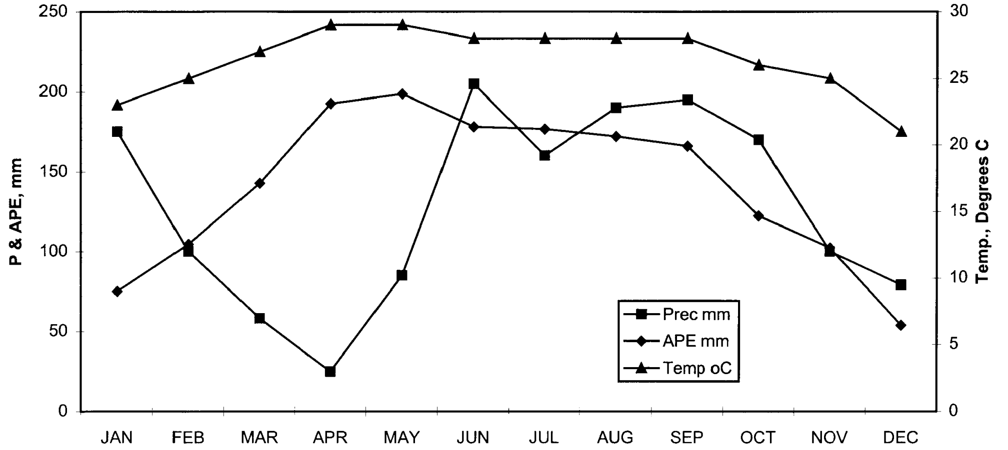


Figure 3. Water budget for Chan Chich, Belize: five-year average, 1991–1996.

the great ancient Maya city of Tikal. Detailed study made of the pit's clay stratigraphy led to the conclusion that the clays were produced by mass wasting of the limestone bedrock comprising the uplands surrounding the bajo. Today, the soil these authors described would be classified as a Vertisol (Jacob 1995). Cowgill and Hitchinson (1963, 12) paid relatively little attention to a layer of "carbonaceous material of unknown nature and origin" found at a depth of about 5 m. This layer yielded a radiocarbon date of 11,560 ± 360 B.P. Unfortunately, no mention is made as to whether the measured sample was pretreated to minimize hard-water error; thus, it is possible that this date is erroneously old. Hard-water error can result from the dissolution of ancient limestone in the watershed and incorporation of the ^{14}C-deficient carbon into shell carbonate (Islebe et al. 1996).

Dahlin and colleagues made more extensive soil investigations in a large bajo adjacent to the large center of El Mirador (Dahlin, Foss, and Chambers 1980; Pope and Dahlin 1989; Dahlin and Dahlin 1994). They found Vertisols to be the most prevalent soil within the bajo, interpreted to indicate that similar environmental conditions had prevailed throughout Maya times. It is noteworthy that the stratigraphy in most soil pits included one or more buried topsoil (Ab) horizons. We will discuss further below the significance of the Ab horizons found at Tikal and El Mirador.

A heated debate has centered on the issue of whether or not the seasonal wetlands characteristic of interior bajos today comprised a suitable environment for intensive wetland agriculture. Following the detection of wetland fields in the Bajo Morocoy, many scholars believed that similar field systems would likely be found throughout the interior bajos of the central and southern Maya Lowlands (Turner 1978; Harrison 1990).[3] Furthermore, it appeared for a period of time that airborne synthetic aperture radar (SAR) had successfully detected patterning consistent with canals and wetland field systems across wide areas of the Lowlands (Adams 1980; Adams, Brown, and Culbert 1981; Adams et al. 1990). Unfortunately, interpretation of the SAR data was flawed, with SAR system noise or bedrock fracturing producing false patterning, including areas that were not wetlands (Pope and Dahlin 1989, 1993; Adams 1993; Dunning, Beach, and Rue 1997).

Investigations of bajos near the ancient city of Rio Azul in northeastern Guatemala reinforced the fact that there is considerable environmental heterogeneity within these basins (Culbert, Levi, and Cruz 1989, 1990). Variation exists in drainage, soils, and vegetation associations. Mapping and excavations revealed networks of possible ditches towards the margins of the Bajo Pedernal. It should be noted, however, that others have suggested that such ditches were actually natural anastimorizing channels (Jacob 1995; Pope and Dahlin 1993). Nevertheless, it is critical to note that the seasonal swamps found today in interior bajos are far from environmentally homogeneous, with some areas having greater agricultural potential than others (Culbert et al. 1996; Kunen et al. 2000). Others have argued that the Vertisols prevalent today in many interior bajos would have made significant agriculture difficult (Pope and Dahlin 1989, 1993; Dahlin and Dahlin 1994). They argue that these soils are often deficient in phosphorus, potassium, and zinc, low in organic matter, poorly aerated, overly acidic, subject to seasonal shrinking and swelling capable of tearing crop roots, extremely hard when dry, and plastic and sticky when wet. Dahlin and Dahlin (1994) suggested that bajos may have been more likely used principally as areas of managed forest. However, we have found few such limitations in the upland bajos in northwestern Belize (Beach et al. forthcoming; Dunning et al. forthcoming). Whether or not bajos are agriculturally limited, they cover large areas of the southern and central Maya Lowlands, and it would be surprising if these basins did not play a significant land use role throughout the course of Maya civilization.

Cultural Historical Context

Maya people began settling in the Lowlands by at least 4,000 B.P., initially in small, scattered farming communities. The earliest known major urban centers in the Maya Lowlands, Nakbe and El Mirador (Figure 1), flourished in the Middle and Late Preclassic periods (900 BC–AD 150), but were effectively abandoned thereafter (Hansen 1992). These centers lie adjacent to some of the largest bajos in the region. Many other large Maya communities in the southern Lowlands, such as Tikal, Calakmul, Uaxactun, Rio Azul, and La Milpa, had their origins in Preclassic times but continued to flourish and grow during the subsequent Protoclassic and Classic periods (AD 150–900). These urban centers are also situated adjacent to bajos. Evidence suggests that many of these persisting communities began constructing reservoirs and other water and land management features towards the end of the Preclassic period and into the Classic (Scarborough 1993; Dunning 1995). Across much of the Maya Lowlands, the population continued to grow steadily throughout the Classic period up to the time of the "Classic collapse," between AD 800 and 900, when populations across the interior Lowlands plummeted sharply and many urban centers were effectively abandoned.

Methods and Results

We collected the data reported in this section during paleoenvironmental and archaeological investigations near La Milpa in 1997 and 1998, and between Yaxha and Tikal, Guatemala in 1999. In both cases, investigations included survey and mapping of topography, hydrology, soils, vegetation, and cultural features. Our work included extensive geoarchaeological trenching, sediment coring, and excavations of cultural features.

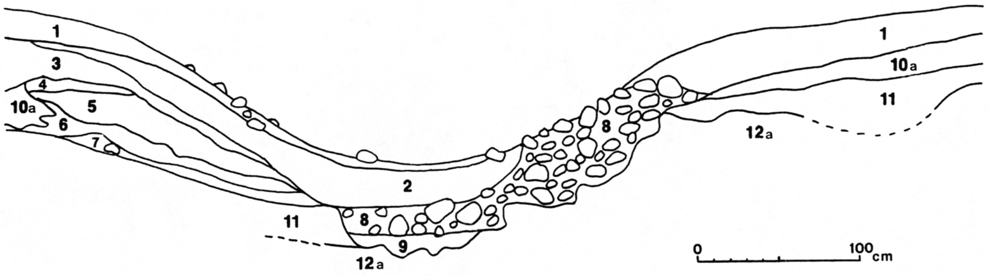
Investigations at La Milpa, Belize

The ancient city of La Milpa is located in northwestern Belize near the eastern margin of the large interior karst plateau, a hydrologically elevated area characterized by rugged free-draining uplands and numerous bajos (Dunning, Beach, Farrell, and Luzzadder-Beach 1998; Dunning et al. forthcoming). The La Milpa site center is situated atop a topographically prominent ridge on the plateau and is flanked by bajos of various sizes. Soils on the limestone uplands across this region are fertile but shallow clay Rendolls (or Rendzinas), soils that are vulnerable to erosion where they occur on sloping terrain. Bajo soils are chiefly deeper clay Vertisols, but transitional soils occur along the catena up to the crest. Native vegetation ranges from deciduous swamp forest in the bajos to tropical wet/dry deciduous forest across the uplands, reflecting the influence of the regional dry season (Brokaw and Mallory 1993).

The earliest Maya occupation thus far discovered at La Milpa occurred during the Middle Preclassic period (900–400 BC). However, the first monumental architecture in the site center dates to the subsequent Late Preclassic period (400 BC–AD 150) (Guderjan 1991; Tourtellot et al. 1994; Hammond et al. 1996, 1998). Occupation and construction at La Milpa continued, with some interruption, through the middle of the Terminal Classic (ca. AD 900), after which the site and region were largely and abruptly abandoned. Sometime during the Classic occupation of La Milpa, the Maya modified portions of the ridge-top site center to create large reservoirs (Scarborough et al. 1995).

Our investigations in the drainages and bajos flanking La Milpa revealed evidence of significant environmental disturbance. These investigations included the detailed mapping of Drainage 1 on the eastern side of the site center and Drainage 3 on the west. We excavated twenty-nine geoarchaeological pits and trenches, twenty-seven water and soil management features (dams, weirs, and terraces), and eighteen associated residential features in the two drainages and the bajos into which they disgorge.[4] Several of the more significant trenches excavated in Drainage 3 and the associated Far Western Bajo are discussed below.

Operation V33a is one of several trenches across the lower reaches of the Drainage 3 channel (Figure 4). Soil



Vegetation:
Upland forest and corozal

Soil Units:
1) Very dark gray (5YR3/1) sandy clay (±5% coarse sand); large crumb structure.
2) Very dark gray (5YR3/1) sandy clay (±40% coarse sand and small limestone pebbles); small crumb structure.
3) Dark gray (5YR4/1) sandy clay (±20% coarse sand); fine crumb structure.
4) Very dark gray (7.5YR3/0) sandy clay (±5% coarse sand); small subangular blocky structure; faint slickensides.
5) Grayish brown (10YR5/2) sandy clay (±20% coarse sand); large subangular blocky structure; slickensides.
6) Black (5YR2.5/1) clay; large subangular blocky structure; slickensides.
7) Dark grayish brown (10YR4/2) clayey coarse sand (±40% clay); large crumbs.
8) Fifty percent sub-rounded gravel, cobbles, and small boulders in a matrix of very dark gray (10YR3/1) sandy clay (±15% coarse sand).
9) Grayish brown (10YR5/1) clayey coarse sand (±40% clay).
10a) Dark grayish brown (10YR4/2) sandy clay (±5% coarse sand); large subangular blocky structure; slickensides.
11) Yellowish brown (10YR5/6) sandy clay in a matrix of decomposing limestone boulders.
12a) Hard limestone bedrock.

Figure 4. Profile of Operation V33a showing stratigraphy typical of the lower reaches of Drainage 3.

Unit 6 is a buried topsoil with soil humates dating to about 1200–910 BC (calibrated) (Beta-112474). This soil was buried multiple times by fluvial sediments. At one time, the lower reaches of the Drainage 3 channel underwent massive aggradation, and coarse alluvium (Unit 8) completely choked the channel. Subsequent erosion reopened the channel and flushed out much of the Unit 8 alluvium. Where Drainage 3 disgorged onto the nearly flat bajo floor, some 70 m lower in elevation than the La Milpa site center, deposition of coarse sediments formed a wide, deltaic fan incised by braided channels. Operation BH6 revealed two ephemeral channels marked by slackwater deposits of finer, more organic sediments (Units 3 and 5) (Figure 5). Humates in Unit 5 (100–130-cm depth) date to 415–365 BC (calibrated) (Beta-118306); humates in Unit 3 (30–60-cm depth) date to AD 330–440 (calibrated) (Beta-118305).

Beyond the delta was a concomitant aggradation of finer sediments across the Far Western Bajo floor. Fifteen trenches excavated in this bajo revealed a general buried soil (paleosol). In Operation BH9, this ancient soil comprises Unit 5a (Figure 6), where faint organic matter (Saprist) and pollen were fortuitously preserved. Most of the pollen was partially oxidized but could still be readily identified. That pollen assemblage was dominated by *Typha* (cattail), a plant characteristic of perennial wetlands and lake margins, and by other aquatic vegetation (Table 2). Long-distance *Pinus* (pine) and *Quercus* (oak) pollen were also identified; such pollen are typically trapped in bodies of open water. In combination, these pollen indicate the former presence of a perennial wetland, probably containing pockets of open water. The composition of Unit 5a is consistent with the peaty surface-horizon forming in a perennial wetland, a very different ecosystem from the seasonally desiccated scrub forest that occupies the bajo today. Unit 5a has been radiocarbon-dated to AD 15–110 (calibrated) (Beta-121443).

Another line of evidence about environmental change in these bajos can be found in the isotopic composition of carbon (C) in organic matter (OM) in the buried soils found in the bajos flanking La Milpa. The composition of Unit 5a in Operation BH9 also indicates that this buried horizon represents an ancient peat layer that formed within a perennial wetland (Figure 7). Similar findings have been reported from buried soil found in a large bajo near Nakbe (Figure 1) (Jacob 1995). Plants with a C3 photosynthetic pathway have a $\delta^{13}C$ value near −27‰, whereas plants with a C4 pathway have a $\delta^{13}C$ value near −14‰. OM in surface soils in the Nakbe and La Milpa bajos had an average value near −27‰, reflecting the present-day arboreal, seasonal swamp forest vegetation. In the buried soils at Nakbe, however, OM had average values around −23‰, suggesting the derivation of OM from both C4 and C3 herbaceous plants and

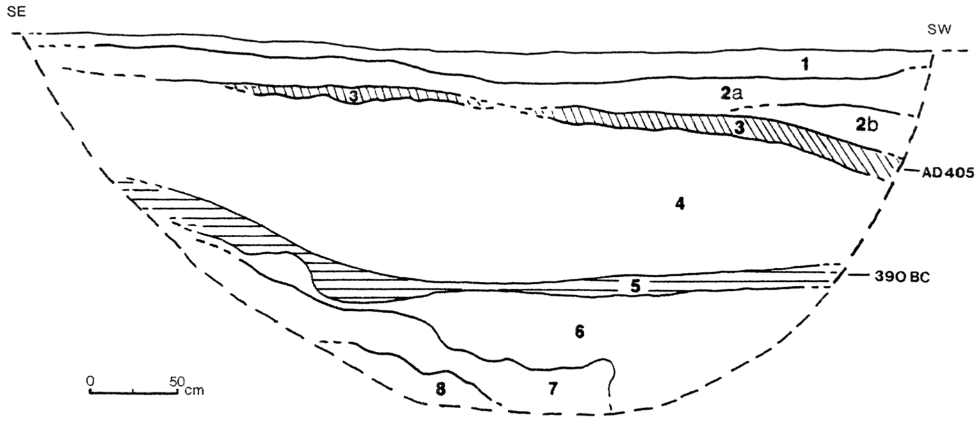
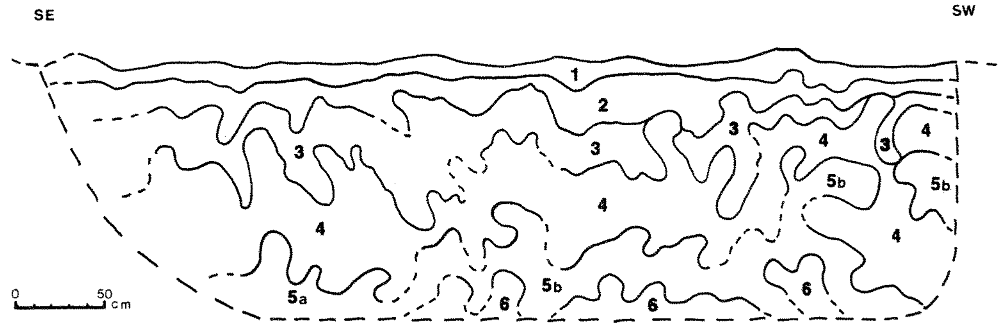


Figure 5. Profile of Operation BH6 showing stratigraphy typical of deltaic deposition at the mouth of Drainage 3.

Vegetation:
Corozal forest

Soil Units:

1) Black (7.5YR2/0) clay; large crumb structure.
2a) Black (5YR2.5/1) sandy clay (±40% coarse sand); large crumb structure; ±10% gravel and small cobbles.
2b) Dark gray (5YR4/1) clayey sand (±40% clay); large crumb structure; ±10% gravel and small cobbles.
3) Very dark gray (5YR5/1) sandy clay (±20% medium sand); blocky to massive structure.
4) Fifty percent sub-rounded gravel, cobbles and small boulders in a matrix of dark yellowish brown (10YR4/4) clayey coarse sand (±20% clay).
5) Very dark gray (7.5YR3/0) clay; massive.
6) Matrix of grayish brown (7.5YR5/2) clayey coarse sand interspersed with 30% sub-rounded gravel, cobbles, and small boulders.
7) Pale yellow (2.5YR7/4) clay with ±20% reddish yellow mottles; massive; slickensides.
8) Limestone bedrock.



Vegetation:
Tintal-scrub forest and sawgrass

Soil Units:
1) Black (5YR2.5/1) clay; large crumb structure.
2) Dark gray (5YR4/1) clay with ±20% yellowish red mottles (5YR5/8); large crumb structure.
3) Gray (5YR5/1) clay with ±40% yellowish red mottles; medium subangular blocky structure.
4) Light gray (5YR7/1) clay with ±10% yellowish red mottles and ±5% coarse sand; massive.
5a) Very dark gray (7.5YR3/0) clay; interfingered with thin bands of sapric material; massive.
5b) Very dark gray (7.5YR3/0) clay with ±20% red and light gray mottles; massive.
6) White (5YR8/1) clay with ±30% reddish yellow (5YR7/8) mottles; massive.

Figure 6. Profile of Operation BH9 revealing stratigraphy typical of the Far Western Bajo floor.

from moisture-loving trees. Since the herbaceous species in tropical wetlands include both C4 and C3 plants, OM derived from such plant communities will always contain a mixture of carbon isotopes (Boutton 1991). Isotopic C in buried soils from bajos near La Milpa is even more supportive of the former presence of herbaceous vegetation. OM $\delta^{13}C$ values from these soils ranged from −18.3‰ to −23.2‰, midway between the −13‰ value expected for exclusively herbaceous C4 plants and the −27‰ value expected for exclusively woody C3 plants. These isotopic C values correspond well to the mixed herbaceous and aquatic woody vegetation found within and bordering perennial wetlands. At present, we have no evidence that the Maya were cultivating this perennial wetland in the Preclassic. We have found eroded artifacts scattered throughout the sediments down into the deepest paleosols. The Maya were all around the area and, if nothing else, this wetland would have provided a reliable source of water during the dry season in an area where no such water exists today.

Table 2. Pollen from Unit 5a, Operation BH9, Programme for Belize Archaeological Project

Long-distance types
  Pinus (Pine) 8
  Quercus (Oak) 4
Aquatic types
  Typha (cattail) 88
  Cyperaceae (sedge) 33
  Cladium (Sawgrass) 6
Open-area types
  Poaceae (grass) 29*
  Asteraceae (Composites) 10
  Alismataceae (pickerelweed) 3
  Polygonaceae 1
  Amaranthus 1
Forest types
  Fabaceae (Legume family) 1
  Haematoxylon (logwood) 1
  Coccoloba (Bob) 1
  Hirea (Liana) 1
  Burcera (gumbolimbo) 1
  Moraceae (fig family) 2
  Combretaceae/Melastomataceae 3
  Myrica (wax myrtle) 2
  Machaerium/Dahlbergia 1
  Rubiaceae 1
Other
  Unknown A (possibly *Casearia*) 2
  Indeterminate 1

Note: Based on a standard count of 200 pollen grains; numbers are absolute quantities.
*May be in part *Olyra*, an aquatic grass.

Unit 4 in Operation BH9 is a thick layer of fine sandy clay sediment that buried Unit 5a and 5b (Figure 6). We interpret this burial to have resulted from substantial deforestation and subsequent erosion of the slopes in the Far Western Bajo watershed. The preservation of peat indicates that sedimentation occurred rapidly. Deforestation and the large-scale deposition of clay sediments in the bajo probably caused long-term hydrologic and ecological changes (Figure 8). Sedimentation and eutrophication can greatly degrade wetland functions (National Research Council Committee on Characterization of Wetlands 1995). Also, a deforested and eroded watershed would have severely retarded rainfall infiltration and evapotranspiration, leaving a much higher percentage to run off through seasonal channels or into karst swallow holes. Further, the new dense-clay layer raising the base elevation of the bajo floor may have also con-

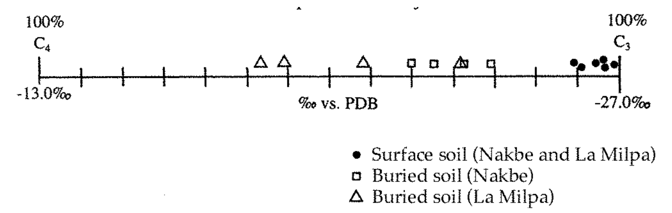


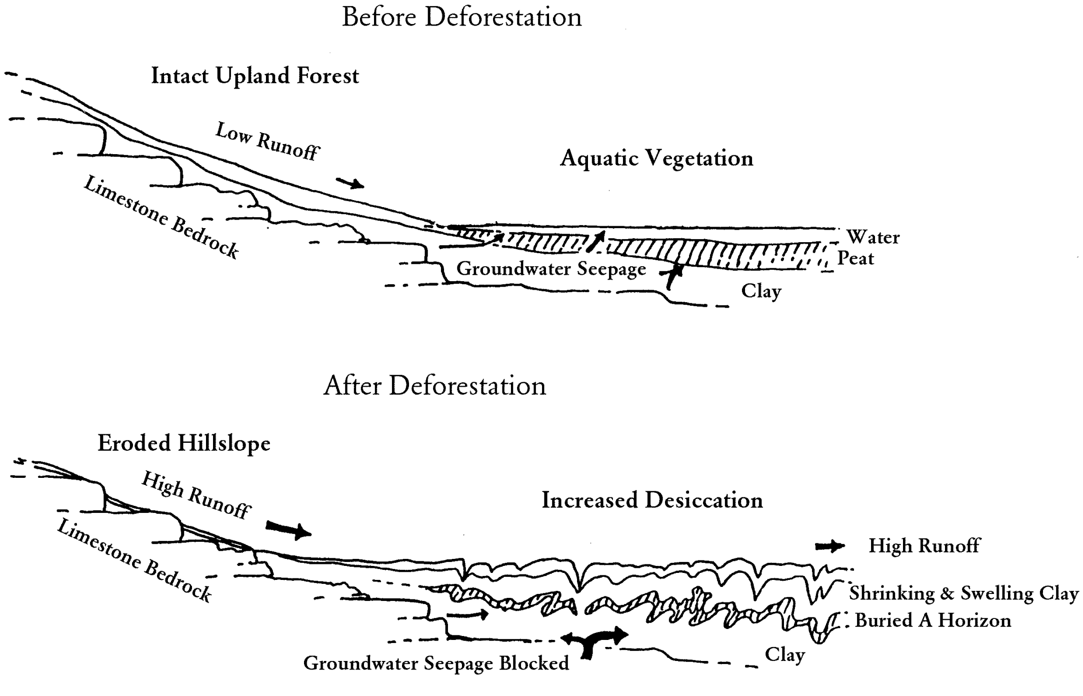
Figure 7. $\delta^{13}C$ of soil organic matter in La Milpa and Nakbe bajos. Nakbe data from Jacob (1995), figure 4-16.

fined groundwater seepage preventing recharge of the wetland. Such groundwater contributions are often critical for maintaining wetland moisture levels. Both effects would have resulted in significantly reduced soil moisture levels in the dry season. These changes may have initiated the transformation from an herbaceous aquatic-adapted vegetative complex to a scrub-forest complex adapted to drastic seasonal moisture fluctuations.

The violent distortion and fragmentation of Unit 3 and lower strata in Operation BH9 (Figure 6) is the result of significant argilloturbation (clay shrink and swell activity) (Beach et al. forthcoming). One factor contributing to this argilloturbation was probably differential pressure-loading and confining pressure within the accumulating sediment comprising Units 3 and 4 (Paton 1974). Another contributing factor was the onset of drying and wetting extremes, probably reflecting deforestation, rather than climate change, within the bajo watershed. However, we cannot discount the potential regional climatic drying that may have also contributed to desiccation and argilloturbation in the bajos (e.g., Brenner et al. 2000; Hodell, Brenner, and Curtis 2000; Pope et al. 2000; Hodell, Brenner, and Guilderson 2001). This broken stratigraphy is characteristic of upland bajo soil profiles throughout the La Milpa area. Investigations in a smaller bajo at the mouth of Drainage 1 revealed similar distorted strata, including buried Preclassic topsoil (Dunning and Beach 2000; Beach et al. forthcoming). Notably, since the reforestation of the bajo after the region was depopulated around AD 900, argilloturbation of the surface soil has been relatively minimal, as evident in the stable development of surface-soil horizons (Figure 6, Units 1 and 2).

Evidence thus far strongly suggests that deforestation and soil erosion associated with Late Preclassic (400 BC–AD 150) populations and agriculture at La Milpa were the root causes of the changes occurring in local bajos. Our investigations at La Milpa and in surrounding lands, including forty-two geoarchaeological trenches and twenty-six radiocarbon dates from buried soils, consistently indicate severe environmental disruption associated with Preclassic land clearance (Dunning et al. 1999; Dunning and Beach 2000).

The Preclassic population in the La Milpa area was smaller than later Classic numbers, but they probably


Before Deforestation

After Deforestation

Figure 8. Schematic representation of anthropogenic change in an interior Maya Lowlands *bajo*.

practiced extensive forms of forest clearance and agriculture, generating disproportionately high environmental disturbance. Much of the region's sloping upland terrain was probably denuded of its soil cover. This conclusion concurs with previously documented evidence that suggests that, for some regions, the Maya of the ensuing Early Classic period may have inherited a severely eroded landscape from their ancestors (Jacob 1995; Beach 1998; Dunning, Rue, Beach, Covich, and Traverse 1998; Dunning et al. 1999; Dunning and Beach 2000).

Ancient land-use on gently sloping lands flanking the Far Western Bajo and other bajos in the vicinity of La Milpa included extensive networks of agricultural terraces, berms, and field walls (Figure 9) (Tourtellot et al. 1994; Hughbanks 1998; Kunen 2001). Recent work at Nakbe in the northern Peten has also documented extensive terracing around the margins of bajos (Hansen et al. 2000). In one instance, massive colluviation buried a bajo-margin terrace, sealing and preserving the Late Preclassic planting surface. Analysis of the buried terrace soil indicates that it was being built up and enriched with organic mucks derived from a perennial wetland (presumably in the adjacent bajo). Carbon-isotope analysis of soil behind a bajo-margin terrace at La Milpa also indicates enrichment with muck.

Investigations at the huge site of Calakmul and the adjacent El Laberinto Bajo suggest that during the transition from Preclassic to Classic occupation around AD 200, an agricultural system evolved emphasizing the terracing and intensive cultivation of colluvial soils accumulating along the bajo margins (Gunn et al. 2000). The system of walls and terraces around the La Milpa bajos may also represent the development of bajo-margin intensive agriculture.

Despite the transformation of the Far Western Bajo at La Milpa from a perennial wetland to a seasonal swamp forest, this area continued to be a focus of Maya settlement in the Classic period. In fact, population grew considerably during the Classic, both along the margins of the bajo and on a large, rocky "island" within it (Kunen 2000). These findings strongly suggest that these bajos continued to be an important resource, although we have no direct evidence of the nature of Classic land-use on the bajo floors themselves.[5]

Investigations Near Yaxha and Tikal

Investigations of large interior bajos near Yaxha and Tikal have also revealed dense settlement dating from Late Preclassic through Late Classic times on flanking uplands and on "islands" within the bajos (Culbert et al. 1996; Fialko 1999; Kunen et al. 2000). Immediately north of the ancient city of Yaxha lies the sprawling (approximately 150 km^2), topographically complex Bajo La Justa. This bajo contains a variety of seasonal wetland types and is dotted with numerous islands of variable size, including one on which was built the major monumental architectural center of Pozo Maya. Nearby is one of the more distinctive features found to date in a bajo: the Aguada Maya, a 13,200 m^2 bermed, rectangular, perennial pond. Although the Aguada Maya may have begun as a natural pond, it was clearly heavily modified by human labor. Many of the Bajo La Justa sites contain evidence of significant Preclassic and Early Classic settlement, but occupation appears to have been greatest in the Late Classic. We strongly suspect that the modification of the Aguada Maya dates at least in part to the Late Classic. This assertion is also supported by evidence indicating that earlier features on the bajo floor may have been buried by sedimentation.

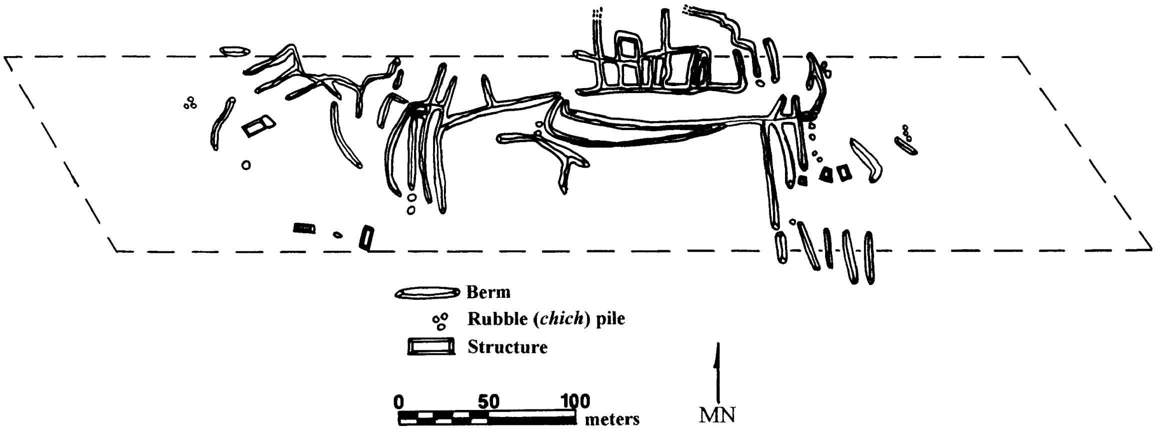


Figure 9. Map of a portion of the eastern margin of the Far Western Bajo, La Milpa (Far West Drainage Survey Block 16, mapped by Paul Hughbanks and Julie Kunen) showing agricultural terraces and field walls.

In 1999, numerous pits and trenches were excavated in a variety of environmental contexts in the Bajo La Justa. Most of these revealed clay-heaved, distorted Vertisols broadly similar to those observed near La Milpa. We again interpret these argilloturbation features to be the result of combined subsidence and compression associated with clay-sediment deposition and to shrinking and swelling associated with seasonal wetting and drying. In most of the excavations carried down to a sufficient depth, Ab horizons occurred at depths ranging from 80 to 290 cm. Only one of these paleosols has been radiocarbon-dated.

Operation 6D3 was a hand-dug extension of a narrow backhoe trench, located a few hundred meters downslope from the northernmost monumental architecture at Yaxha. This extension was completed because the small backhoe could only reach a depth of about 1.5 m. Much of the upper portions of the revealed profile resemble that of a typical bajo Vertisol (Figure 10). However, the lower portions of the excavation produced two distinctive features. Unit 6 is a wavy band of black, organic clay interspersed with residual Saprist (faint organic matter), similar to the peaty paleosol found in the Far Western Bajo at La Milpa. Carbon isotopes from Unit 6 also indicate this deposit formed in a perennial wetland (Figure 7). Fortuitously, Unit 6 also preserved pollen of many aquatic species, such as water lilies and cattails as well as open-water-deposited pine and oak pollen (Table 3). Pollen also indicate considerable open, grassy areas. One *Zea Mays* pollen grain indicates that the Maya may have been cultivating nearby areas, since these pollen do not travel far from their source. Unit 6 produced a radiocarbon date of AD 75 (calibrated) (Beta-134143). Unit 5 is a stratum of gray clay that appears to include an approximately 160-cm-wide ridge bounded on both sides by ditches some 30–40 cm in depth. Both the ridge and ditches are continuous features across the width of the excavation (1 m). Unit 4 is a pale clay that we interpret to be a slope wash and precipitate deposit derived from nearby low limestone ridges.

At present, we interpret the stratigraphy in Operation 6D3 as follows. Around AD 75, this portion of the Bajo La Justa was a perennial wetland with pockets of open water and wide, grassy margins. Whether the Maya were cultivating maize in the bajo (probably with the use of ditching) or on higher ground nearby is unclear. Some time after AD 75, this section of the bajo began to rapidly fill with gray, colluvial clay, probably coincident with forest clearance on adjacent uplands. It appears that the Maya may have brought this new clayey surface into agricultural production using ditching and mounding. However, continued colluviation further filled the bajo, eventually transforming it from a perennial to a seasonal wetland—a process analogous to that described above for La Milpa. A thin topsoil formed in this deposit after Maya abandonment.

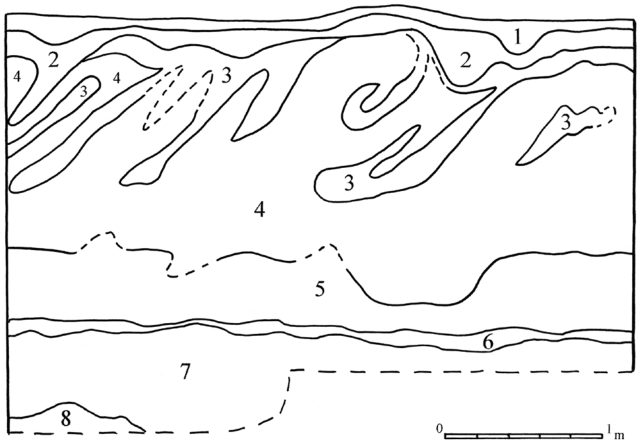
Trenches excavated nearby in the Bajo La Justa in 1996 and partially reopened in 1999 revealed deeply buried channels filled in with clayey sediment (Kunen et al. 2000). Portions of these buried channels included very sharp "cuts" into underlying *sascab* (marl), suggestive of human modification. The date of these channels remains unknown, however, and conclusive evidence of human modification has not been recovered.

As with La Milpa, the presence of heavy Classic period settlement on bajo "islands" and margins strongly suggests that the Bajo La Justa continued to be an important resource area even after its transformation into a seasonal wetland. The presence of the Aguada Maya within the bajo further suggests that the Maya may have attempted to manipulate soil moisture conditions in nearby portions of the bajo to improve agricultural productivity. In the large Bajo Zocotzal southwest of Tikal, Fialko (1999) found Late Classic dams and weirs in two arroyos leading into the bajo, indicating attempts to manage water at least within localized areas.

Discussion

We cannot yet conclude that all—or even most—interior bajos in the southern and central Maya Lowlands contained perennial wetlands at some point in their past, but evidence to that effect is mounting. As noted above, Jacob (1995) suggested that carbon isotopes in buried soil horizons in a bajo near Nakbe indicated that these buried organic layers originated in peaty deposits formed in perennial wetlands analogous to contemporary *civales* but much larger. It is also possible that the paleosols studied earlier in bajos near El Mirador and Tikal also represent old, remnant peats (Cowgill and Hutchinson 1963; Dahlin et al. 1983; Dahlin and Dahlin 1994). Thus far, we do not know the degree to which Preclassic Maya people practiced any form of agriculture directly in the former perennial wetlands of the interior bajos. However, the preferential settlement of bajo margins during the Preclassic can most simply be explained by their importance as a water source in a region that is practically waterless at the height of the annual dry season today. The rapid sedimentation that occurred in many bajos suggests that significance disturbance, probably including quarrying, was taking place on adjacent uplands (Hansen et al. 2000).

If our model of bajo transformation represents condi-



Vegetation:
Mixed palm bajo forest.

Soil Units:
1) Black (5YR2.5/1) clay; large, hard crumbs; dense root mat.
2) Very dark gray (7.5YR3/0) clay; large, hard crumbs; diminishing roots.
3) Dark gray (7.5YR4/1) clay; platy to massive; slickensides.
4) Light gray (10YR7/2) clay; 1–2% coarse sand; small, platy peds; slickensides.
5) Gray (10YR6/1) clay; 3–4% coarse sand; massive; slickensides.
6) Black (7.5YR2/0) clay with visible tissue impressions interbedded with pockets of sapric peat; clay is platy; peat is highly compressed.
7) Gray (10YR5/1) clay; 5–6% coarse sand; massive; scattered small, black Mn oxide inclusions.
8) White sascab and weathering, cherty limestone.

Figure 10. West profile of Operation 6D3, Bajos Communities Project, Guatemala.

tions affecting much of the interior portions of the central and southern Maya Lowlands, it has important implications for understanding changes that occurred in Maya civilization towards the end of the Preclassic period. One of the most notable changes occurring at that time was the abandonment of El Mirador, Nakbe, and nearby urban centers (Hansen 1992). Notably, these were the largest known Preclassic urban centers in the Maya Lowlands. It is possible that their large populations made them particularly vulnerable to environmental disturbance, including prolonged drought (Hodell, Brenner, and Guilderson 2001). Or, perhaps because of their great size, environmental degradation was more severe or rapid than in neighboring areas, thereby triggering abandonment. Although the environmental disturbance generated by Preclassic people was certainly significant elsewhere, it may not have been so rapid or acute as around El Mirador and Nakbe, because Preclassic populations were much smaller in other localities. This difference may help explain why, in neighboring places such as Tikal and La Milpa, population continued to grow and urban development persisted.

Recent syntheses of paleoclimatic models and data found convergent indications of maximal rainfall across the southern Maya Lowlands around 1000 BC (Brenner et al. 2000; Pope et al. 2000), a condition that may have helped establish perennial wetlands in many bajos. Convergent data also indicated that gradual but irregular climatic drying ensued, with maximal dryness occurring around AD 100, possibly playing a significant role in the transformation of bajos from perennial to seasonal wetlands and in the transition from the Preclassic to Classic periods in Maya civilization; such drying also apparently occurred around the end of the Late Classic, circa AD 800 (Hodell, Brenner, and Curtis 2000; Hodell, Brenner, and Guilderson 2001).

In many places like La Milpa, the loss of perennial water sources in the bajos necessitated developing new water sources and more water-conservative agriculture. Thus, it is not surprising that during the transition from the Preclassic to the Classic, reservoirs became an integral part of the urban landscape at many Southern Low-

Table 3. Pollen from Unit 6, Operation 6D3, Bajo Communities Project, Guatemala

Long-distance types	
Pinus (Pine)	21
Quercus (Oak)	14
Liquidambar	1
Ulmus/Chaetoptelea	2
Aquatic types	
Typha (cattail)	5
Cyperaceae (sedge)	4
Cladium (sawgrass)	15
Nymphea (water lily)	20
Open area types and cultigens	
Poaceae (grass)*	47
Asteraceae (composites)	21
Polemoniaceae	1
Laminaceae	1
Waltherea	2
Zea mays	1
Forest types	
Fabaceae (Legume family)	1
Bursera (gumbolimbo)	2
Moraceae (Fig family)	6
Combretaceae	9
Myrica (wax myrtle)	2
Anacardiaceae	2
Erthroxylaceae	1
Byrsonima	4
Sebastiana	4
Alnus	1
Sapotaceae	1
Celtis	2
Other	
Unknown A (may be *Casearia*)	1
Unknowns	2
Indeterminate	7

Note: Based on a standard count of 200 pollen grains; numbers are absolute quantities.
*May be in part *Olyra*, an aquatic grass.

land centers (Scarborough 1993). The localized control of water resources by urban elites, the intensification of local agricultural production, and the centralization and stratification of land wealth were also fundamental components of the Preclassic-Classic transition (Dunning 1995). These processes were seemingly brought about in part by the adaptations necessitated by the transformation of the bajos and by apparent climatic drying, and probably also facilitated by the disruption of the urban hierarchy accompanying the fall of El Mirador and nearby Preclassic centers.

Evidence from settlement patterns at La Milpa, Bajo La Justa, and elsewhere in the southern and central Maya Lowlands suggests that large numbers of people continued to live along bajo margins throughout the Classic period. Part of this pattern may be attributable to locational inertia, but part was undoubtedly related to agriculture. However, both the nature and success of ancient agriculture in the bajos remain problematic and in need of further investigation.

More broadly, our findings demonstrate the potentially devastating and long-term consequences of tropical deforestation. The transformation of bajos from perennial to seasonal wetlands occurred about 2,000 years ago. Even after the general abandonment of the region around AD 900, most bajos remained seasonal wetlands, with only a few pockets of perennial moisture (*civales*) slowly being reestablished. For the Maya, transformation of the bajos was apparently initially a significant problem, but was later overcome by adaptive ingenuity that flourished into complex agricultural systems by the Late Classic (Dunning and Beach 2000). Nevertheless, the success experienced by Classic Maya civilization was also finite. By AD 900, large sections of the Lowlands—particularly the interior areas—were largely abandoned, a process that is itself far from understood.

Our research also contributes to the corpus of evidence dismissing the "*leyenda verde*" (Turner and Butzer 1992; Whitmore and Turner 2001) or "pristine myth" (Denevan 1992; Butzer 1993)—the idea that the ecosystems of the New World were relatively undisturbed by pre-Columbian occupation. We have only recently begun to appreciate the magnitude of environmental changes brought about by Native American activities. Although it has been suggested that pre-Columbian environmental disturbances have been greatly exaggerated (e.g., Vale 1998), our investigations strongly indicate that the state of many of the wetlands of the Maya Lowlands to this day is partly a product of pre-Hispanic human-environment interactions.

Our findings are consistent with a principle tenet of the "new ecology": namely, that the biophysical environment is inherently more unstable than is usually recognized in traditional systems models, and that human interactions add an even greater dynamic flux to environmental systems (cf. Botkin 1990; Zimmerer 1994; Balée 1998). We see the changes that occurred in the bajos as the product of complex interactions between human disturbance, climate change, and a highly vulnerable environment. With the removal of human disturbance, the bajo ecosystems certainly did not return to their predisturbance state. The long-term impacts of even low-technology human disturbance of tropical ecosystems should be considered as these areas are colonized for agricultural development today.

Acknowledgments

Much of the work reported here has been carried out as part of the Programme for Belize Archaeological Project, under the general supervision of Fred Valdez, Jr., and with the gracious cooperation of the Department of Archaeology, the Ministry of Tourism and the Environment, and the Programme for Belize. Investigations during 1997 and 1998 were carried out with the support of a National Science Foundation grant to Vernon Scarborough and Nicholas Dunning. Earlier work was supported by funds from a National Geographic Society grant to Scarborough in 1992 and a Heinz Family Foundation grant to Dunning in 1994, and from the University of Cincinnati, University of Texas, Georgetown University, George Mason University, and generous private donors. Dunning and Timothy Beach undertook investigations in 1996 as part of Boston University's La Milpa Archaeological Project, headed by Norman Hammond and Gair Tourtellot. Hammond and Tourtellot are to be thanked for their cooperation and friendly exchange of ideas over the past several years, which have enriched our work immensely. Numerous personnel of the Programme for Belize Archaeological Project have contributed to the work reported here, including Alan Covich, Jon Hageman, Paul Hughbanks, Julie Kunen, John Lohse, David McDowell, Hugh Robichaux, Kerry Sagebiel, Frank Saul, Julie Saul, Lauren Sullivan, and Skye Wagner. Some of the work reported here was carried out as part of the Bajo Communities Project, directed by Pat Culbert. This research is being conducted as part of Subproyecto Intersitios, directed by Vilma Fialko, as part of the larger Proyecto Triangulo of the Instituto de Antropología e Historia (Guatemala). Recent funding for the Bajo Communities Project has been provided by a grant from NASA to Culbert, Fialko, and Tom Sever. Numerous personnel from the Bajo Communities Project contributed to the work reported here from the 1999 season, including Rosa María Chan, Vilma Fialko, Liwy Grazioso, Gustavo Martínez, John Murphy, and Tom Sever. Hammond, Tourtellot, John Jacob, G. S. Humphreys, Scott Fedick, Jeffrey Baker, Bruce Dahlin, Joel Gunn, Richard Hansen, Peter Harrison, Bill Doolittle, Andrew Sluyter, B. L. Turner, II, and Betsy Lazaron provided helpful comments on earlier versions of this article, including versions presented at the 95th Annual Meeting of the Association of American Geographers, 23–27 March 1999, Honolulu, Hawaii and in the "Mesoamerican Wetlands" symposium at the 65th Annual Meeting of the Society for American Archaeology, 5–9 April 2000, Philadelphia, Pennsylvania.

Notes

1. In addition to the report edited by Oldfield (1998), readers interested in ongoing work on global environmental change are referred to the other projects sponsored by the International Geosphere-Biosphere Programme (IGBP), information on many of which is available on its website.
2. The concentration of wetlands varies considerably across the Maya Lowlands. Generally, wetlands are most common in riparian areas towards the margins of the region and within the large structural depression known as the Mirador Basin. Detailed delimitation of wetland areas has been accomplished in some portions of the lowlands (e.g., Klepeis and Turner 2001).
3. The wetland fields in the Bajo Morocoy have been cited as evidence for the use of *seasonal* wetlands for intensive agriculture because the soil surface horizon in this bajo dries out for several months each year (Gliessman et al. 1983; Adams et al. 1990; Harrison 1990; Adams 1993). However, despite being drier than the riparian perennial wetlands of northern Belize (where many wetland fields have been investigated), conditions in the Bajo Morocoy may be significantly wetter than those in many interior bajos (where other wetland fields have yet to be securely identified) (Pope and Dahlin 1989, 1993).
4. These numbers do not include excavations made in the site-center reservoirs at La Milpa or investigations made at other sites in the Programme for Belize. For further discussion of investigations in Drainage 1 at La Milpa, please refer to Dunning and Beach (2000).
5. We have found several wetland fields complexes, including ones clearly in use during the Late Classic period, in riparian and spring-fed perennial wetlands in low-lying areas over 10 km southeast of La Milpa and below the Rio Bravo Escarpment. However, these perennial wetlands are much lower in elevation than the upland bajos near La Milpa and areas farther west and have very different hydrologies.

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