HUMAN ECOLOGY, AGRICULTURAL INTENSIFICATION AND LANDSCAPE TRANSFORMATION AT THE ANCIENT MAYA POLITY OF UXBENKÁ, SOUTHERN BELIZE

by

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DISSERTATION ABSTRACT

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Title: Human Ecology, Agricultural Intensification and Landscape Transformation at the
Ancient Maya Polity of Uxbenká, Southern Belize

Identifying connections between land use, population change, and natural and human-induced environmental change in ancient societies provides insights into the challenges we face today. This dissertation presents data from archaeological research at the ancient Maya center of Uxbenká, Belize, integrating chronological, geomorphological, and settlement data within an ecological framework to develop methodological and theoretical tools to explore connections between social and environmental change or stability during the Preclassic and Classic Period (~1000 BC to AD 900).

High-precision AMS ^{14}C dates from Uxbenká were integrated with stratigraphic information within a Bayesian framework to generate a high-resolution chronology of sociopolitical development and expansion in southern Belize. This chronology revises the previous understanding of settlement and development of Classic Maya society at Uxbenká and indicates specific areas of investigation to elucidate the Late and Terminal Classic periods (AD 600-900) when the polity appears to disintegrate. A geoarchaeological record of land use was developed and interpreted with respect to regional climatic and cultural histories to track landscape transformations associated with human-environment interactions at Uxbenká. The first documented episode of landscape instability (i.e., erosion) was associated with farmers colonizing the area. Later, landscape stability in the site core parallels Classic Period urbanization (AD 300-900) when swidden agriculture was likely restricted in the core. Another erosional event followed political disintegration as farmers resumed cultivation in and around the abandoned city.

Maize yields derived from contemporary Maya farms in the area were used to estimate the maximum population size of Uxbenká during its Classic Period peak. The maximum sustainable population is estimated between 7500 and 13,000, including a potential population of ~525 elites in the core, assuming low levels of agricultural intensification. This accords well with the lack of archaeological evidence for intensive land management during the Classic Period (e.g., terraces). An ecological model developed using maize productivity and other environmental/social datasets largely predicts the settlement pattern surrounding Uxbenká. Settlements in marginal areas may be evidence of elite intra-polity competition during the Late Preclassic Period (ca. AD 1-300), though it is possible that marginal areas were settled early as garrisons to mediate travel into the site core.

This dissertation includes previously published and unpublished co-authored material.

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In completing this dissertation, I am struck by what the turn-of-the-20th century Russian philosopher-mystic George Ivanovich Gurdjieff called the process of 'self-remorse' that comes with acknowledging the 'conscious labors and intentional sufferings' that our forebears took upon themselves to give us what we usually take for granted today. He illustrates this emotion early in his vast allegory *Beelzebub's Tales to His Grandson* at the moment Beelzebub's grandson Hassein first makes this realization:

> "Only now have I come to understand that everything we have at the present time and everything we use – in a word, all the contemporary amenities and everything necessary for our comfort and welfare – have not always existed and did not make their appearance easily.
>
> It seems that certain beings in the past have during very long periods labored and suffered very much for this, and endured a great deal which perhaps they even need not have endured.
>
> They labored and suffered only in order that we might now have this and use it for our welfare.
>
> And this they did, either consciously or unconsciously, just for us, that is to say, for beings quite unknown and entirely indifferent to them.
>
> And now not only do we not thank them, but we do not even know a thing about them, but take it all as in the natural order, and neither ponder nor trouble ourselves about this question at all. ....
>
> And so, my dear and kind Grandfather [Beelzebub] ... I have gradually, with all my presence, become aware of all this, the need to make clear to my Reason why I personally have all the comforts which I now use, and *what obligations I am under for them.*"
>
> G.I. Gurdjieff (1973:76-77; *emphasis added*)

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Table Page

CHAPTER I

INTRODUCTION

Characterizing the tempo and mode of ancient landscape transformation under intensive agricultural production in relation to social, ecological and climatic change is crucial to understanding the development and disintegration of complex societies (deMenocal 2001; Redman 1999, 2005; van der Leeuw and Redman 2002). Intensification, defined here as increased labor input into resource acquisition or production, is a crucial component in the emergence of complex societies, which share the hallmarks of social hierarchy, differential access to resources, division of labor, technological elaboration, and craft specialization (Boserup 1965; Carneiro 1970; Earle 1987; Flannery 1972; Friedel and Schele 1988; Netting 1993; Price and Gebauer 1995). Intensification increases productive capacity of a landscape by increasing production yields per unit area while decreasing returns on labor. This can provide an economic foundation for population growth, relatively stable and persistent forms of land tenure, and social resilience (Redman 2005). Contemporary societies, while comprising multiple scales of both extensive and intensive resource production and distribution, are increasingly viewed as subject to the same external and internal disturbances that transformed ancient societies (e.g., prolonged drought, anthropogenic environmental degradation, demographic crisis, warfare, disease). The growing public concern over the fate of societies places great demands on archaeologists and the archaeological record to go beyond descriptions of ‘collapses’ to explain the processes by which complex societies emerge, persist, develop and disintegrate in the context of the changing human ecosystem and provide insights into our future prospects (Redman 1999, 2005; van der Leeuw and Redman 2002).

In the last two decades, natural and anthropogenic environmental change has gained predominant explanatory weight in the disintegration of Classic Lowland Maya polities. Stretching from the Petén (Guatemala) through Belize and into Mexico's Yucatán peninsula, the Maya Lowlands saw the emergence of socially stratified and politically complex societies from the Middle Preclassic (1000/800 – 400 BC) through the Terminal Classic (AD 80 – 1000) periods (Demarest 2004:8-12). Maize farming formed the main economic and cultural basis of Maya society, supplemented by cultivars such as beans, manioc, ramón nuts, and cacao, as well as a variety of hunted and gathered wild game, fish, and plant resources. Transformation of the subtropical and tropical lowland forests through human use has a long history that continues to be elucidated. High resolution regional climate and geomorphic records have provided evidence for deforestation and erosion associated with urbanization, and extended droughts throughout the Classic Period that undermined already fragile productive capabilities, contributing to the Classic Maya 'collapse' (Culbert 2004; Curtis et al. 1996; Deevey et al. 1979; Demarest 2006; Gill 2000; Haug et al. 2001, 2003; Hodell et al. 1995, 2001; Webster 2002). In danger of getting lost in the hype of Maya megadroughts is the fact that multiple land use strategies, conservative and otherwise, were employed throughout the Maya region that allowed for the development and stability of polities for extended periods. In the part of the Maya lowlands where water sources were localized in *cenotes* (e.g., the Yucatán), or highly alkaline (e.g., the Petén), drought was likely a dominant factor in the Classic Period "collapse" (e.g., Lucero 2002; Scarborough 2003), perhaps so dominant as to obscure the other ecological and social dynamics leading to Terminal Classic political disintegration. Tracking Maya-environment interactions in the wetter climate and richer soils of southern Belize may de-emphasize the role of adverse effects of natural and human-induced environmental change, allowing the complexities of land use decisions, intensification strategies and demographic change to be more clearly understood.

Through the study of site-specific adaptations to local environmental conditions, climate regimes, and social development, I seek to understand how individual land use decisions permitted growth of these polities and elaboration of social forms within a changing ecological context. This approach reflects my belief that while archaeology (and anthropology) has the ability to address problems relevant to human societies at any spatial or temporal scale, the observations used to develop and test theories must be empirically grounded and oriented at human scales of perception and action to be informative. Individual subsistence farmers, for example, may take into account environmental and sociopolitical conditions at regional scales over the long term, but deciding when to clear fields, when and what to plant, how to allocate labor, and so on, are often dictated by local conditions and immediate-term considerations.

Focusing on individual decision-making in terms of land use and settlement in the archaeological record is achieved in parts of this study through the use of models from Human Behavioral Ecology (HBE), which, as a part of Evolutionary Ecology, maintains *methodological individualism* as a central concept (Smith and Winterhalder 1992:39-41; Winterhalder 1994; Winterhalder and Smith 1992). As described by Smith and Wintehalder (1992:39), “[m]ethodological individualism ... holds that properties of groups (social institutions, populations, societies, economies, etc.) are a result of the actions of its individual members", and that explanations of group actions should necessarily be built "from the bottom-up". At Uxbenká and most Classic Maya centers, this places the individual commoner and their household unit as the focus of most land use decision making, while acknowledging the potential for top-down management of group resources (land, labor, agricultural production, etc.) by elites. While some aspects of HBE have been argued to be overly reductive (Winterhalder and Smith 1992:23), methodological individualism can serve as a theoretical bridge between processual and post-processual approaches, specifically in regards to critiques of the former for failing to acknowledge individual agency in negotiating social formations including gender and class (e.g., Brumfiel 1992).

HBE provides a coherent framework in which to integrate a diverse array of social, ecological and historical data to build models of past behavior and to generate testable hypotheses about the archaeological record. They also are flexible and readily generalizable, so that insights gained at smaller spatial and temporal scales (or with more simplified models) can be applied and tested at larger scales (or with more complex models) (Winterhalder and Kennett 2006).

To build a context for the application of HBE models at the ancient Maya center of Uxbenká, this study synthesizes data from the broad archaeological literature on the Lowland Maya, and presents new data and analysis of: architectural chronology beginning in the Late Preclassic Period (60 BC – AD 220) through the Late Classic Period (AD 600-800); the geoarchaeological record of changing land use in the site core from the early Middle Preclassic Period (ca. 970 BC – 620 BC) through the Terminal

Classic Period (AD 800-900); empirical data on contemporary maize yields surrounding Uxbenká and the nearby Maya village of Santa Cruz to develop estimates of past population density at Uxbenká; and development and testing of an ecologically-based predictive model of settlement through the center's history. To orient the reader with the region where Uxbenká is found, I provide the following background summary, which is elaborated upon in each of the remaining chapters

Setting and Background of Uxbenká

Southern Belize is home to diverse geologic and ecological zones, from the Maya Mountains to the west, into the foothills that host the primary ancient Maya centers of Pusilhá, Uxbenká, Lubaantun, and Nim Li Punit (Figures 1.1, 1.2), across the narrow strip of coastal plains to the mangrove swamps and lagoons of the coast where Maya salt production and maritime trade flourished during the Classic and Postclassic periods (McKillop 2008). The Maya Mountains served as a natural boundary separating southern Belize from the rest of the ancient Maya world and are composed of a mixture of Cretaceous intrusive and extrusive rocks, volcanics (e.g. rhyolite and welded tuffs) and metavolcanics (Bateson and Hall 1977). People living in the immediate vicinity of these durable rocks (e.g., Ek Xux and Muklebal Tzul; Abramiuk and Meurer 2006) capitalized on these raw materials for the manufacture and trade of groundstone milling tools from the Late Preclassic through Terminal Classic periods (50 BC-AD 1000; Prufer et al., 2011).

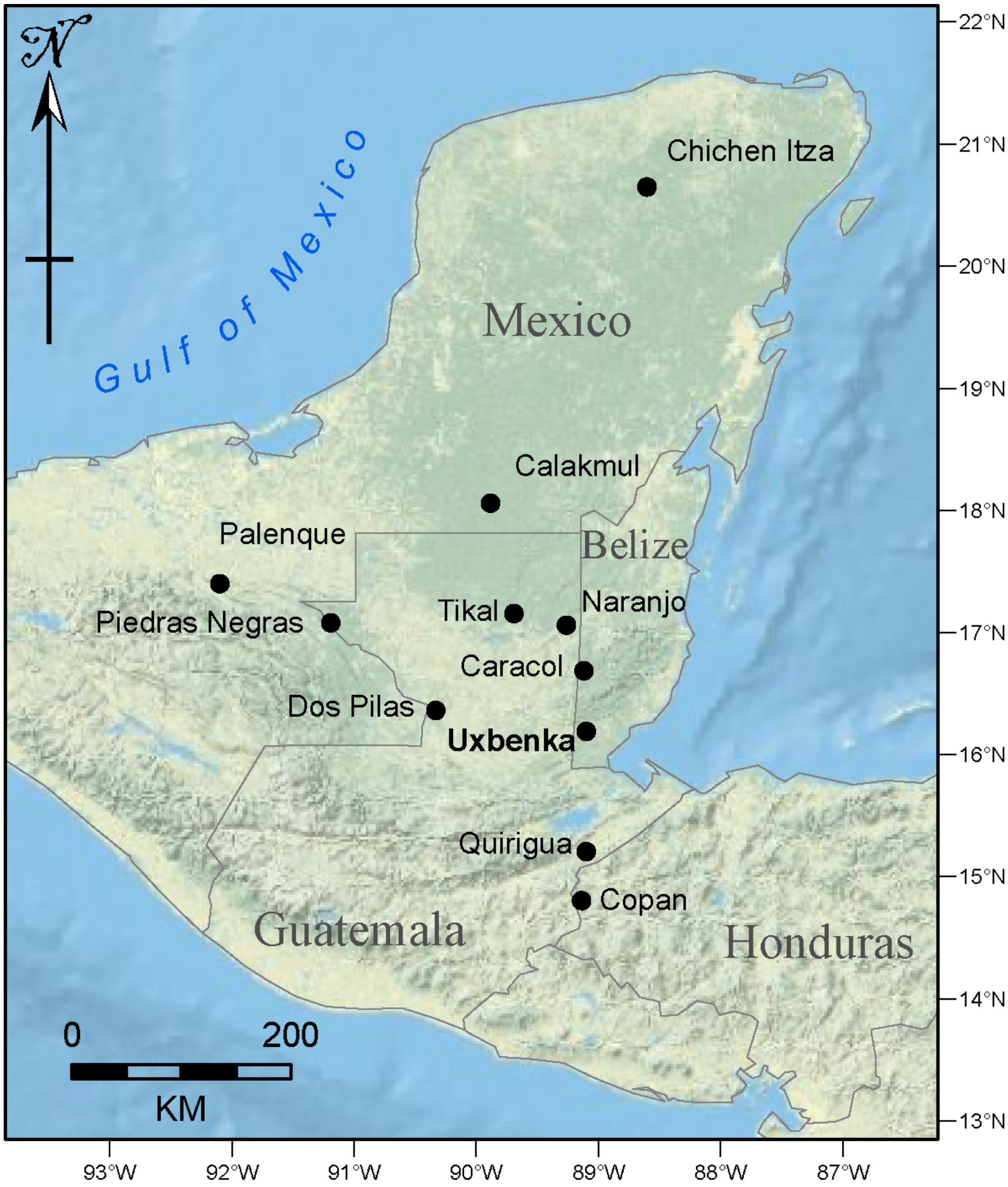


Figure 1.1. Location of Uxbenká in relation to Lowland Maya sites discussed in the text (map by C. Ebert).

Figure 1.2. Location of Uxbenká and other Lowland Maya sites in southern Belize (map by C. Ebert).

The foothills of the Maya Mountains are comprised of Cretaceous limestones and a series of interbedded Tertiary marine sediments known locally as the Toledo Beds (synonymous with the Sepur Formation in Guatemala) (Keller et al. 2003). The Toledo Beds range from shallow water limestones and dolomites to deeper water calcareous shales, mudstones and sandstone members (Keller et al. 2003; Miller 1996; Wright et al. 1959).

Most of the known ancient Maya centers in the region are set on these Tertiary sediments, with the exception of Pusilhá in the south, which is set on a Cretaceous limestone. Uxbenká and Pusilhá were the earliest centers established during the Late Preclassic (AD 20-200; Culleton et al. 2012; Prufer et al. 2011) and Early Classic (AD 300-600; Braswell et al. 2004), respectively. The chronologies of Lubantuun and Nim Li Punit are less well-understood, but both appear to be restricted to the Late Classic (AD 600-800; Hammond 1975; Hammond et al. 1999).

The character of the Toledo Beds is expressed differently at each of these locations – massive sandstone beds form natural stone plazas at Nim Li Punit, for example, but extensive mudstone and sandstone outcrops form natural terraces surrounding Uxbenká. The zone around Uxbenká is close to a discontinuity between Cretaceous and Tertiary members of the Toledo Formation, expressed most notably by a prominent Cretaceous limestone karst ridge immediately south of the site and the present village of Santa Cruz (Keller et al. 2003; Miller 1996). The karstic ridge, locally known as “The Rock Patch”, contains several caves that are the subject of on-going archaeological research (Prufer et al. 2011). This karst ridge dominates the drainage of the Rio Blanco, which flows with its tributaries over the Tertiary beds south until meeting the southwest-northeast trending ridge where it abruptly turns to the east. Eventually the Rio Blanco enters the karst at Oke’bal Ha Cave and exits as Blue Creek to the south at Hokeb Ha Cave (Miller 1996).

The coastal plain between the foothills and Caribbean Sea is made up primarily of Pleistocene fluvial sediments discharged from drainages originating in the Maya Mountains and associated foothills. North of Deep River the soils are rocky, heavily weathered and covered in open pine savannah. Aside from a few sites along rivers (Graham 1994), ancient Maya settlements on the savannah are unknown, presumably because the soils are poorly suited to maize agriculture. South of the Monkey River the pine savannah gives way to cohune palm (*Attalea cohune*) forest where many of the modern villages are located and are founded upon maize, citrus, rice and ground-crop cultivation. The earliest human occupations in this zone are poorly understood, but a fluted point found near the village of Big Falls on the Rio Grande suggests Paleoindian (~13,000 cal. BP) activity (Lohse et al. 2006; Weintraub 1994). Several Archaic Period projectile points (Lowe Points; 2500-1900 BC) have also been found in plowed fields between Big Falls and the village of Hiccatee to the north, but prehistoric settlement is generally limited to scattered evidence of small Classic period settlements.

Mangrove swamps and brackish lagoons that are largely inaccessible without watercraft characterize the coastal zone of southern Belize. Sea level rise and stabilization is implicated in the formation of extensive mangrove swamps during the middle Holocene, from 6000-3000 cal BC (McIntyre et al. 2004; Wooller et al. 2007). The earliest documented settlements date to the Early Classic (AD 300-600). These include the modest sites of Butterfly Wing (mouth of Deep River) and Wild Cane Cay that both suggest the exploitation of marine and estuarine resources and early maritime activities (Graham 1994; McKillop 1996, 2010). The Late Classic Period saw the rise of a salt production industry and maritime trade that persisted into the Postclassic (McKillop

1995, 1996, 2005a, 2005b, 2008, 2010). Remains of wooden salt processing stations, structures, weirs and a canoe paddle have been documented at several coastal sites that have been submerged and preserved by ~1m of relative sea level rise since the Late Classic. Obsidian artifacts from Guatemalan sources found at Wild Cane Cay also suggest that these coastal sites were engaged with overland trade networks likely facilitated by up-river canoe travel to the west as well as maritime connections with the north to the Belize River Valley and coastal Yucatán (McKillop 1989).

Monsoonal rains largely drive erosion and deposition on the coastal plain. Precipitation decreases from the coast (~4000 mm/yr) to the interior (2400 mm/yr) as elevation increases (Heyman and Kjerfve 1999). Annual rainfall in the area of Santa Cruz village, the location of Uxbenká, is estimated at ~2700-3400 mm/yr. The annual climate cycle of southern Belize is marked by distinct wet and dry seasons with relatively little seasonal variation in temperature through the year. The onset of wet conditions differs from year to year, but typically runs from June through September, when monthly rainfall ranges from 400-700 mm (Hartshorn et al. 1984; Heyman and Kjerfve 1999; Wright et al. 1959). A short (2-3 weeks) dry spell known as the “canicula” often occurs in August (Wright et al. 1959). The months of February through April are the driest months (averaging 40-70mm/mo), and this is the period in the traditional *milpa* cycle when forest is cleared for the wet season crops of maize, beans and other “ground foods” (Heyman and Kjerfve 1999; Wright et al. 1959). The hurricane season, as elsewhere in the tropics, occurs between August and October. Southern Belize is largely shielded from easterly winds by the highlands of northern Honduras so hurricanes rarely make landfall. Hurricane Iris in October 2002 was a devastating exception that left roughly 10,000 people homeless in Toledo District and destroyed that year's wet season milpa crops (Zarger 2002:xii-xiii).

Dissertation Fieldwork

Fieldwork for this dissertation was carried out at Uxbenká and the lands around Santa Cruz village over multiple field seasons from June 2006 to October 2010. The initial reconnaisance trip to Uxbenká in June 2006 was focused on identifying and recovering speleothems from Yok Balum Cave with Doug Kennett, Kevin Cannariato and Keith Prufer. I observed the possible terrace features in the Uxbenká at this time, and planned for a preliminary season of excavations in 2007. The 2007 season was broken up into a 3-week trip from February to March recovering sediment cores from around Toledo District, and a 5-week trip from May to June to conduct preliminary excavations on the presumptive terraces in the site core.

The 2008 field effort spanned 9 weeks from April to June where I made extensive geoarchaeological excavations in the site core area, and did geologic reconnaissance of the areas to the east of the the site core (i.e., settlement groups 25-28). The 2009 field season ran for 10 weeks from April to June, being split between additional geoarchaeological excavations in the site core and *Cochil Bul* area, water retention features to the east of the site core, and setting maize yield plots in the *milpas* around Santa Cruz. I returned for 3 weeks in September and October of the year to quantify the yields in those plots. I carried out settlement excavations at five settlement groups from April to June 2010, as well as establishing that seasons maize yield plots, which were revisited in October for 3 weeks to collect the final yield data.

Organization of the Dissertation

Chapter II describes integration of high-resolution AMS radiocarbon dates with stratigraphic information from selected archaeological sequences into a Bayesian framework to produce a new chronology of major construction events in the Uxbenká site core. The data are drawn from four seasons of investigations by members of the Uxbenká Archaeological Project directed by Dr. Keith M. Prufer (University of New Mexico) using contextual information produced by his team and radiocarbon samples processed at the University of Oregon Archaeometry Facility and measured at The Keck Carbon Cycle AMS Facility at UC Irvine. The calibration program OxCal was used to devise Bayesian models that allowed for events that are not directly dated – such as the initial clearing of a building site or the placement of a plaster floor – to be estimated based on its stratigraphic relationship to directly dated events in well-constrained sequences. It can also trim the calibrated ranges of directly dated events, which is advantageous within the reversals in the radiocarbon curve during the Classic Period (AD 300 – 900). Results of this analysis indicate earlier initial construction of three main architectural groups in the site core than previously supposed, with the main plaza established during the Late Preclassic Period (60 cal BC – cal AD 220), and continued remodeling and replastering of the groups into the Early Classic Period (cal AD 300-600). These results confirm Uxbenká as the earliest known Maya center in southern Belize (Prufer et al. 2011), and point to specific areas of the Late Classic Period chronology to be refined by further work at the site. This chapter, prepared as a co-authored work with Dr. Prufer and Dr. Douglas J. Kennett, is published in the *Journal of Archaeological Science*.

Chapter III presents the results of geoarchaeological work within the Uxbenká site core from the early Middle Preclassic Period (ca. 970 BC – 620 BC) through the Terminal Classic Period (AD 800-900). Paleosols indicate human activity, land clearance, and erosion consistent with swidden agriculture starting in the Middle Preclassic Period, and provide the earliest evidence of ceramics in southern Belize. The urban landscape during the Early and Late Classic periods (AD 300-800) was notably stable, possibly due to the relocation of *milpas* outside the city center. The absence of terraces in this hilly landscape suggests that swidden cultivation remained viable without these labor investments throughout the Classic Period. Increased erosion and landscape instability in the urban core during the Terminal Classic Period (AD 800-900) suggests that the area was largely abandoned in terms of permanent settlement by that time, and the land had reverted to swidden cultivation by a remnant farming population. This chapter was prepared as a co-authored work with Dr. Prufer and Dr. Kennett, and has been submitted to *Geoarchaeology: An Interdisciplinary Journal*.

Chapter IV describes the quantification of maize yields under swidden cultivation by the contemporary Maya farmers of Santa Cruz village, on whose lands the ruins of Uxbenká are located. Yield data were collected in 2009 and 2010 and compared to soil nutrient and landscape characteristics to identify areas of greatest desirability for household settlements around Uxbenká during its florescence. These data were then used to estimate the potential maximum population that could be sustained under different scenarios of overall productivity, fallow length, and level of intensification. Maximum population of Uxbenká during the Classic Period was estimated to range between 7500 and 13,000 people within the 6km radius that could have been under its political influence. This population is modeled at a five-year fallow period, on the verge of what would be a true short fallow system, and suggests a low level of agricultural intensification consistent with the lack of terracing and other similar features described in Chapter III. The estimate of household settlement density predicted here can be tested against future work in household, settlement and landscape archaeology at Uxbenká. This chapter was prepared as a co-authored work with Dr. Bruce Winterhalder (UC Davis), Claire Ebert (Penn State University), Dr. Prufer, and Dr. Kennett, and will be submitted to *Human Ecology*.

Chapter V presents the development and testing of a population ecology model of settlement expansion around Uxbenká based on the Ideal Free Distribution (IFD) and related Ideal Despotic Distribution (IDD). The locations of 22 known civic/ceremonial architectural groups and household settlement groups were ranked based on three measures of suitability: agricultural potential (using the maize yield data presented in Chapter IV), access to fresh water, and proximity to the site core. The prediction of the IFD model is that the highest ranked habitats should be settled first, and as population density increases, settlements will expand into less favorable habitats over time. Comparison of the existing archaeological chronology with settlement ranks shows a general conformity with the IFD, in that several of the earliest Late Preclassic settlements are found in high-ranked locations near the site core, and in the most agriculturally productive areas away from the site core. The location of a substantial and early civic-ceremonial group (Group I) confounds the predicted pattern and is found in a much lower-ranked habitat to the west of the Uxbenká's urban core than is predicted by the model. The presence of Group I in a marginal habitat early in the settlement history of

Uxbenká may be indicative of hierarchical conditions best described by the IDD and suggests competitive exclusion of the site core by a ruling elite. This suggests that status rivalry between competing elites played a significant role in the social geography and settlement history of the site as early as the Late Preclassic. The results of this analysis demonstrate the utility of formal IFD and IDD models to define ecological and social factors affecting population distributions in the ancient Maya Lowlands and to identify and explain instances of status competition more broadly in the archaeological record. This chapter was prepared as a co-authored work with Dr. Winterhalder, Ms. Ebert, Ethan Kalosky (University of New Mexico), Dr. Prufer, and Dr. Kennett, and will be submitted to *Journal of Anthropological Archaeology*.

Chapter VI summarizes the major findings of this dissertation and places them within a broader methodological and theoretical context.

CHAPTER II

A BAYESIAN AMS ^{14}C CHRONOLOGY OF THE CLASSIC MAYA CENTER OF UXBENKÁ, BELIZE

This work was published in volume 39 of the *Journal of Archaeological Science* in May 2012. Keith M. Prufer provided access to stratigraphic information and excavation profiles from the archaeological work at Uxbenká. I processed the radiocarbon samples, evaluated the existing chronometric database, and incorporated the chronological and stratigraphic information in a Bayesian framework for analysis and interpretation. Douglas J. Kennett provided guidance and original insights into the crhonological interpretations. I was the principle investigator for this work.

Archaeological research in the Maya region is heavily dependent upon ceramic typologies to estimate the age of sites. In parts of the Maya lowlands where these typologies are well-established (e.g., central Petén, Belize Valley) they are used to determine relative cultural sequences and sometimes rough estimates of absolute age (e.g., Culbert and Rice 1990; Demarest et al. 2004). Ultimately these age estimates are based on older uncalibrated ^{14}C dates and the large error margins of these older ^{14}C dates make some of the finer grained ceramic age estimates (sometimes shorter than 50 years) unrealistic. In the last two decades archaeologists have employed multiple complementary (or alternative) chronometric techniques to augment and refine ceramic-based chronologies in Mesoamerica, including archaeomagnetism (Wolfman 1990); obsidian hydration (Webster et al. 2004); epigraphy (LeCount et al. 2002), and AMS ^{14}C dating, to improve site chronologies and the age estimates of certain ceramic types

(Garber et al. 2004; Healy 2006; LeCount et al 2002; Moyes et al. 2009; Prufer et al. 2011; Rosenswig and Kennett 2008; Saturno et al. 2006; Webster et al. 2004). Several major analytical and statistical improvements in AMS ^{14}C dating and calibration now allow more precise chronological estimates that sometimes approach +/- 15-30 calibrated years under ideal circumstances (Kennett et al. 2011). Precise and accurate age determinations are necessary to compare cultural sequences against high-resolution historical, environmental and climatic datasets as archaeologists in the Maya region ask increasingly sophisticated and relevant historical, demographic and environmental questions (e.g., Beach et al. 2009, Braswell 2003; Demarest et al. 2004; Aimers and Hodell 2011; Turner 2010; Lentz and Hockaday 2009; Webster 2002). Identifying causal relationships between social and environmental effects in these records requires chronological precision capable of establishing the true order of those events, and ideally discerning whether events are actually contemporaneous (Marcus 2003:344-345).

In this chapter I build upon the growing number of AMS ^{14}C studies in the Maya region and the work of the Uxbenká Archaeological Project (Prufer et al. 2011) by employing a Bayesian chronological framework to generate a more precise chronology for the growth and contraction of this Classic Maya polity in southern Belize. The Bayesian analysis of radiocarbon dates from archaeological sites is becoming routine in Britain (Buck 2004; Bayliss and Bronk Ramsey 2004; Bayliss et al. 2007) and programs like OxCal (Bronk Ramsey 1995, 2001, 2005, 2009) provide a prepackaged set of Bayesian statistical tools to help develop finer-grained archaeological site chronologies. Having been the focus of an intensive high-precision radiocarbon dating program for several years (Prufer et al. 2011), the site provides a unique opportunity to apply a

Bayesian approach to a Lowland Maya site, and demonstrate the potential for broader applications in the Maya region and elsewhere in Mesoamerica. First I review of the regional archaeological chronology, and then give a basic overview of the Bayesian approach to incorporating archaeological observations with radiocarbon data using OxCal. These techniques are applied to a sample of the Uxbenká AMS radiocarbon database to investigate the tempo of development and decline at the site based on the available data.

The Setting of Uxbenká in the Maya Lowlands

While noting that regional chronologies differ in the timing of Lowland Maya culture-historical phases, the temporal units discussed in this chapter generally follow Demarest's (2004:13) chronological scheme (Table 2.1). Because of the relatively late development of ceramic technology in Belize, the Late Archaic is considered to extend until ca. 1000-800 BC in local or sub-regional contexts (see Lohse 2010).

Table 2.1. Lowland Maya chronological periods (after Demarest 2004:13 and Lohse 2010)

Period	Span
Late Archaic	3000 BC – 1000-800 BC
Middle Preclassic	1000-800 BC - 400 BC
Late Preclassic	400 BC - AD 300
Early Classic	AD 300 - AD 600
Late Classic	AD 600 - AD 800
Terminal Classic	AD 800 - AD 1000
Early Postclassic	AD 1000 - AD 1300
Late Postclassic	AD 1300 - AD 1519

When Uxbenká was first settled it was positioned in a geopolitically marginal region. Through time it found itself situated near trade routes connecting larger polities, including Tikal, Copán, and Caracol (see Figure 1.1). The temporal span considered in this chapter covers the latter portion of the Late Preclassic Period (ca. 100 BC - AD 300), through the Classic Period (AD 300-1000). The Late Preclassic witnessed both the development and disintegration of major political centers in the central Maya Lowlands, with massive expansion and political centralization occurring at Tikal and Calakmul corresponding with a decline of authority at the earlier power centers of Nakbe and El Mirador (Folan et al. 1995; Hansen 2006; Harrison 2006; also Martin and Grube 2008). The Early Classic in the Petén is characterized by the ascendancy of Tikal as a regional power, and the extension of its influence southward towards Copán around AD 426 (Sharer 2003: 322). Tikal's greater regional influence was possibly stimulated by increased interaction after AD 378 with the highly centralized and expansionistic state of Teotihuacan located in the central Mexican highlands (see Braswell 2003). This would have facilitated Tikal’s access to lucrative trade routes in the southern Petén and southeastern lowlands (Sharer 2003: 351).

Southern Belize is located in a geographic and cultural frontier of the Maya Lowlands. Like other Maya frontiers (Henderson 1992), it was both peripheral to, yet connected with the cultural and political developments occurring in larger and more economically and politically powerful centers (Schortman and Urban 1994). During southern Belize’s apogee between AD 400-900 its polities were involved in a variety of trade and exchange activities, focused on mineral and biotic resources (e.g., groundstone, cacao, clays for ceramics production; Abramiuk and Meurer 2006; Dunham 1996; Dunham and Prufer 1998; Graham 1987), agricultural production (Prufer 2005a), and marine resources that linked polities from the Petén to the Caribbean Sea (Hammond 1978; McKillop 2005a, 2005b).

Until recently most regional settlement chronologies relied on architectural features (e.g., ballcourts), epigraphic data, and to a lesser extent comparison of ceramics with other regions of the Maya Lowlands (e.g. Dunham 1996; Hammond 1975; Leventhal 1990, 1992). In general, these studies indicate that the number of polities and density of settlements were highest during the Late Classic. To the north of Uxbenká, in the Stann Creek District, Graham (1994) found evidence of pre-AD 600 settlements along the coastal plain, though much of that region's settlement history is Late and Terminal Classic. Sites such as Pomona, Mayflower, and Kendal are located along rivers seasonally navigable by canoe, and have been suggested to be interconnected nodes along river systems (Graham 1994: 320). Coastal sites may have been organized as subsistence bases that engaged in procurement of marine and estuarine resources (Graham 1994: 316) or, in some cases, also mediated maritime trade networks (McKillop 2005a, 2005b). Among the earliest sites in southern Belize is the coastal shell midden of Butterfly Wing at the mouth of Deep River, which is thought to date to the Late Preclassic based on sherds of mammiform tetrapod vessel supports and outflaring wall dishes (McKillop 1996:57, 2010:96). The presence of obsidian and other exotic goods identifies it as a trading port, and links it with other Late Preclassic sites at Cancun, Cerros and Moho Cay. Radiocarbon dates from Early Classic settlements on Wild Cane Cay indicate maritime communities established by AD 300, though mercantile seafaring was largely a post-AD 500 phenomenon that persisted into the Postclassic (McKillop 2005a, 2005b, 2006).

The early communities closest to Uxbenká were in the southeastern Petén (Guatemala), positioned along the western foothills of the Maya Mountains. Most of these settlements postdate AD 600, though there were Preclassic occupations at Sacul, Ixkun, Xutilha, and Ixtonton in the Dolores area (Laporte 1994, 2001; Laporte and Ramos 1998). Throughout the watersheds that drain the western Maya Mountains of Guatemala, including the Rios Machaquila, San Luis, and Pusilhá, there is evidence of continuity between the Preclassic and Early Classic in what Laporte (2001:17) called the "Peripheral Chicanel" sphere, defined by the continuation of Preclassic ceramic types well into the Early Classic period. Laporte suggested a geopolitical landscape of competing rural elites autonomous from the larger central Petén polities from AD 100 to AD 600 (Laporte 1996a, 1996b; Laporte and Ramos 1998). The southeastern Petén, like southern Belize, witnessed greater population centralization during the Late and Terminal Classic periods, and evidence for Early Classic occupations is spotty (Brady 1989: 207; Laporte 2001).

The only other Preclassic or Early Classic complex polity known in the region is Ek Xux, located in the interior of the eastern Maya Mountains along the Bladen Branch of the Monkey River (Dunham and Prufer 1998). Nine sites with public architecture are known from survey in the eastern flank of the Maya Mountains, but excavation data only exist for Ek Xux and Muklebal Tzul, both located in adjacent valleys near the headwaters of the Bladen Branch. Ceramic evidence suggests Ek Xux was settled during the Late Preclassic and persisted as a relatively small community through the sixth century AD. Muklebal Tzul, located on a series of high ridges 3 km to the west of Ek Xux, appeared rather suddenly on the landscape after AD 600 and quickly eclipsed its small neighbor (Prufer 2005a).

With the exception of Uxbenká and Ek Xux, southern Belize apparently hosted few population centers through most of the Early Classic, until the region rapidly grew to include at least 10 monument bearing polities and over 100 smaller communities after ca. AD 550. The best known of these are Lubaantun, Pusilhá, and Nim Li Punit. Hammond (1975:52) conducted excavations at Lubaantun and, based primarily on ceramics, suggested that the site was founded between AD 679 and AD 783 (i.e., Maya calendar date 9.15.0.0.0 +/- 1 katun). He also noted that the ceramic assemblage was dominated by Tepeu 2/3 Petén styles of the Late Classic (maximally AD 700-890). Hammond argued for links between southern Belize and sites in the Pasión River area of the western Petén (1975: 295), which are supported by more recent studies at other Late Classic centers (Braswell et al. 2005; Prufer 2005a; McKillop 2006). Lubaantun lacks epigraphic history from monuments, though three carved ballcourt markers have been stylistically dated to the Late Classic (Wanyerka 2004). Pusilhá was excavated by a British Museum expedition (Joyce 1929; Joyce et al. 1927), Hammond (1975:274), Leventhal (1990, 1992) and Braswell (Bill and Braswell 2005; Braswell et al. 2004). Hieroglyphic texts suggest that the polity may have formed as late as AD 570 and persisted at least through AD 790. Excavations in core and domestic contexts support this chronology (Braswell and Prufer 2009: 48), though small amounts of Early Classic materials have been recovered from cave sites in the vicinity. Ceramic data suggest a Late Classic affiliation closely aligned with Tepeu sphere polities in the Petén, particularly in the Pasión and Petexbatun areas (Bill and Braswell 2005). Nim Li Punit is the least studied polity in the region. It is located on a 100 m high ridge overlooking the coastal plain (Hammond et al. 1999). Most of the published chronological material on Nim Li Punit comes from 25 carved monuments found in the elite plazas of this highly consolidated center. These have been interpreted to suggest the site was occupied only during the Late Classic, with stelae erected between AD 711 and AD 830 bracketing a short dynastic history for the polity, but the possibility of earlier and later non-dynastic site use must be kept open. The Nim Li Punit inscriptions are described as both “unique and idiosyncratic” (Grube et al. 1999: 36) with examples of reverse order readings, inverted calendar signs, and evidence that the placement and carving of the monuments may be temporally separated events. Epigraphers have also suggested that the people of Nim Li Punit regularly interacted with occupants of sites to the southeast, based largely on the presence of a possible toponym glyph for Copán (Wanyerka 2009: 465).

Artifacts and monuments indicate ties between southern Belize and the central Petén from AD 370-500, probably via trade routes through the southeastern Petén (Prufer 2005a). Epigraphic accounts of ties developing after AD 500 between southern Belize and sites located in the southeast periphery have been proposed, e.g., with Copán and Quirigua (Braswell et al. 2005; Grube et al. 1999; Marcus 1993; Wanyerka 2009: 440-477) or Altun Ha (Wanyerka 2009: 473). Archaeological evidence to corroborate these relationships remains to be found. By the 9th century AD there is little archaeological evidence of any substantial inland Postclassic occupation, though the difficult work of identifying and recovering these contexts in southern Belize has barely begun. The persistence of maritime trade into the Postclassic Period at coastal sites suggests the potential for a continued, if politically diminished, presence in the inland areas of southern Belize.

Methods

Radiocarbon Sampling and Measurement

In a region with few absolute dates from archaeological contexts, the AMS radiocarbon dating program allows the UAP to develop an independent chronology of the growth and contraction of Uxbenká as a political center. Charcoal and other organic samples from well-documented stratigraphic contexts (see below) were prepared along with standards and backgrounds at the University of Oregon Archaeometry Facility and the University of California Irvine Keck Carbon Cycle AMS Facility (UCI KCCAMS) following standard practices as previously described by Prufer et al. (2011:Note 1). Samples for dating were collected during excavations directly from discrete features (e.g., hearths, burn features), plaster floors, or from within construction fill. These were taken “at the trowel’s edge”, not recovered from screened sediments. Where possible a single piece of wood or charcoal was selected to avoid the averaging inherent in bulk samples, and pieces likely to be shorter-lived (e.g., twigs) were chosen to reduce any old wood effect (Schiffer 1986; Kennett et al. 2002). All dates are reported in Table 2.2 as conventional radiocarbon ages corrected for fractionation with measured $\delta^{13}C$ according to Stuiver and Polach (1977). Calendar ages discussed in the text are 2-sigma calibrated ranges (95.4% probability; for clarity, discontinuous ranges are simplified in the text). Calibrations were produced using OxCal 3.01 (Bronk Ramsey 1995, 2001, 2009), employing the IntCal09 atmospheric curve (Reimer et al. 2009). Calibrated dates are discussed in terms of ‘cal AD’ or ‘cal BC’ as distinct from dates derived from epigraphic and seriational methods.

Table 2.2. AMS ^{14}C dates from Uxbenká used in Bayesian modeling

Sequence/ Phase	UCIAMS- #	Provenience	Conventional ^{14}C age (BP)	2-σ cal range (prior)
Group A West A1 Sub Op 08-4				
	56360	Structure A1. Buried Structure Fill, 198cmbd.	1840±15	AD 120-230
	56359	Structure A1. Level 5, 169cmbd.	1780±15	AD 140-200 (3.8%) AD 210-330 (91.6%)
	56367	Structure A1. Level 4, 108cmbd Fea. 1.	1635±15	AD 350-370 (1.2%) AD 380-440 (88.3%) AD 480 530 (5.9%)
	56368	Structure A1. Level 4, 120cmbd Fea. 2.	1585±15	AD 420-540
Group A A6 SubOp 07-3 & Plaza Plaster SubOp 07-5				
	46297	Structure A6. Level 5, 367cmbd. First fill.	1755±25	AD 220-390
	42807	Structure A6. Level 5, 292 cmbd. Second fill.	1720±15	AD 250-390
	42805	Structure A6. Level 5, 224 cmbd. Second fill.	1700±15	AD 250-300 (18.8%) AD 320-410 (76.6%)
	42809	Structure A1. Level 5, in plaza plaster floor.	1490±15	AD 540-610
	46298	Structure A1. Level 5, in plaza plaster floor.	1585±25	AD 410-540
Group B SubOp 08-7 Unit 2				
	56361	Unit 2. Level 6 Construction Fill, 204 cmbd	1755±15	AD 235-340
	56371	Unit 2. Level 6 Construction Fill, 143 cmbd	1735±15	AD 240-380
	56370	Unit 2. Level 5 Construction Fill, 139 cmbd	1730±15	AD 250-390
	56369	Unit 2. Level 5 Construction Fill, 121 cmbd	1760±15	AD 230-340
	57044	Unit 2. Level 3. On Level 4 Floor, 95 cmbd	1745±15	AD 230-350
Group B Other				
	56362	Structure B2 SubOp 08-9. Base of wall.	1770±15	AD 210-340
	56365	Structure B14 SubOp 08-10. Level 5A. 191 cmbd.	1725±15	AD 250-390
	56364	Structure B1 SubOp 08-8. Base of staircase.	1315±15	AD 650-710 (78.3%) AD 740-770 (17.1%)
Group D Late Preclassic/Early Classic Phase				
	67955	SubOp 9-15 Unit 2. Level 3 Box Lu'um blw plaster. 136cmbd	1830±15	AD 130-240
	67238	SubOp 9-14 Unit 1. Level 7. 4th Floor Fill. 192cmbd	1775±20	AD 140-200 (4.6%) AD 210-340 (90.8%)
	67961	SubOp 9-14 Unit 1. Level 7. 3rd Floor Fill. 169cmbd	1750±20	AD 230-350 (94.3%) AD 360-380 (1.1%)
	67960	SubOp 9-14 Unit 1. Level 6. 2nd Floor Fill. 153cmbd	1800±20	AD 130-260 (90.8%) AD 300-320 (4.6%)
	67959	SubOp 9-14 Unit 1. Buried Structure Fill. 158 cmbd	1710±15	AD 250- 300 (30.7%) AD 310- 400 (64.7%)
	67239	SubOp 9-13 Structure 5. Level 4. 95 cmbd	1695±20	AD 250-300 (17.3%) AD 320-410 (78.1%)
Group D Late Classic Phase				
	67957	SubOp 9-14 Level 3 Box Lu'um. 105cmbd	1345±15	AD 650-685
	67958	SubOp 9-14 Level 3 Box Lu'um. 80cmbd	1465±15	AD 565-640
	67965	SubOp 9-13 Structure 5. Level 3 63 cmbd	1225±15	AD 710-750 (16.8%) AD 760-880 (78.6%)

The architectural stratigraphy at Uxbenká is complex because most structures have several construction phases and remodeling episodes, and a range of natural and cultural site formation processes (see Schiffer 1987) have and continue to affect the deposits. In some cases older materials may have been reused for the construction of later structures. Interpretation is further complicated by post-depositional alterations at Uxbenká, and most Lowland Maya sites, due to erosion, bioturbation by burrowing animals and tree-throws, modern landuse and looting. Rosenswig (2009) provides a cogent treatment of the often under-appreciated complexities involved in structural stratigraphy in Mesoamerica, particularly at Classic Period sites where (arguably) more focus is placed on the "glamour" of elaborate architecture than on the quotidian aspects of formation processes (Rosenswig 2009:2, amplifying Shott 2006:4). Despite devoting effort to careful excavation and stratigraphic correlation between observed architectural elements, cross-referencing multiple individual radiocarbon sequences through common features such as plaster floors is often difficult. Stratigraphic information recorded during excavations in the 2006 to 2009 field seasons were used to select the sample of radiocarbon dates that are incorporated into the Bayesian analysis of Groups A (the Stela Plaza), B and D (Figure 2.1A). Emphasis was placed on excavation units exhibiting clear natural and architectural stratigraphy, including plaster floors, masonry construction, and multiple construction episodes.

The Bayesian Framework

Classical statistical analysis has dominated archaeological inquiry and is well suited to a wide range of observations made by archaeologists (Drennan 2010; Shennan 1997; Thomas 1986). In contrast to classical statistics, Bayesian statistical analysis derives posterior information (*a posteriori*) by combining prior information (*a priori*), a likelihood function (a particular probability function) and the available data (Buck and Millard 2004: p. VII). The best examples in archaeology come from chronology building where a variety of non-quantitative contextual information (e.g., stratigraphic position,

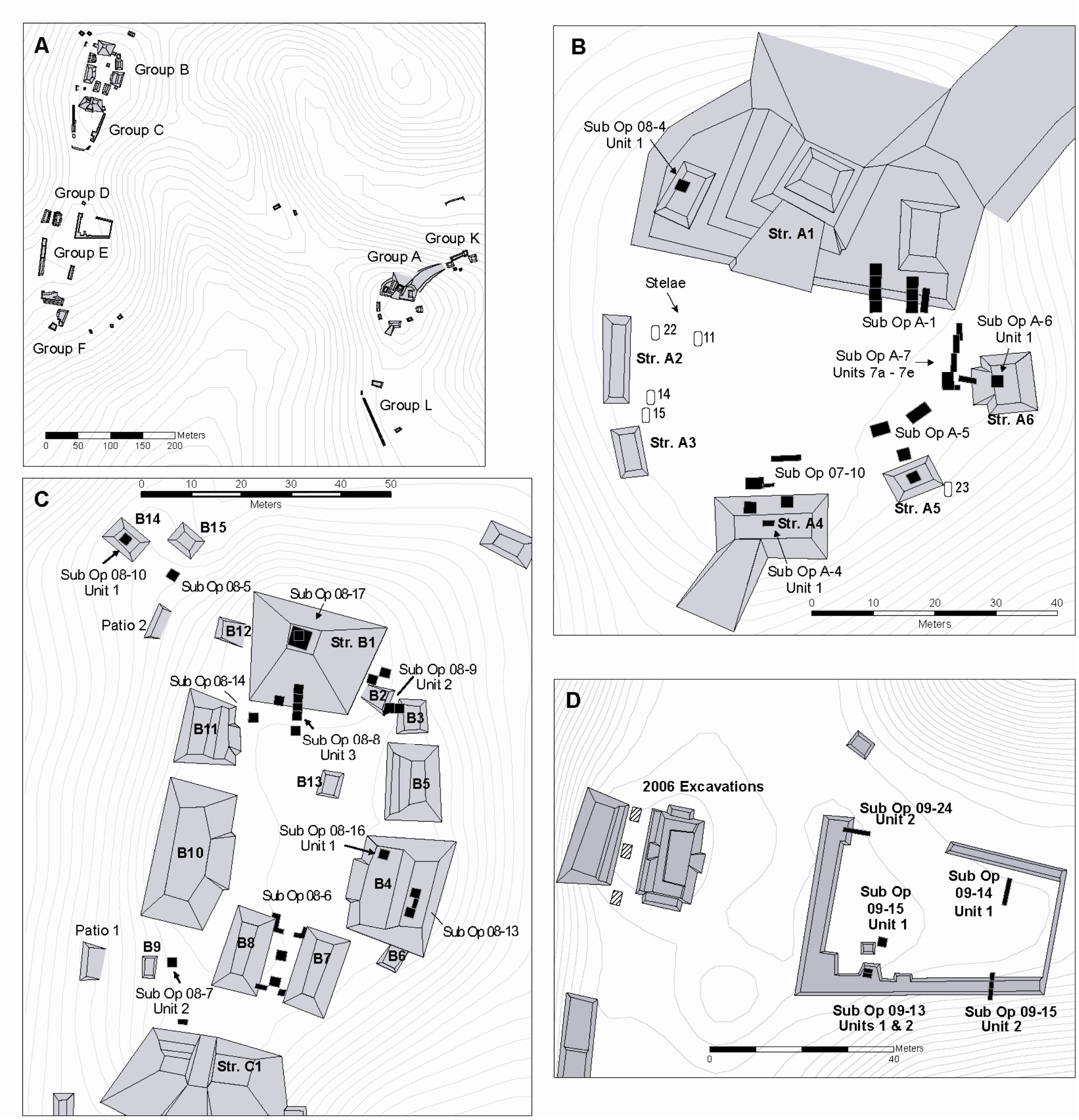


Figure 2.1. Detail maps showing excavations at: A) the Uxbenká site core; B) Group A (Stela Plaza); C) Group B; and D) Group D (original figures by C. Ebert).

diagnostic artifact assemblages) can be integrated with probability distributions from radiocarbon dates (Bayliss and Bronk Ramsey 2004; see below).

The major benefits of a Bayesian approach are that a statistical environment is created that incorporates a wider range of information about stratigraphy and archaeological materials, and that the results of these models can be used to direct research and make sampling decisions. Using *a priori* information can make some researchers uneasy (see Steier and Rom 2000), but by forcing the assumptions of the priors to be made explicit it provides a framework to formalize assumptions and to build and test multiple models with new data. Agreement indices (*A*) provide a way of determining how each alternative model fits with the available data, and are generated for the posterior distributions of each radiocarbon date in a model, as well as the overall model itself (Bronk Ramsey 2000: 201). Agreement indices falling below a critical value (*A'c* = 60%) indicate a poor fit of data with the model, and can be used to identify potential outlier dates or problematic stratigraphic assumptions in the model. It should be noted that, strictly speaking, when *A*>*A'c* (i.e., there is agreement between the model structure and the dates) it *does not* mean that the model assumptions and structure *are correct*: it simply tells us that we have no reason based on the data at hand to reject the model as it stands.

A list of OxCal commands and the relevant archaeological phenomena that are commonly encountered during excavation are presented in Table 2.3. The reader is referred to the OxCal's supporting documentation for detailed considerations of analysis and command structures, as well as other published archaeological case studies in Britain (Bayliss et al. 1999, 2007 [and articles therein]), the Mediterranean (Bronk Ramsey et al. 2010; Manning et al. 2006), and Mexico (Kennett et al. 2011).

Table 2.3. Examples of OxCal commands and relevant stratigraphic situations

OxCal Command	Stratigraphic Situation
Phase (Unordered Group)	Multiple dates within a fill. Multiple features on a living surface occupied for some duration Groups of dates separated by a common stratigraphic marker e.g., a floor, a sterile sediment layer, tephra, or distinctive ceramic assemblages.
Sequence (Ordered Group)	Dates separated by a series of plaster floors. Dates on materials in well stratified middens. Series of phases
Boundaries	Events that bracket the beginning and end of a phase but are not directly dated, e.g., excavation of a burial or storage pit; clearing or leveling a site before construction; cessation of construction; partial demolition of a structure.
Event	An undated event not necessarily related to a *phase*, thus differing from *boundary* in that it could be within a *sequence*.
Cross-reference	When a common stratigraphic marker can be correlated between two or more *sequences*, e.g., a layer of pavers, a floor, a tephra, or a burning event, can be traced between sequence with otherwise unconnected profiles.
Span	Calculates the span of time represented by the elements of a phase, e.g., how long a living surface was used before being covered over or replastered.

A sample of 28 AMS radiocarbon dates from the 2006 through 2009 field seasons was included in this analysis. Radiocarbon data for samples from Groups A and B have been reported and discussed in Prufer et al. (2011); dates and stratigraphic information for Group D are drawn from the Uxbenká Archaeological Project technical report on the 2009 excavation season (Ebert et al. 2010).

Results

Group A (Stela Plaza)

Group A, also known as the Stela Plaza, is a plaza group set on a hilltop in the eastern part of the Uxbenká site core containing six known structures and 23 recorded stelae (Figure 2.1B). Leventhal worked at Group A in the late 1980s, recording and describing the stelae and conducting excavations in the plaza itself. Dates preserved on six of the monuments indicate monument production and dedication occurred during the Early and Late Classic periods (AD 378 to AD 781; Table 2.4), with the dates of AD 378 stylistically attributed to Stela 11 and a calendar round date in AD 455 on Stela 23 making these the earliest datable monuments in southern Belize.

Table 2.4. Stela dates from Group A, Uxbenká

Monument	Long Count Date	Gregorian Date	Comments
Stela 11	-	AD 378	After the reign of *Chak Tok Ich'aak I*; Schele and Looper (1996) suggest AD 437 for this stela
Stela 23	09.01.00.00.00	AD 455	Period ending date derived from a calendar round date (Prufer and Wanyerka 2005)
Stela 14	09.12.00.00.00	AD 672-692	Partial inscription, inferred 12th katun
Stela 19	09.12.11.13.11	AD 684	
Stela 22	09.16.00.00.00	AD 751	Period ending date
Stela 15	09.17.10.00.00	AD 781	Period ending date

The Uxbenká Archaeological Project team excavated several structures in the Stela Plaza, including A1 (the largest construction in the group), A4, A5 and A6. Multiple test trenches were also excavated across the plaza floor between 2006 and 2010. Results of these investigations suggest that the hilltop was leveled in the latest part of the Late Preclassic, with some of the earliest construction fills below structure A1 dating to cal AD 120-230 (UCIAMS-56360). Evidence of walls and other structural features in direct contact with the mudstone bedrock (known as *nib* in the local Mopan Maya) under A1 and in front of A6 indicates that sections of the plaza must have been completely excavated to bedrock before major construction of Group A took place (Prufer et al. 2011). A date on charcoal below the A6 wall is also consistent with a Late Preclassic clearing event (cal AD 130-330; UCIAMS-33400).

Excavations along the margin of A1 (specifically SubOps 07-5 and 08-4) reveal multiple phases of construction and remodeling related to periodic reorganization of the plaza for ceremonial or political purposes (Prufer et al. 2011). After the initial Late Preclassic clearing event, it appears that a much smaller structure was put in place under what is now the west flank of Structure A1. A portion of one of the walls of this structure was uncovered at ~180 cm below the surface of A1 in SubOp 08-4 Unit 1, measuring roughly 1 m high and made of 10-12 courses of the local sandstone slabs typically used to build these structures (Figure 2.2). The Late Preclassic ^{14}C date noted above (UCIAMS-56360) was recovered from construction fill within this buried structure. The early structure was built over a layer of crushed *nib* fill directly above bedrock. In contrast to the rest of the known architecture in the Stela Plaza, which is oriented roughly along (or just east of) the cardinal axes, the wall exposed in Unit 1 is oriented at 53°/233°mN. A fill deposit consisting of sediment and loose sandstone slabs covers the buried structure and contains one Late Preclassic/Early Classic charcoal date of cal AD 140-330 (UCIAMS-56359). Two burn events occur on top of this fill deposit and suggest a persistent surface dating later in the Early Classic (Feature 1: UCIAMS-56367, cal AD 350-530; Feature 2: UCIAMS-56368, cal AD 420-540). Roughly 1 m of subsequent construction fill overlies these features and presumably represents renewed building on Structure A1 at or after the end of the Early Classic.

A 6m-long profile exposed from the Stela Plaza floor into the eastern side of Structure A1 in SubOp 07-5 shows the stratigraphic relationship of the plaza construction to the later additions to the building (Figure 2.3). Excavation into the eastern flank of Structure A1 (on a flat platform similar to the one where SubOp 08-4 was placed) cut through a mixed layer of overburden and sandstone blocks and two layers of crushed bedrock fill before revealing a burn feature dating to the Late Preclassic Period (UCIAMS-42825; cal AD 70-220) and a charcoal sample from a deeper deposit of dark soil and burned ceramics dating to the Early Classic (UCIAMS-42808; cal AD 250-390)

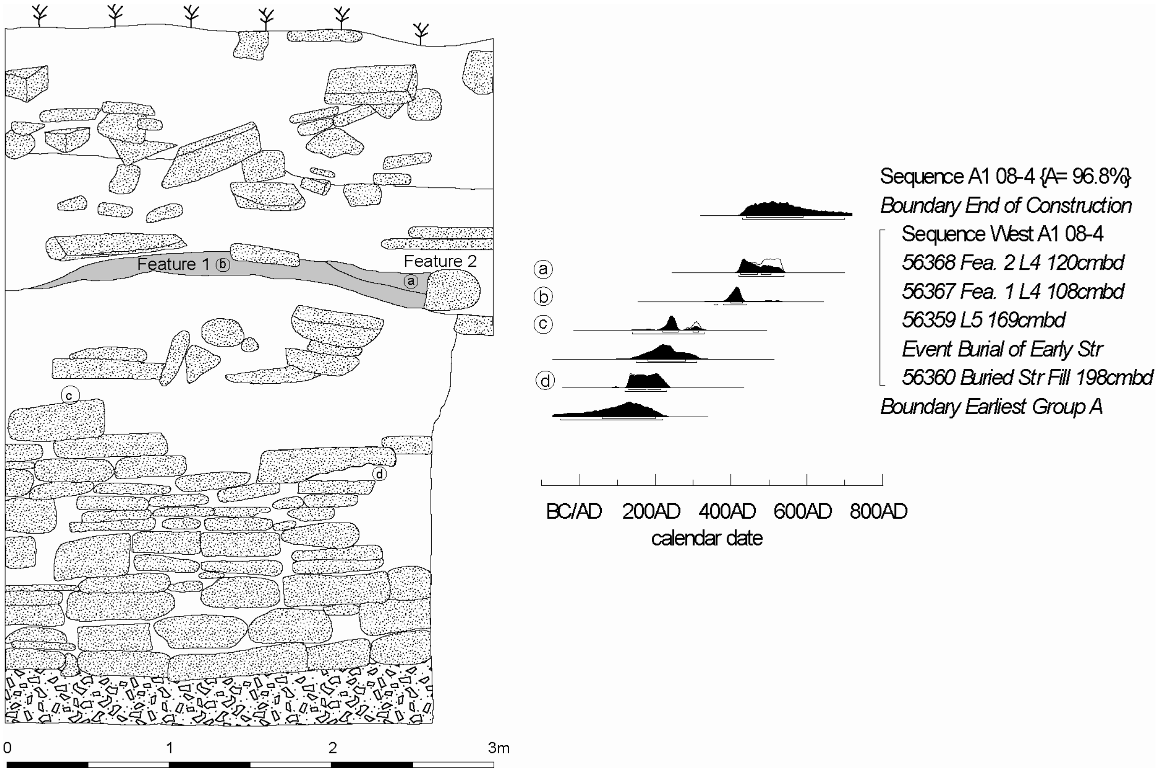


Figure 2.2. Profile of Unit 1, SubOp 08-4 on Str. A1 showing location of AMS ^{14}C samples and modeled calibrations.

overlying the *nib* bedrock. The inconsistency between the dates could be due to disturbance related to later construction, or an old wood effect in the charcoal from Feature 1. Assuming that the lower deposit is accurately dated, this indicates a surface that had originally been exposed in the beginning of the Early Classic Period and was subsequently buried by construction of the later facade of Str. A1. The stepped facade of Str. A1 is exposed in the same profile, where collapse debris was removed to reveal the remaining intact south face of the building. This wall was built directly on the *nib* bedrock, indicating that any overlying soil in what would become the plaza floor was removed before this time. As described by Prufer et al. (2011) the depths where bedrock is encountered differ by ~1.5 m on Structure A1 and the plaza floor suggesting a sharp discontinuity behind the facade. This could be due to a natural joint in the bedrock, as has

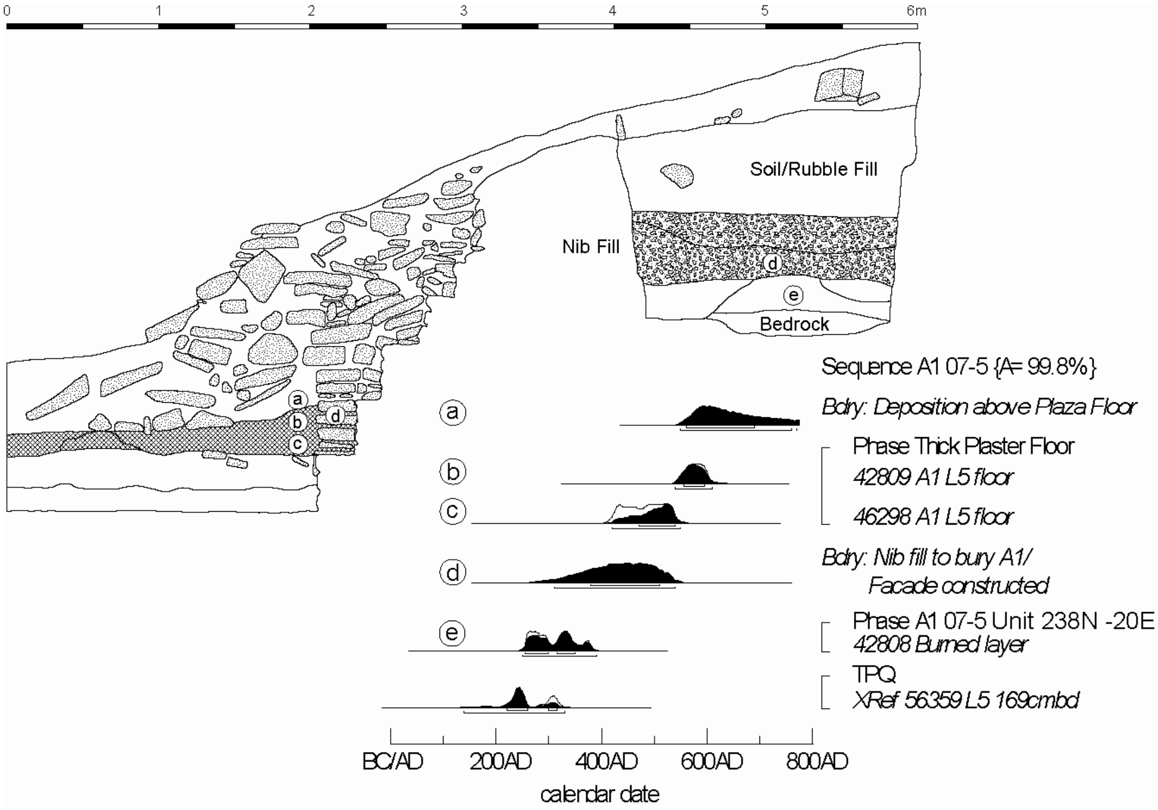


Figure 2.3. Profile of SubOp 07-5 on Str. A1 showing location of AMS ^{14}C samples and modeled calibrations.

been observed in geomorphic excavations and stream channels in the Uxbenká site core and elsewhere, or a purposeful modification of the bedrock by the ancient occupants to take advantage of an existing hilltop feature to create a more imposing ceremonial structure. Regardless, clearing down to bedrock, erecting the facade, and burying the earlier architecture was a key event in the development of the Stela Plaza, whose date can be constrained by a thick plaster floor in the plaza that abuts and therefore post-dates the facade. Two dates were obtained from charcoal recovered from within the plaster floor, which likely represent material incorporated during the plaza’s construction and use during the latest part of the Early Classic (UCIAMS-46298: cal AD 410-540; UCIAMS-42809: cal AD 540-610).

A third series of dates relates to the smaller structure A6 on the east side of the Stela Plaza excavated in 2006 (SubOp 06-7) and 2007 (SubOp 07-3). SubOp 06-7 was conducted off the structure and revealed a stone wall in front of Str. A6 that is inferred, based on its location and alignment, to be part of an earlier construction that may have been leveled or simply buried during the construction of A6. The wall sits directly on bedrock, and a date on charcoal from beneath the wall straddles the Late Preclassic/Early Classic transition (UCIAMS-33400; cal AD 130-330). Str. A6 itself appears to have been constructed in at least three phases as indicated by a series of fill layers capped by plaster floors (Figure 2.4). Three AMS dates on charcoal put these construction events in the Early Classic, with the earliest layer, which sits upon bedrock, dating to cal AD 220-390 (UCIAMS-46297). Two dates from the second fill layer fall into a similar timeframe (UCIAMS-42807: cal AD 250-390; UCIAMS-42805: cal AD 250-410).

Each of the profiles in these excavations can be modeled as a separate *sequence*. This allows for timing of events that are not directly dated to be estimated, such as clearing the plaza to bedrock or constructing a facade. For SubOp 08-4, the sequence begins with a *boundary*, the earliest use of the hilltop, followed by the construction of the early structure under Structure A1, the burial of that structure (an *event*), followed by the creation of the two burned features, and ending with the final *boundary*, the end of construction of Str. A1. In SubOp 07-5, the sequence begins with a *terminus post quem*, which is a *cross-reference* to the date in SubOp 08-4 on the fill above the buried structure, UCIAMS-56395, since it is assumed that all of the construction exposed on the east side of Str. A1 post-dates the earlier construction. This is followed by the use of the burned ceramic layer within Str. A1. The Late Preclassic date on Feature 1 (UCIAMS-

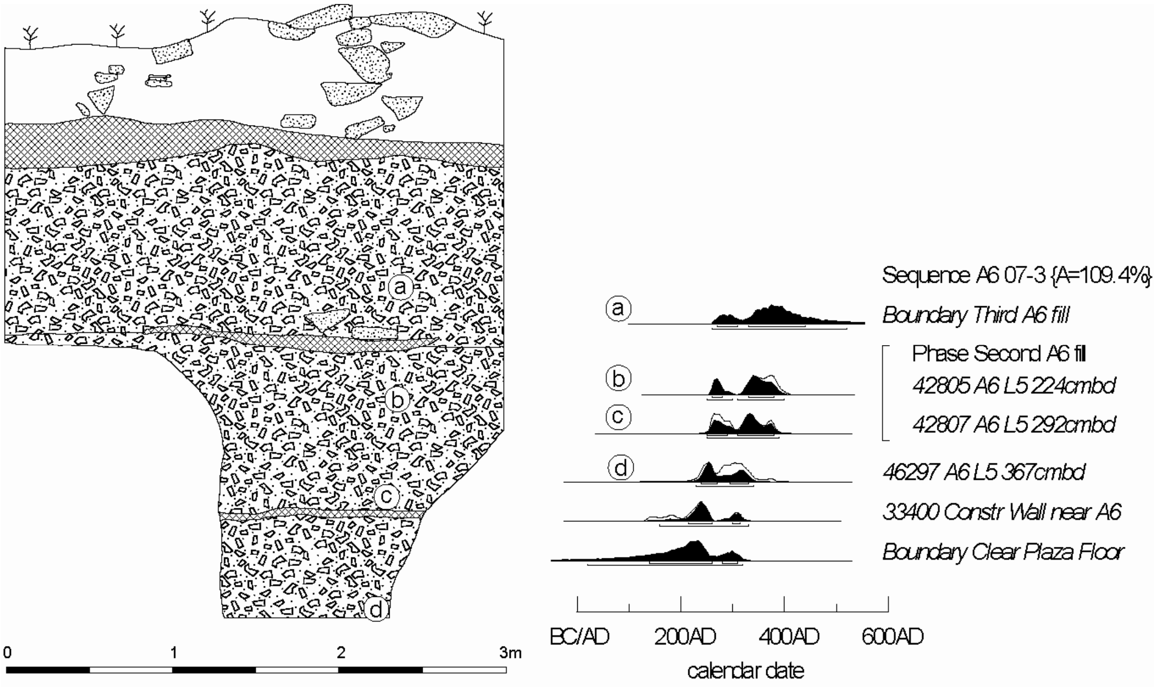


Figure 2.4. Profile of SubOp 07-3 on Str. A6 showing location of AMS ^{14}C samples and modeled calibrations

42825), as mentioned above, is problematic when included even as part of an unordered group (a *phase*) with the later date on the deeper ceramic layer. Models that include this date produce very low agreement indices and so it is excluded from this sequence. A *boundary* representing the placement of *nib* fill and the construction of the Str. A1 facade follows, and the two dates from within the thick plaster floor in front of A1 are modeled as a *phase* followed by a final *boundary* that represents subsequent deposition above that floor. The sequence for Str. A6 cannot be stratigraphically linked to those in A1 based on current knowledge. It begins with a *boundary*, the clearing of that section of the plaza down to bedrock, then the construction of the wall in front of Str. A6, the placement of the first fill in A6, followed by a *phase* comprising the two dates in the second fill event, and ending with a *boundary* representing the placement of the third fill layer. Modeled results for these sequences are presented in Table 2.5.

Table 2.5. Modeled results for three Group A stratigraphic sequences

Sequence	UCIAMS-#	Provenience	Conventional ^{14}C age (BP)	Modeled 2-σ cal range
West A1 08-4				
	Boundary	*Earliest Group A*		*50 BC - AD 220*
	56360	Str. A1. SubOp 08-4. Buried Structure Fill, 198cmbd.	1840±15	AD 120-230
	Event	*Burial of Early Structure*		*AD 150-310*
	56359	Str. A1. SubOp 08-4. Level 5, 169cmbd.	1780±15	AD 220-330
	56367	Str. A1. SubOp 08-4. Level 4, 108cmbd Fea. 1.	1635±15	AD 355-440
	56368	Str. A1. SubOp 08-4. Level 4, 120cmbd Fea. 2.	1585±15	AD 420-540
	Boundary	*End of Early Classic Construction*		*AD 430-700*
East A1 SubOp 07-5				
	TPQ	*UCIAMS-56359 (cross-referenced)*		
	42808	Str. A1. SubOp 07-5. 238N/-20E. L.7, burned layer.	1725±15	AD 250-390
	Boundary	*Placement of Nib Fill/Construction of Facade*		*AD 310-540*
	46298	Str. A1 .SubOp 07-5. 236N/-20E. L.5, in plaster floor.	1585±25	AD 420-550
	42809	Str. A1. SubOp 07-5. 236N/-20E. L.5, in plaster floor.	1490±15	AD 540-610
	Boundary	*Deposition Above Plaza Plaster Floor*		*AD 550-770*
Str. A6 SubOps 06-7 & 07-3				
	Boundary	*Clearing to Bedrock*		*AD 20-320*
	33400	West of Str. A6. SubOp 06-7. Level 4, beneath wall.	1790±25	AD 160-330
	46297	Str. A6. SubOp 07-3. Level 5, 367cmbd. First fill.	1755±25	AD 230-340
	42807	Str. A6. SubOp 07-3. Level 5, 292 cmbd. Second fill.	1720±15	AD 250-390
	42805	Str. A6. SubOp 07-3. Level 5, 224 cmbd. Second fill.	1700±15	AD 250-400
	Boundary	*Placement of Third Fill*		*AD 260-520*

Group B

Group B was first identified by Hammond (1975:289-290) and later excavated by Leventhal (1992:145) who designated it as the North Group. It consists of an enclosed plaza on a hilltop at the northern end of a 400m-long modified ridge to the west of Group A. The main structures include a temple (Str. B1), a ballcourt (Str. B6 and B7) and three patio structures (Str. B3, B5, and B11; Figure 2.1C). The UAP excavations that provide the data for this analysis were conducted in 2008. Excavations of the front stairway of Str. B1 (Op 08-8) produced a Late Classic ceramic assemblage consistent with elite ritual use, including numerous unslipped modeled effigy censer fragments, Petén Gloss Wares and other polychrome ceramics. A single AMS date from under a slumped step produced an age range of cal AD 650-710 (78.3%) and AD 740-770 (17.1%) (UCIAMS-56364). An Early Classic component at Group B is evident in the excavations in the main plaza and a smaller bench to the west side of Str. B1, all buried by later construction. Units placed between Strs. B2 and B3 (Subop 08-9) uncovered a section of a 1.6 m high masonry wall buried below the visible structures, and not showing any clear connection to the later architecture in terms of layout or organization. A single radiocarbon sample from the base of the wall dated to cal AD 210-340 (UCIAMS-56362), which is consistent with Early Classic construction in the Stela Plaza. A charcoal date from a buried midden-like fill stratum in Str. B14 also falls into the Early Classic at cal AD 250-390 (UCIAMS-56365).

The episodic nature of Early Classic construction in Group B is revealed in excavations in front of Str. B9, a low platform on the southwestern edge of the plaza (SubOp 08-7). Three construction episodes are marked by plaster floors and structural elements exposed in Unit 2 (Figure 2.5). A series of large cut limestone and sandstone blocks were found lying on the *nib* bedrock in the basal deposits of this unit (2 mbs). These blocks were probably put into place to level and extend the southwest edge of the plaza after clearing the space down to bedrock. A fill layer containing ceramic sherds and river snail (jute; *Pachychilus* sp.) shells overlies the bedrock and abuts the block construction, and is capped by a thin plaster floor. Two charcoal samples from this stratum date to cal AD 235-340 (UCIAMS-56361) and cal AD 240-380 (UCIAMS-56371). What appears to be collapsed rubble from a constructed wall overlies this floor and is covered by another layer of fill and a second plaster floor. Two charcoal samples from this fill date to cal AD 230-340 (UCIAMS-56369) and cal AD 250-390 (UCIAMS-56370). Finally, a third fill and plaster floor is exposed immediately below the modern

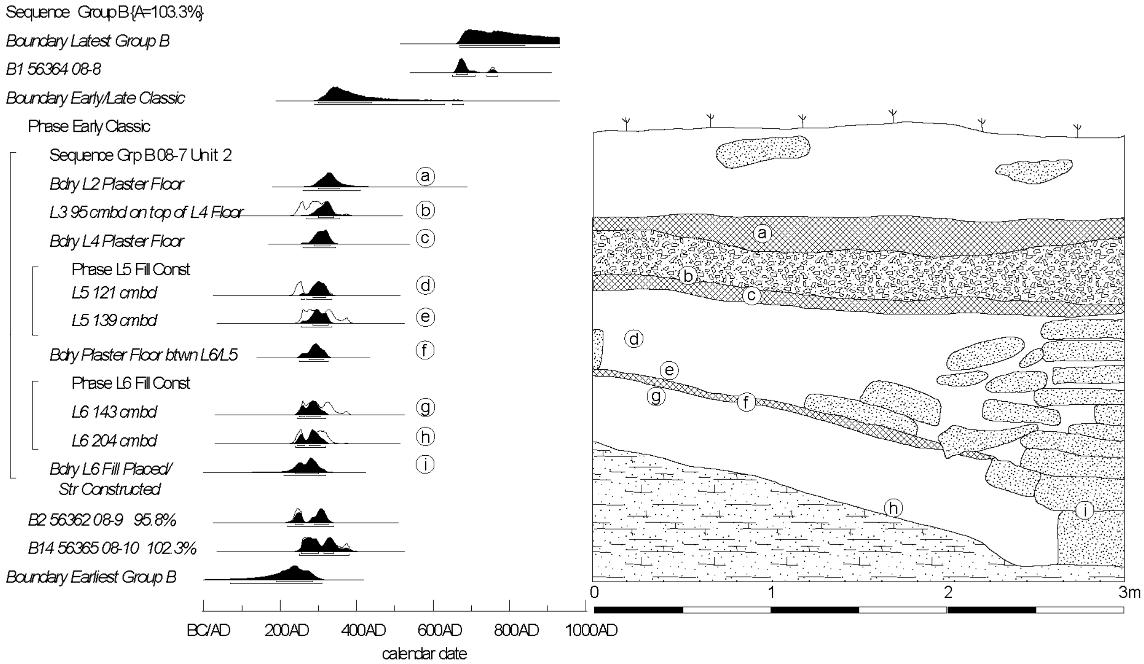


Figure 2.5. Profile of Unit 2, SubOp 08-7 in Group B showing location of AMS ^{14}C samples and modeled calibrations

surface (A horizon) of the plaza floor. Charcoal recovered from directly on top of the plaster floor also dates to the Early Classic at cal AD 230-350 (UCIAMS-57044).

With the exception of the five dates within Unit 2, SubOp 08-7, the stratigraphic relationships of the Group B AMS ^{14}C dates are difficult to establish with certainty. This is primarily because the individual suboperations are widely separated across (and off of) the plaza. However, to make use of all the existing data I incorporate them all into a broad *sequence*, with the Late Preclassic/Early Classic dates organized as a *phase*, followed by the single Late Classic date from the slumped step in front of Str. B1. Three *boundaries* are established within this sequence: the earliest construction and clearing activities on Group B; the transition between Early and Late Classic construction activities (e.g., the Str. B1 staircase and presumably the ballcourt); and the latest construction activities in the Late Classic. Within the Late Preclassic/Early Classic phase, the SubOp 08-7 dates are placed in a *sequence* beginning with a *boundary* representing the construction of the wall, followed by two *phases* containing the pairs of dates from the L6 and L5 fills, and the final date on charcoal above the upper most floor. These are separated by boundaries representing the construction and use of the three floors in the sequence. As noted the two dates from between Strs. B2 and B3 and from Str. B14 are included with this sequence in an unordered *phase*. Modeled results for the sequence are presented in Table 2.6.

Table 2.6. Modeled results for the Group B stratigraphic sequence

Sequence/ Phase	**UCIAMS-#**	**Provenience**	**Conventional ^{14}C age (BP)**	**Modeled 2-σ cal range**
	Boundary	*Earliest Group B*		*AD 60-310*
Grp B 08-7 Unit 2				
	Boundary	*First Wall Constructed*		*AD 210-320*
	56361	Level 6 Construction Fill, 204 cmbd	1755±15	AD 240-320
	56371	Level 6 Construction Fill, 143 cmbd	1735±15	AD 245-320
	Boundary	*Plaster Floor between L5/L6*		*AD 250-325*
	Difference	*First Wall constructed - Floor between L5/L6*		*-5-75 cal yr*
	56370	Level 5 Construction Fill, 139 cmbd	1730±15	AD 255-335
	56369	Level 5 Construction Fill, 121 cmbd	1760±15	AD 250-335
	Boundary	*Level 4 Plaster Floor*		*AD 260-345*
	Difference	*Floor between L5/L6 – L4 Floor*		*-5-50 cal yr*
	57044	Level 3. On Level 4 Floor, 95 cmbd	1745±15	AD 270-335
	Boundary	*Level 2 Plaster Floor*		*AD 270-420*
	Difference	*L4 Floor – L2 Floor*		*-5-95 cal yr*
Grp B Early Classic				
	56362	Between Str. B2-B3 SubOp 08-9. Base of wall.	1770±15	AD 230-340
	56365	Str. B14 SubOp 08-10. Level 5A. 191 cmbd.	1725±15	AD 250-380
	Boundary	*Transition between Early and Late Classic Construction*		*AD 290-670*
Grp B Late Classic				
	56364	Str. B1 SubOp 08-8. Base of staircase.	1315±15	AD 650-770
	Boundary	*Latest Group B*		*AD 650-930*

Three instances of the *difference* command are also included in the model to estimate the duration between construction events in the Unit 2 sequence (the first construction and the subsequent placement of plaster floors). The maximum 2σ ranges for these estimates vary from 50 to 95 cal years, but the distributions are skewed towards larger values, so the intervals between construction events may be much shorter, perhaps every 15-25 years. Weighted means for these probability distributions suggest: ~23 years passed between the construction of the wall and the placement of the plaster floor between L5 and L6; ~16 years elapsed before the placement of the L4 floor; and the L2 floor was laid down ~27 years after that.

The wide estimated range for the *boundary* between the Early and Late Classic construction phases (cal AD 290-670) is due to the lack of dates falling in the later part of the Early Classic. It seems unlikely that there was no construction or modification of Group B architecture during this period. However, it may simply reflect the areas excavated and sampled during the 2008 excavations. The result indicates a chronological issue to be addressed by ongoing strategic excavations at Group B.

Group D

Group D is located on the same long ridge as Group B and is immediately south of Group C, which is contiguous with both (Figure 2.1D). Group D is conspicuously flat as the result of leveling during Uxbenká's construction. Primary structures include a ball court that was subject to limited investigations in 2006 (Prufer et al. 2007) and a raised open plaza surrounded by low (30-40 cm tall) walls and a few small platforms that were excavated in 2009 (Ebert et al. 2010). This open plaza occupies roughly two-thirds of a finger ridge that extends off the main landform to the east. Excavations revealed a series of construction episodes and provided the sample of radiocarbon dates analyzed here.

Two 6x1 m stratigraphic trenches (SubOps 09-12 and 09-15) in Group D cut through multiple fill and plaster layers within the plaza and indicated the broad outline of construction events, while other excavations focused on Structure 5 (SubOp 09-13) and the area immediately in front of the structure (SubOp 09-14). The generalized stratigraphic sequence for the Group D plaza suggests that after initial clearing of the ridgeline a fill of crushed *nib* bedrock was laid down to level the surface and then plastered. A charcoal date recovered from within this *nib* fill in SubOp 09-15 Unit 2 (UCIAMS-67955) dates this event at the end of the Late Preclassic at cal AD 130-240. Multiple fill and plastering episodes covered this initial building phase. Three plaster floors were identified in Unit 2 and four were identified in SubOp 09-14 Unit 1 across the plaza (Figure 2.6). Considering the differing number of floors in each unit and the distance between them it is not possible to directly correlate these plastering events. Multiple charcoal samples recovered from the Unit 1 floor fills promised to generate a very detailed construction chronology for the plaza, but despite the apparently well-stratified exposure, several reversals occur. Working from the stratigraphy, it appears that at some point after the plaza was established, a now-buried structure was constructed in the Early Classic. A single AMS ^{14}C date from fill within this structure dates to cal AD 250-400 (UCIAMS-67959). Two plaster floors abutting this were constructed subsequently and finally the entire structure was buried and plastered over completely. Dates within these floor fills are problematic, though they all fall in the Early Classic. In stratigraphic order the three fills date to cal AD 140-340 (UCIAMS-67238), cal AD 230-380 (UCIAMS-67961), cal AD 130-260 (90.8%) and cal AD 300-320 (4.6%; UCIAMS-67960). The three floors make a reasonable *sequence* on their own, but including the structure fill date before them results in a very low agreement index (*A*=55.4%). In the present case there is no clear justification for rejecting any one of these dates, though bioturbation, old charcoal incorporated in the fill, and other processes are likely at work. For the purposes of this analysis the dates were grouped as an unordered *phase*

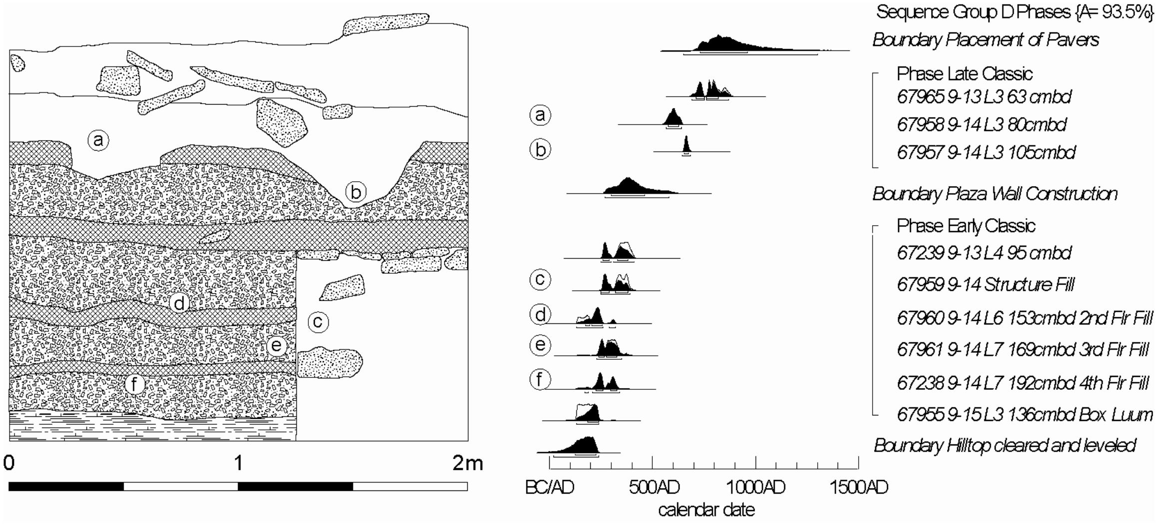


Figure 2.6. Profile of Unit 1, SubOp 09-14 in the Group D plaza showing locations of AMS ^{14}C samples and modeled calibrations

representing Early Classic construction. Above the highest plaster floor in the unit is a distinctive stratum of dark midden-like soil containing ceramic sherds and capped by a layer of sandstone slabs, presumably paving stones. Two charcoal dates from within this fill fall securely in the Late Classic (UCIAMS-67958: cal AD 565-640; UCIAMS-67957: cal AD 650-685), suggesting a renewal of construction on the plaza at this time.

The wall surrounding the plaza was exposed in SubOp 09-15 Unit 2 and runs into Structure 5, which was excavated as part of SubOp 09-13. As it sits directly above the plaster floors in Unit 2, it is inferred that after the series of Early Classic plastering events, the low wall (60-80 cm high) was built around the plaza perimeter. Two dates from 09-13 help to bracket the date of construction: cal AD 140-340 (UCIAMS-67239) from Level 4 below the Structure 5 masonry; and cal AD 710-880 (UCIAMS-67965) in the fill of the structure itself. The construction of the plaza wall can be used as a *boundary* between two unordered *phases*. The Early Classic phase includes the AMS ^{14}C dates from the floor fills in SupOps 09-14 and 09-15, plus the Level 4 date from 09-

13.The Late Classic *phase* comprises the two dates on the paver fill from SubOp 09-14 and the structure fill date from 09-13. Two further events can be included as *boundaries* in the overall Group D *sequence*: the placement of the pavers, and the subsequent deposition of the surface scatters. Modeled results for Group D are presented in Table 2.7.

Table 2.7. Modeled results for the Group D stratigraphic sequence

Sequence/ Phase	**UCIAMS-#**	**Provenience**	**Conventional ^{14}C age (BP)**	**Modeled 2-σ cal range**
	Boundary	*Hilltop Cleared and Leveled*		*AD 20-240*
Grp D Early Classic Phase				
	67955	Grp. D. SubOp 9-15 Unit 2. Level 3 Box Lu'um blw plaster. 136cmbd	1830±15	AD 130-240
	67238	Grp. D. SubOp 9-14 Unit 1. Level 7. 4th Floor Fill. 192cmbd	1775±20	AD 170-340
	67961	Grp. D. SubOp 9-14 Unit 1. Level 7. 3rd Floor Fill. 169cmbd	1750±20	AD 230-350
	67960	Grp. D. SubOp 9-14 Unit 1. Level 6. 2nd Floor Fill. 153cmbd	1800±20	AD 130-320
	67959	Grp. D. SubOp 9-14 Unit 1. Buried Structure Fill. 158 cmbd	1710±15	AD 250-390
	67239	Grp. D. SubOp 9-13 Structure 5. Level 4. 95 cmbd	1695±20	AD 250-410
	Boundary	*Plaza Wall Construction*		*AD 270-580*
Grp D Late Classic Phase				
	67957	Grp. D. SubOp 9-14 Level 3 Box Lu'um. 105cmbd	1345±15	AD 645-685
	67958	Grp. D. SubOp 9-14 Level 3 Box Lu'um. 80cmbd	1465±15	AD 565-640
	67965	Grp. D. SubOp 9-13 Structure 5. Level 3 63 cmbd	1225±15	AD 690-870
	Boundary	*Pavers Placed*		*AD 650-1300*
	Boundary	*Surface Scatters Deposited*		*AD 700-present*

Though not well constrained, the model suggests that initial clearing and leveling occurred at the end of the Late Preclassic at cal AD 20-240. A series of plastering episodes and the construction of the buried structure in SubOp 09-14 followed, possibly straddling the Preclassic/Classic transition and continuing into the Early Classic. The construction of the plaza wall is unfortunately poorly constrained to cal AD 270-580, but this range does place the event squarely in the Early Classic rather than the Late Classic. The placement of the areally extensive paver layer is broadly estimated at cal AD 650-1300 (with a 1σ range of cal AD 730-960), and the surface scatters must have been deposited some time thereafter. The terminal ages of both the upper boundaries are poorly constrained by this model, which would benefit from additional research. For example, if diagnostic ceramics in the surface scatters indicated a distinctly Late Classic component, a *terminus ante quem* could be added to the model at the assumed date of the end of the Late Classic (i.e., at AD 800, following Demarest 2004). This points to a direction for future chronological work at Uxbenká.

Discussion

Integration of the stratigraphic data with the existing high-resolution AMS ^{14}C dates from the urban core of Uxbenká provides strong evidence for its organization as a sociopolitical entity during the Late Preclassic, with further bursts of architectural modification at the beginning of the Early Classic and Late Classic periods respectively (Figure 2.7). Initial clearing and leveling of the ridgeline hilltops that make up the civic-ceremonial core began at Group A (the Stela Plaza) at cal 50 BC-AD 220, followed by Group D at cal AD 20-240, and Group B only slightly later at cal AD 60-310. Accretion of multiple plaster floors in each plaza group occurred across the transition from the Late Preclassic to the Early Classic from ~ AD 200-400, a practice that appears to have ended by cal AD 400 at Groups B and D. The only remodeling or construction evident in the latter part of the Early Classic Period (between cal AD 400-550) appears to be the addition of the facade construction on Structure A1 in the Stela Plaza that is estimated to have been placed at cal AD 310-540. Estimates of the latest episode of construction at each group are poorly constrained and provide little insight into the timing of the ultimate demise of Uxbenká. Excavations targeting potential Late Classic and Terminal Classic

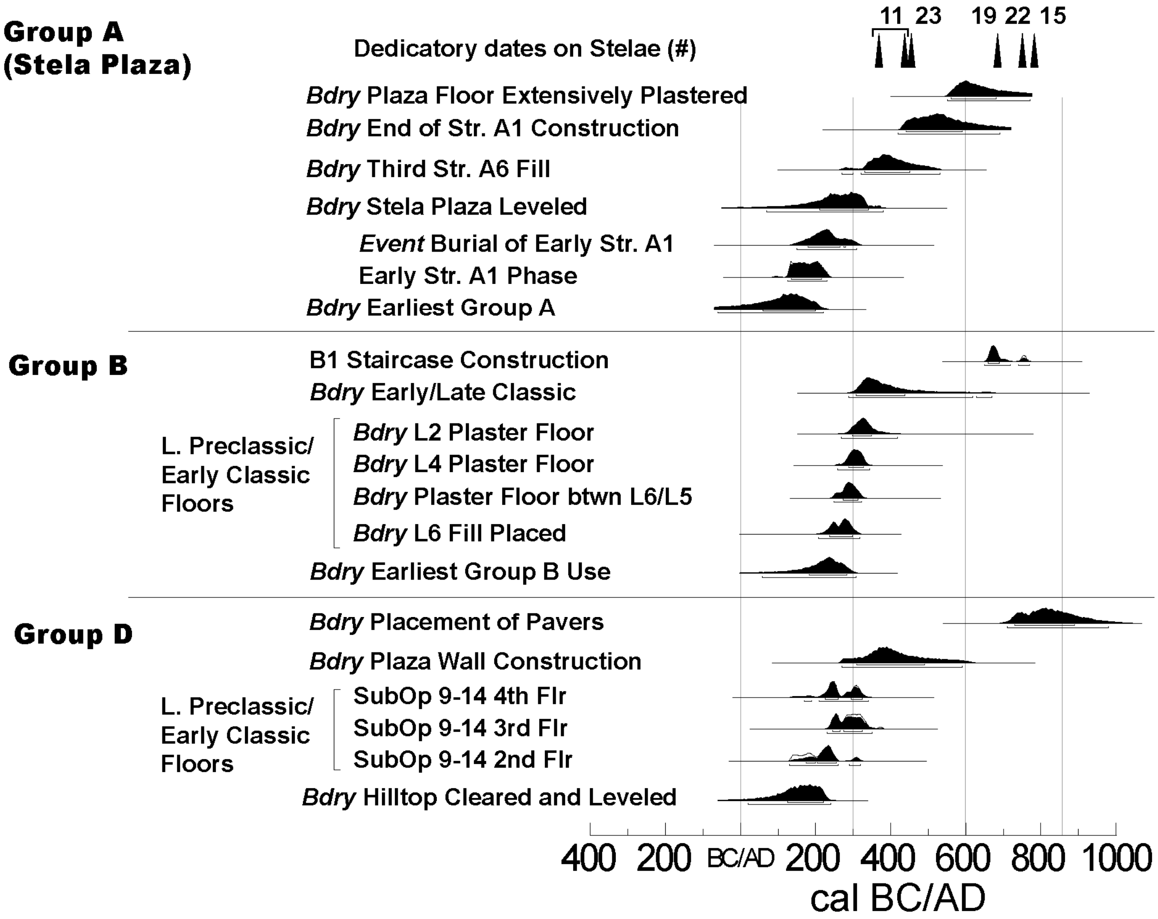


Figure 2.7. Summary of modeled calibrations for key construction episodes at Groups A, B and D.

contexts at Groups A and B are ongoing and may provide more concrete data to refine these sequences. The clearest Late Classic event at Group A is the major plastering episode of the plaza floor in front of Str.A1, estimated between cal AD 550-770. Dedicatory dates on stela from Group A indicate monument carving had begun by the Early Classic (St. 11, ca. AD 378; St. 23; AD 455) and continued into the Late Classic after the last major plastering episode in the Stela Plaza (St. 22, AD 751; St.15, AD 781), after which there is no secure radiocarbon evidence for use of the area.

The flurry of construction and replastering during the Late Preclassic and Early Classic periods at Uxbenká is striking because it precedes the earliest dated monuments in Group A by as much as 200-300 years. Similar bursts of remodeling and construction activities are seen elsewhere in the Late Preclassic among the Lowland Maya. At San Estevan in northern Belize, Rosenswig and Kennett (2008) describe a series of Late Preclassic plastering episodes that cap Middle Preclassic midden layers and define what would become the site center in the Late Preclassic. A direct AMS ^{14}C date on charcoal dates the later floor to cal 50 BC - AD 40 (UCIAMS-17903), which places the construction of the first ballcourt at San Estevan in the Late Preclassic Chicanel ceramic phase. Around the same time in the New River valley, multiple construction and plastering episodes occurred through the Late Preclassic at Cuello (Hammond 1991; Hammond and Gerhardt 1990), and monumental construction began at Lamanai (Pendergast 1981) and Cerros (Scarborough 1983; Freidel 1986). The end of the Late Preclassic (~AD 250-300) also witnessed the abandonment of El Mirador and Nakbe in the northern Petén with the possibility of increased warfare and inter-polity conflict in that region and highlights the localized factors affecting political development and disintegration (Hansen 1998, 2006).

This analysis pushes the political integration of Uxbenká slightly earlier than previously estimated by Prufer et al. (2011:218), and further removes the timing of the initial large-scale landscape modifications from the potential Tikal connection inferred from the mention of Chak Tok Ich’aak I on Stela 23 (AD 360-378). By that time, it appears that the early major construction activities had ceased, though both Early Classic stelae (11 and 23) at Group A do fall into the period when the outer plaza wall at Group

D was constructed, i.e., broadly estimated at cal AD 270-590. It is possible that the remodeling at Group D had more to do with the site reorganization at the time of the emergence of monument dedications at Uxbenká than do the earlier clearing and leveling episodes. Since the perimeter wall along with the fills it contains obscure the earlier features of that plaza, they may represent an effort to renew or rededicate that portion of the site towards a new purpose, as Prufer et al. (2011) have argued for a buried Late Preclassic settlement mound between Groups A and B.

I have been able to model construction episodes at Group A and B that fall into the first part of the Late Classic. The extensive plastering episode at the Stela Plaza occurred at cal AD 550-770, and the staircase construction and dedication on Structure B1 is estimated at cal AD 650-770. The events at Groups A and B represent substantial inputs of time and labor, and in the case of the staircase on Structure B1, great ceremonial import. Not only do these estimated dates for these events coincide with the Late Classic stela (ca. AD 672-781) at Uxbenká, they occur as the other major polities in southern Belize appear (Lubaantun, and Nim Li Punit) or expand (Pusilhá). The presence of Tepeu 2/3 ceramics associated with this florescence also suggests more interaction with the Petén during the Late Classic. Given that context, it is possible that the Late Classic renovations at Groups A and B, presumably the respective ceremonial and civic centers of the Uxbenká urban core, may have been an effort by local leaders to renew or reinforce their position within a landscape of increasing sociopolitical complexity and interaction regionally.

The stela dates suggest a point of caution in interpreting the results of this analysis. Fewer construction episodes in the urban core during the later part of the Early

Classic and Late Classic Periods do not necessarily reflect a hiatus in the occupation and use of Uxbenká during these periods. This analysis focuses primarily on architectural events because of the stratigraphic constraints they provide for Bayesian modeling, so more mundane or ritual activities that occurred between remodeling episodes are underrepresented. Further, the latest occupations at any archaeological site are stratigraphically shallowest and often the most disturbed deposits, which will preclude them from this type of analysis (see Webster et al. 2004 for an in-depth treatment of this problem at Copán). Most importantly in this regard, the present focus on the site core is at the expense of the broader settlement history away from the urban core. In the case of Copán, elite residences in the Copán pocket and more rural zones persisted for at least a century after the Late Classic dynastic collapse (~AD 810) and some rural farming populations persisted until sometime in the 11th century AD (Webster and Freter 1990; Webster et al. 2004). So at Uxbenká the few construction events known during the later part of the Early Classic (i.e., ca. AD 400-600) may not be representative of a "hiatus" at the polity on the larger scale, but merely a shift in focus to other residential communities outside of the site core. Work underway at Uxbenká in elite residential groups near the urban core and others in more rural agricultural settlements should provide an interesting test of these ideas.

The attempt to integrate a large number of high-resolution AMS ^{14}C dates with stratigraphic information within a Bayesian framework at Uxbenká provides a model for applying this approach to other stratigraphically complex Mesoamerican sites. The demands on the quality of archaeological information and the dated contexts are quite high, and the proper interpretation of stratigraphic associations is crucial. Using a

Bayesian dating approach forces consideration of excavation strategy and sampling techniques before excavations begin, and ideally to use insights gained in one season as *a priori* data to guide excavations and ^{14}C sample collection in subsequent seasons. In the case of Uxbenká, there is now a better understanding of its early construction history. The use of OxCal to estimate events that are not directly datable has pushed the establishment of this polity back earlier than previously thought (Prufer et al. 2011). On the other hand, the poorly constrained events within the Late Classic and Terminal Classic construction sequences have crystallized numerous issues involved in dating those periods that are key to understanding the processes of political disintegration in the tropical Maya lowlands. Using this current knowledge, it is possible to take strategic aim at the parts of the site most likely to contain the more elusive later construction phases in an efficient and focused manner.

Conclusions

The Bayesian chronology developed here provides new insights into the developmental history of Uxbenká's urban core and provides a statistical framework for future chronological refinement. The earliest leveling and clearing at Group A (the Stela Plaza) began during the Late Preclassic at cal 50 BC – AD 220, roughly 100-200 years earlier than previously thought (Prufer et al. 2011). This was followed by similar landscape modifications at Group D (cal AD 20-240) and Group B (cal AD 60-310) and a period of multiple plastering and remodeling episodes in both plazas. The leveling and construction during the Late Preclassic and the Early Classic that established the nascent urban core of Uxbenká preceded all evidence for dated stone monuments at the site, as the earliest known stela was dedicated in AD 378. Based on the available evidence there is relatively little construction in the site core that dates after the Early Classic Period from ca. AD 400-600. However, the Group A plaza was substantially replastered in the Late Classic at cal AD 550-770 along with the construction and dedication of a staircase in Group B (Structure B1; cal AD 650-770). These events coincide with the dedication of stela at Uxbenká and the appearance or expansion of other regional polities (e.g., Pusilhá, Lubaantun, Nim Li Punit) that is possibly tied to increased interaction with the Petén region. Secure Terminal Classic contexts have been difficult to identify, but remain a focus of ongoing investigations at Uxbenká.

CHAPTER III

CHANGING AGRICULTURAL AND URBAN LANDSCAPES AT THE CLASSIC MAYA CENTER OF UXBENKÁ, BELIZE

The work presented in this chapter was developed as an unpublished co-authored manuscript with Dr. Keith M. Prufer and Dr. Douglas J. Kennett. I conducted the geoarchaeological excavations at Uxbenká, recorded the stratigraphy, processed the radiocarbon samples reported here, and analyzed the data. Fieldwork was conducted under the supervision of Dr. Prufer. Dr. Kennett provided useful suggestions on the integration of climate and geomorphic records, and valuable interpretations of the possible land use strategies at Uxbenká.

Contemporary problems of deforestation and erosion have become synonymous with the expansion of nation-states, global population increases, and intensified agricultural production. This has stimulated archaeologists to consider landscape transformation and the environmental impacts of agricultural systems (Barker 2008; Bellwood 2005; Diamond and Bellwood 2003; Kennett and Winterhalder 2006; Smith 2007) and their expansion associated with the proliferation of state level societies during the last 6000 years (Dunning et al. 2002; Kolata 1986; O’Hara et al. 1993; Redman 1992, 1999; Zeder 1991). Virtually all models of sociopolitical development and collapse consider landscape transformation and associated decreases in yields, agricultural or otherwise, as one mechanism stimulating societal change (e.g., Kennett et al. 2011; Kohler and van der Leeuw 2007; Winterhalder et al. 2010). The growth of urban centers also presents a complex ecological problem (Grimm et al. 2000; Zeder 1991); both reducing agricultural activity in the urban core and expanding it in the periphery. The degree that landscapes are altered is an empirical question heavily dependent upon local context, including geological substrate, vegetation cover, and topographic controls on hydrology and geomorphic processes. The sensitivity of landscapes to changing anthropogenic and environmental conditions can only be determined through applied geoarchaeological work.

Anthropogenic alteration of the landscape has featured prominently in models of the emergence, persistence and transformation of ancient Maya sociopolitical and economic systems (Demarest et al. 2004; Demarest 2006; Webster 2002) and empirical evidence indicates that deforestation and erosion occurred in several parts of the tropical Maya lowlands starting as early as the Late Preclassic Period (Anselmetti et al. 2007; Beach 1998; Beach et al. 2006; Brenner et al. 2002; Curtis et al. 1996, 1998; Dunning et al. 2002; Islebe et al. 1996; Mueller et al. 2010). Paleoclimatologists have also identified intervals of greater or lesser rainfall during the Late Holocene that would have altered vegetation cover and promoted erosion (Haug et al. 2001, 2003; Hodell et al. 1995, 2001, 2005; Mueller et al. 2009; Stahle et al. 2011; Webster et al. 2007). Complex land use histories in the Maya Lowlands described in the last two decades have shown that the ancient Maya adapted to local conditions of soil fertility, seasonal drought, and social organization to produce multiple land use strategies, and that generalizations about Maya agricultural practices often fail at inter-regional scales (Beach et al. 2006, 2008; Dunning et al. 2002; Fedick 1996a; Fedick and Ford 1990). Therefore, explaining the emergence and disintegration of individual Maya polities requires site-specific geoarchaeological records integrated with cultural histories and climate records.

In this chapter I explore landscape changes before, during and after the formation of the Classic Period Maya center of Uxbenká. The cultural chronology framing this discussion draws from Demarest (2004:13) but is modified to follow the Late Archaic and Middle Preclassic Period divisions proposed by Lohse et al. (2006; see Table 2.1) The urban core of Uxbenká consists of six plaza groups that were carved from ridgelines in this hilly landscape (Figure 3.1). Group A contains the remnants of 23 carved sandstone stela dating to the Early and Late Classic periods and is presumed to be the main ceremonial locus at the site (Prufer et al. 2011). Groups B-F are a contiguous arrangement of plazas running along a ridgeline roughly 400m to the northwest of Group A. The Group B plaza is a flattened hilltop and is surrounded by a series of range structures and a large platform mound at its northern extent. A ballcourt dominates the southern extent of the plaza. A second ballcourt is evident in the Group D plaza. Construction in Uxbenká's urban core began in the Late Preclassic, with the earliest known structure in Group A dating to 60 cal BC - cal AD 220 (Culleton et al. 2012). The massive effort of leveling and expanding ridgelines to form the Group B and D plazas occurred slightly later, but still at the end of the Late Preclassic at cal AD 60-310 and cal AD 20-240, respectively. There was a flurry of replastering and plaza renovation activity until the first part of the Early Classic Period, and then less evidence for building activity between cal AD 350-550. Architectural modifications are documented at Groups A, B, and D after AD 550, including extensive plastering of plaza floors, laying paving stones, and the augmentation of facades on existing structures. The latest dedicatory date preserved on stelae at Group A indicatesthat monument carving continued until AD 781. Political disintegration and the abandonment of this city in the Terminal Classic are

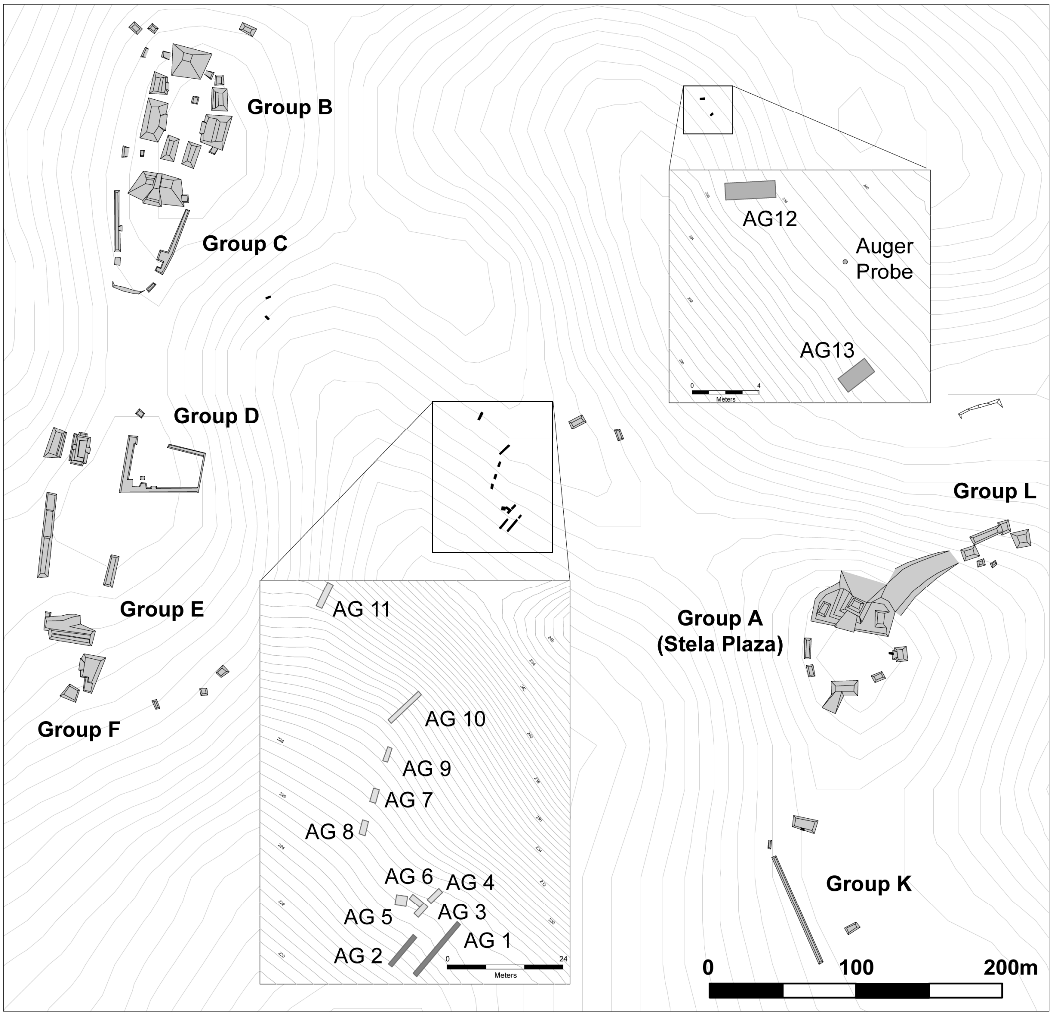


Figure 3.1. The Uxbenká site core, showing locations of geoarchaeological excavations in A) the core,and B) the *Cochil Bul* area to the north (basemaps by C. Ebert).

topics of ongoing research at Uxbenká, but there is currently no evidence for a Post-Classic (after AD 1000) occupation of the site. The work presented here provides a broader context for interpreting the urban and agricultural ecology of this small Maya center.

Climatic Context

The Late Holocene climate history of Mesoamerica has been rapidly developing since the mid-1990s with increasing attempts to explain major cultural transformations with climate events. This is particularly the case with a series of Terminal Classic droughts and the sociopolitical disintegration of many Maya polities (e.g., Gill 2000; Haug et al. 2001, 2003; Hodell et al. 1995, 2001, 2005; Webster et al. 2007). Cultural adaptations to changing climatic conditions (e.g., agricultural intensification) may have a large effect on the landscape and are known to influence landscape transformations directly due to vegetation change (Mueller et al. 2009). The three records considered here – the Cariaco Basin marine Ti record (Haug et al. 2001, 2003); the Lake Chichancanab, Mexico, core sediment density record (Hodell et al. 2005); and the Macal Chasm, Belize, speleothem record (specifically the luminescence proxy; Webster et al. 2007) – are the most proximate to the site of Uxbenká and they cover the time span of interest (roughly the last 3500 years). Each provides a slightly different proxy for precipitation. General features of the three records are in fair agreement, but often specific details differ between the records (e.g., the timing or structure of Terminal Classic droughts), which is due to the combination of the differing sensitivity of each proxy to climate change, varying chronological precision in the underlying age models, and the potential for regional climate events to have locally distinct and possibly contradictory expressions.

The chronological resolution of the geomorphic record presented here is at the multi-decadal to centennial scale given the pace of many soil-formation processes and the reliance on AMS dates on charcoal within the paleosols to determine age. Each AMS ^{14}C date occurs within a span of soil-formation rather than the exact age of the soil.

Therefore, the annual and decadal features of the climate records (and the conflicts between them at these scales) are de-emphasized in favor of the broader temporal patterns that are potentially linked to changes in soil stability and instability.

After the generally warmer condition during the middle Holocene Thermal Maximum, the Cariaco Basin Ti record indicates an increase in El Niño/Southern Oscillation (ENSO) intensity and variability from ca. 3000 BC, with the highest ENSO intensity between 1500 BC and 400 BC (Haug et al. 2001, 2003). This era of climate vicissitudes spans the end of the Late Archaic and most of the Middle Preclassic periods, and is also seen in the early sections of the Macal Chasm (MC) speleothem luminescence record (starting from ca. 1200 BC; Webster et al. 2007) and the Lake Chichancanab (LC) density record (starting from ca. 850 BC; Hodell et al. 2005). Two severe droughts in the Late Archaic are inferred from Cariaco at 1200–1000 BC and 950–850 BC and may correspond to the two drier periods in the MC record from 1200–1000 BC and 1000–800 BC. The Middle Preclassic Period appears to have experience a prolonged trend of overall drying with marked wet-dry oscillations and punctuated drought episodes between 700 and 500 BC indicated by Cariaco, and 800 and 600 BC in the MC speleothem. Lake Chichancanab also reveals a series of dry episodes between 750 and 300 BC at roughly 100-yr intervals that bleed into the Late Preclassic period. During the Late Preclassic period the three climate proxies show less obvious coherence, but it appears that precipitation was variable during the centuries that opened and closed it according to the LC and Cariaco cores. Drought events in the middle part of the Late Preclassic are also suggested in Cariaco at 200–50 BC and in the MC speleothem at 50 BC–AD 150.

The Classic Period trends in the three records collectively suggest relatively wetter conditions during the Early Classic (with a dry episode recorded on the MC speleothem from AD 450–550 not seen in the other proxies) that give way to a general drying trend persisting through the Late Classic. Here again the details of the records conflict, but all record the driest period since the Middle Preclassic or the end of the Late Preclassic (but of longer duration) from AD 700 to 850. Lake Chichancanab and the MC speleothem both indicate extremely dry conditions into the Terminal Classic Period (AD 850–1000), though this period is punctuated by a relatively wet period in the Cariaco record that corresponds to the Medieval Climatic Anomaly (Haug et al. 2001, 2003).

The History of Maya Land Use

Contemporary landscapes in the Maya region are the products of millennia of land use decisions in the face of changing modes of agricultural production, demographic pressure, local micro-environmental conditions, and climatic change (Beach et al. 2006; Denevan 1992; Dunning 1996; Dunning and Beach 2000; Fedick 1996a; Fedick and Ford 1990; Wingard 1996). Forest clearance through the use of fire was and continues to be an effective, labor-saving component of Maya subsistence systems (i.e., both in foraging and food-production contexts; Nations 2006; Nations and Nigh 1980) and changing charcoal abundance in lake and wetland cores indicate the intensity of forest burning throughout the Holocene. Increased fire frequency in the Maya Lowlands at the beginning of the Late Holocene (~2000 BC) correlates with pollen spectra showing increases in domesticates (*Zea* sp., *Manihot* sp.), disturbance taxa (e.g., Graminaea, Cyperacea) and declines in primary forest arboreal taxa (e.g., Moracaea, Urticacaea, Bursuraceae)

(Piperno and Pearsall 1998). Increasing soil erosion is indicated in several lake records during this period in the Petén (Guatemala) and the Yucatán (Mexico) regions, suggesting the emergence of long-fallow swidden agriculture in upland areas made feasible by the drier Late Holocene climate (Piperno and Pearsall 1998; Rosenmeier et al. 2002a, 2002b).

By 1500 BC, regional adaptations to wetland agriculture became important, notably in the bajos of northern Petén (Hansen 1993, 1994) and the lowland swamps of northern Belize. Earlier research suggested extensive raised fields in the Pasión region of Guatemala (Adams 1980; Adams et al. 1981) and at Pulltrouser Swamp in northern Belize (Harrison 1993, 1996; Puleston 1978; Turner and Harrison 1983) dating primarily to the Late Classic Period (AD 600–800). Further research suggests that many of these are either natural landforms that were never cultivated, or in northern Belize were fields drained by ditching in the Preclassic (~1000 BC), but were not raised *per se* in the manner of *chinampas* (Dunning 1996; Dunning et al. 1991; Pohl and Bloom 1996; Pohl et al. 1996; Pope et al. 1996). Drained fields on Albion Island, and Douglas, Cobweb, and Pulltrouser swamps appear to have been completely inundated and abandoned by ~ 200 BC due to a rising water table (Pohl et al. 1996).

Landscape alteration accelerated in the Maya region after ~1000 BC, as population pressure forced a shift to short-fallow agriculture, putting more land, including less favorable hillslopes, under cultivation in some regions. Buried topsoils dating to 1500 BC at La Milpa and Petexbatun indicate that soil instability and sedimentation rates increased in response to agricultural intensification during the Middle to Late Preclassic (1000 BC–AD 300; Beach et al. 2006; Dunning and Beach 2000;

Dunning et al. 1999). In the Petén lake records, inorganic sediment and charcoal abundance due to the shift to short-fallow swidden is likely superimposed on the signal of drier climate through the Late Holocene, demonstrating the complex linkages between human alterations, vegetation cover, and geomorphic stability (Binford et al. 1987; Curtis et al. 1998; Hodell et al. 1995, 2000; Rice 1993; Rosenmeier et al. 2002a, 2002b). Behavioral responses to environmental degradation during the Preclassic to Early Classic involved decentralization or out-migration to other regions, but soil retention structures (e.g., terraces, check dams) do not appear to have been employed during this period (Dunning and Beach 2000).

New polities were established during the Classic Period (AD 250-800) and agricultural practices intensified from long- to short-fallow systems, amidst a backdrop of growing population and increasingly dry and erratic climate from ~AD 1–1000 (Haug et al. 2003; Hodell et al. 1995, 2000). In this context, diverse human responses to demands on the land are evident and illustrate the complexity of Classic Maya political disintegration. In the Copán Valley, cultivation spread from the productive "pockets" of the valley floor, and eventually onto the hillslopes under steady demographic expansion, overtaxing productive capacity and undermining the geomorphic stability of the soils (Abrams and Rue 1988; Webster et al. 2000; Wingard 1996). Prolonged drought episodes during the Late and Terminal Classic (AD 600–1000) further decreased vegetative cover and exacerbated anthropogenic erosion, culminating in landslides that buried parts of the Main Group under as much as 2 m of colluvium (Abrams and Rue 1988; Fash and Sharer 2003; Webster et al. 2000; Wingard 1996). In the Petén and Yucatán, lake cores show a similar mass-wasting event represented by the "Maya clay" (Binford et al. 1987; Deevey et al. 1979; Hodell et al. 1995, 2000), and in northern Belize the Preclassic drained fields are capped by an analogous stratum (Pohl and Bloom 1996; Pohl et al. 1996; Pope et al. 1996). Centers in the vicinity of Petexbatun, in contrast, show no evidence of increased erosion during this period despite intensive cropping and continual forest suppression seen in pollen records (Beach et al. 2006; Demarest 2006; Dunning 1996; Dunning and Beach 2000; Dunning et al. 1998). A sophisticated array of conservation measures including terraces, check dams, and reservoirs at Petexbatun, La Milpa, and Tamarindito allowed for sustained intensive agriculture without runaway environmental degradation. The elaborately terraced landscapes around Caracól are another example of land conservation in the face of intensive cultivation (Chase and Chase 1998; Chase et al. 2011; Healy et al. 1983).

In sum, multiple land use strategies, conservative and otherwise, were employed until the Terminal Classic (AD 800–1000) in response to changing climate, local soil characteristics, available technology and social organization, along with the perceived need or desire to mitigate the effects of anthropogenic landscape alteration. Given the array of local factors informing these decisions, we may expect that extrapolations from one region’s landscape history to another’s will be inadequate to explain the sociopolitical evolution of any one polity (Beach et al. 2006, 2008; Dunning 1996; Dunning and Beach 2000; Fedick 1996b, 1996c; Fedick and Ford 1990). The site-specific, empirically grounded work described here explores human adaptive responses to natural and anthropogenic environmental change at Uxbenká, and helps elucidate the other social and ecological factors that contributed to societal transformation.

Field Methods

Geoarchaeological investigations were carried out from 2007 to 2009 at Uxbenká, focusing primarily in the site core amid the main civic/ceremonial architecture groups, Groups A, B and D (Figure 3.1; Culleton 2008, 2009, 2010). The main aim of these excavations was to expose geomorphic profiles that would allow cultural features (e.g., architecture, middens, etc.) and paleosols to be identified and described. Where possible, excavation units were taken to bedrock. This was motivated by a desire to identify the most ancient paleosols at the site and to understand the local effect of the bedrock on erosion, deposition and soil genesis. Excavations were conducted initially in natural levels, and sediments screened through ¼-inch wire mesh where possible. Screening all of the heavy clay loam sediment would have been prohibitively time-consuming, so subsamples of sediment were screened to recover artifacts when paleosols and other depositional surfaces were encountered. Artifacts were most commonly recovered by excavators at the trowel’s or shovel’s edge rather than from screens. Profiles were recorded and described according to Birkeland (1999).

Chronology

Radiocarbon samples to establish the ages of palaesols and cultural features were recovered from profiles, features or recovered soil samples, in most cases selecting individual twigs or single charcoal pieces to avoid problems of mixed age samples (Table 3.1). Specimens were pre-treated and combusted along with known-age standards (e.g., OX1 oxalic acid, Queets A wood, FIRI-H) using routine ABA techniques for organics at the University of Oregon. Sample gas was submitted to UC Irvine Keck Carbon Cycle

AMS Facility for graphitization and AMS ^{14}C measurements. Conventional ages are δ^{13}C-corrected using values measured on the AMS according to the conventions of Stuiver and Polach (1977). Ages were calibrated with the IntCal09 atmospheric curve (Reimer et al. 2009) using OxCal 3.01 (Bronk Ramsey 1995, 2001). Most charcoal specimens were recovered from identified A horizons of those soils, and therefore estimate points when the soil was stable and accumulating organic matter over some span of decades or centuries. For a specific exposed paleosol, these dates represent the minimum age (i.e, *terminus post quem*) of their burial. Because many of these dates fall into discrete clusters, paleosols are correlated between units and modeled multiple paleosol ages as *phases* using OxCal to estimate the beginning, end and span in calibrated years. A chronology of geomorphic stability and instability within the Uxbenká site core is established from those estimates.

Table 3.1. Calibrated AMS ^{14}C dates from paleosols

UCIAMS #	**Provenience**	**Conventional Age (^{14}C BP)**	**2σ range cal BC/AD**
Late Archaic			
67230	SubOp 09-1, AG12, 300 cmbd, L3.	3555±20	1960-1770 BC
57040	SubOp 08-1. AG3, L.3, 290-300 cmbd. SS11.	3070±15	1410–1290 BC
56355	SubOp 08-3. AG9, W Wall. Top of Bosh Lu'um, 95-105 cmbd.	2955±20	1270–1080 BC
67953	SubOp 09-1, AG12, 185-190 cmbd, Top of L3.	2900±15	1190-1010 BC
68835	SubOp 09-1, AG13, 280-285 cmbd, Base of Exc.	2875±15	1130-1000 BC
68833	SubOp 09-1, AG12, 201 cmbd, L3.	2810±15	1010-915 BC
57039	SubOp 08-1. AG3, L.3, 290-299 cmbd. SS10.	2810±15	1010–915 BC
Middle Preclassic			
68834	SubOp 09-1, AG13, 170-175 cmbd, gray wedge.	2500±15	770-540 BC
76156	SubOp 09-1, AG12 120-125 cmbd, Top of L2	2490±20	770-520 BC
Late Preclassic/Early Classic			
56350*	SubOp 08-1. AG3, 138cmS/63cmE, L.3, 167cmbd.	1950±15	AD 1-85
57038	SubOp 08-1. AG3, L.3, 200-210 cmbd. SS4.	1830±15	AD 130-240
56354	SubOp 08-1. AG6, L.4, Bosh lu'um, 192cmbd .RC8.	1780±15	AD 140-330
57037	SubOp 08-1. AG6, L.3, 160-170cmbd.	1730±15	AD 250-390
57041	SubOp 08-1. AG6, Fea. 2, 160 cmbd. SS12A.	1725±15	AD 250-390
Late Classic			
36946	AG1, Buried Soil in Zone 2, 100-105 cmbd	1470±50	AD 430-660
56357	SubOp 08-3. AG11, 145cmN in E Wall, 277cmbd. RC15.	1455±15	AD 570-645
56356	SubOp 08-3. AG11, 235cmbd. RC12.	1455±15	AD 570-645
Terminal Classic			
56352	SubOp 08-3. AG8, 212-219cmS/85-95cmE, L.2, 180cmbd. RC6.	1120±15	AD 885-975
56353	SubOp 08-3. AG8, 228-232cmS/70-80cmE, L.2, 198cmbd. RC7.	1115±15	AD 890-980
36947	AG1, Fill at bedrock, Zone 1.	1110±30	AD 870-1020

Results

Bedrock Geology and the Geoarchaeology of Uxbenká

Over the course of several years of archaeological survey and excavation at Uxbenká, the local expression of bedrock geology has been found to dominate geomorphic processes of erosion, deposition, hydrology, and soil formation, as well as influencing the architecture of settlements and the site core. As described above, the sedimentary Toledo Beds comprise a range of interbedded mudstones, sandstones and limestones that are close to horizontal, typically not dipping by more than about 10-15° in the site vicinity. The mudstone strata (locally called *nib* in Mopan Maya) break down readily to form new soils when exposed to weathering, which contributes to the "paradoxical" fertility of the soils around Uxbenká (Hartshorn et al. 1984:76-77). *Nib* is also easily excavated without metal tools, and was used as construction fill in structures of all sizes, which requires a careful eye to distinguish from *in situ* bedrock during excavation. Sandstone strata are generally more durable than the *nib*, even where they are erodible and not well indurated. Resistant sandstone strata overlying friable *nib* result in flattened hilltops with steeply eroded hillsides in some areas, e.g., at SG 1 to the northwest of the site core. In many cases sandstone outcrops eroding from hillsides provided building material for house mounds and other domestic structures. In the case of SG 25 and SG 28 to the east of the site core, an indurated sandstone member with squared vertical joints gives the appearance of deliberate construction, but was simply augmented with a few courses of additional masonry to create a more impressive appearance (Figure 3.2A). Sandstone blocks are the primary construction material for core architecture at Uxbenká, and the large flat sandstone slabs exposed in Santa Cruz

Figure 3.2. Characteristic exposures of the Toledo Beds in the Uxbenká vicinity: A) Sandstone outcrops at SG 25 taking the form of natural steps (note rock hammer for scale); and B) near-vertical joints in the *nib* (mudstone) forming a sheer face in a drainage to the east of the site core.

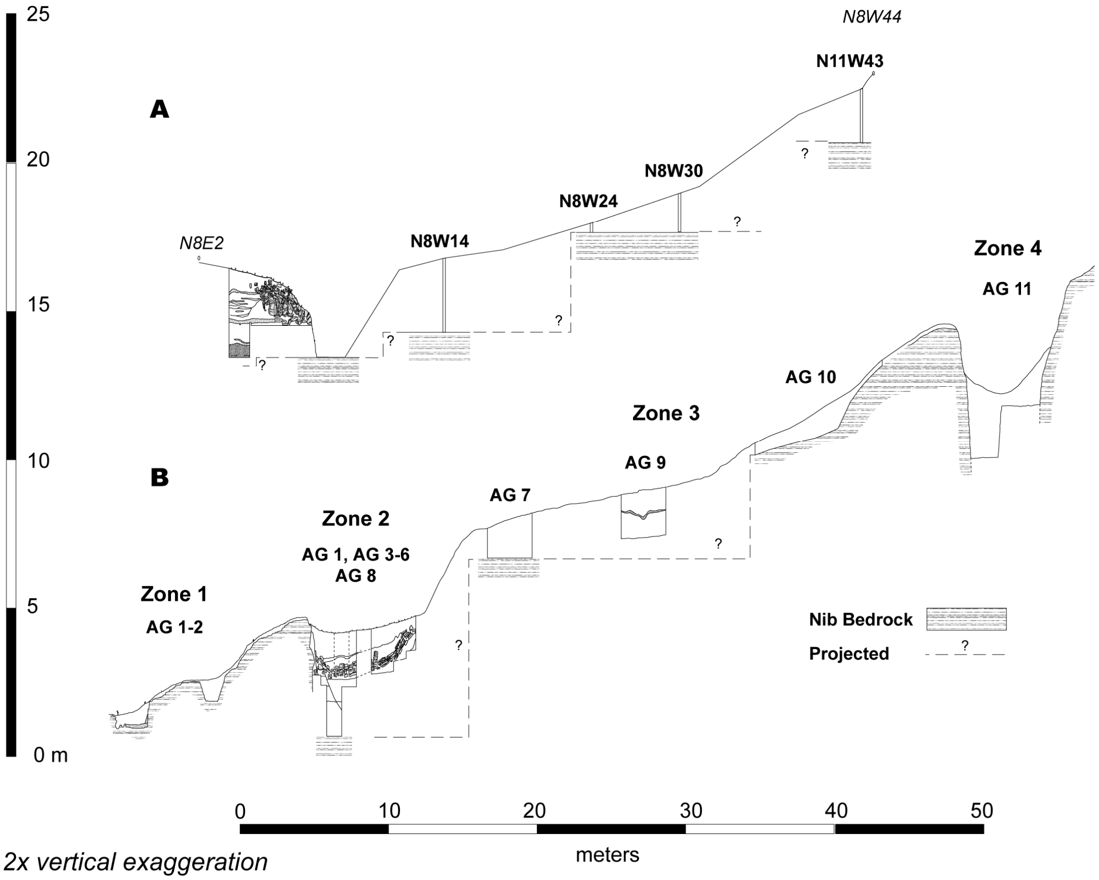
Creek and to the south at SG 35 were an ideal source for the numerous stelae carved and erected at Group A during the Classic Period. The similar character of sandstones at Nim Li Punit may have also contributed to the prevalence of a stela tradition there.

Near-vertical jointing in the *nib* and sandstone is very common in the Uxbenká area, and likely reflects compressional stress from the tectonic activity associated with the uplift of the Maya Mountains since the Cretaceous (cf. Hartshorn et al. 1984:12; Figure II-2). At small scales (1–100cm) these joints contribute to the friability of the *nib* and the ease with which sandstone slabs can be excavated from these outcrops. At larger scales (1-10 m), the joints may be expressions of the faulting itself, and they mark the landscape with narrow vertical chasms that in some places dictate the hydrology by capturing streams, and in others dominate soil processes by creating deep sediment traps (Figure 3.2B). Transects excavated along hillslopes in the site core and just to the east demonstrate this process. Augering on the west slope of the *Ha'il Chepa* drainage near

SG 26 indicates a stepped pattern to the horizontally bedded *nib*, so that soil depth can vary from 10 to 150cm or more even over short distances (Culleton 2010; Figure 3.3A). In the Uxbenká site core between Group A and B the stepped bedrock is punctuated with multiple sediment-filled chasms that create the initial impression of purposeful terracing (Figure 3.3B). In the course of excavating these putative terraces their geological origin became clear, and further observations in the site vicinity have so far revealed no firm evidence for agricultural terracing at Uxbenká. Instead it appears the natural sediment traps serve practically the same soil conservation function, as well as providing the paleosol sequences that span the last 3500 years at Uxbenká that form the body of geoarchaeological data presented here.

Excavations in the Site Core

Eleven excavation units were placed in the site core in 2007 and 2008, most were 1 m wide trenches ranging from 3-13 m long that taken together form a composite hillslope profile spanning ~65 horizontal meters and ~16 m of elevation (Culleton 2008, 2009). For the sake of clarity I divide the slope into four zones that roughly correspond to what were first assumed to be separate terrace platforms, Zone 1 being the lowest elevation and Zone 4 being the furthest upslope (Figure 3.3B) Zone 1 comprises two ~5m wide steps on the hillside excavated to bedrock with two parallel trenches (AG1 and AG2). The trenches exposed irregular channels in the *nib* bedrock running with the strike of the hillslope and ranging from 1-2m wide and 50-100cm deep. Between the channels the soil depth ranged from 10-20cm. No clear paleosols were exposed in the units, but the few artifacts recovered (non-diagnostic ceramic body sherds) were lying almost directly



Note 2x vertical exaggeration

Figure 3.3. Transects showing the marked jointing in the bedrock A) east of the Uxbenká site in the *Ha'il Chepa* drainage, and B) in the site core itself.

on the bedrock, suggesting the channels were relatively free of sediment when the artifacts were deposited. Charcoal recovered from fill at the base of the upper channel in AG1 dates to the Terminal Classic (UCIAMS-36947; 2σ: cal AD 870-1020) likely representing infilling after the abandonment of Uxbenká.

Zone 2 was the focus of fairly intensive work (including units AG1-6 and AG8) as the excavations revealed a series of natural and cultural strata, and sediments extending to a depth of nearly 3.5 m below the present surface (Figure 3.4). A distinct 7-10 m wide trough delineated on the downslope side by a *nib* bedrock outcrop rising about 50 cm above the soil surface markthe area. The outcrop represents the uppermost extent

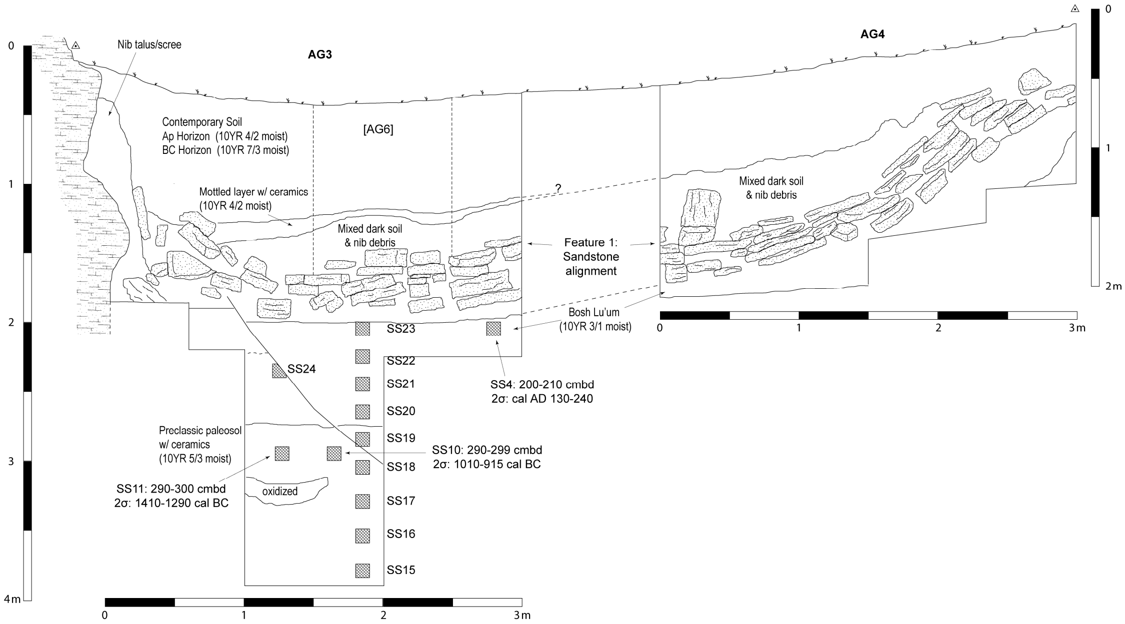


Figure 3.4. Composite profile of AG3 and AG4 west walls, showing sandstone alignment (Feature 1).

of an almost vertical 4 m *nib* bedrock face that forms one margin of a large joint in the bedrock.

A buried soil dating to the Late Classic Period was encountered in the section of AG1 that extended in to Zone 2 (UCIAMS- 36946; 2σ: cal AD 430-660). Units AG3-6 were placed from roughly 10m to the west of AG1, being initially oriented perpendicular to the *nib* outcrop. The number of units excavated was increased to investigate a variety of buried soils and features in the section. Of particular note, a linear alignment of unworked sandstone slabs (Feature 1) was uncovered at 150-200 cmbd running perpendicular to the nib wall and that continued without apparent breaks or corners for more than 7 m. The composite profile shows the feature comprising 3-4 courses of unmodified sandstone slabs (with a few limestone pieces) following the sloping surface of the paleosol. This feature was built upon a dark, organic rich paleosol, and was covered by a complex series of broken nib fill layers and less distinct but readily identifiable strata. Overall the feature appeared to be intact, though slabs adjacent to the nib wall were less coherent, suggesting a disturbance such as an earthquake and associated hill slope slide. As exposed in AG6, Feature 1 was confirmed to be a linear feature, and stratigraphically above the paleosol. The series of strata observed above the paleosol and Feature 1 were also present in AG6. A small lens of burned sediment and charcoal (Feature 2) was found on the surface of the cultural stratum immediately above the paleosol. Charcoal samples from Feature 2 and the stratum on which it was deposited gave identical Early Classic dates (UCIAMS-57041 and UCIAMS-57037; 2σ: cal AD 250-390). Both are stratigraphically superior to the sandstone alignment so these dates are the upper bracket on the age of its construction. Charcoal dates on the paleosol below the alignment in AG3 (SS4, 200-210 cmbd; UCIAMS-57038; 2σ, cal AD 130-240) and AG6 (RC8, 192cmbd; UCIAMS-57038; 2σ, cal AD 140-330) suggest it is a Late Preclassic occupation surface/cultural deposit. Feature 1 is bracketed by Late Preclassic and Early Classic strata and the date of its construction can be estimated using a *sequence* model in OxCal. It appears to have been constructed at the end of the Late Preclassic, or possibly the very beginning of the Early Classic Period (1σ: cal AD 230-290; 2σ: cal AD 200-340). This may be contemporary with the purposeful burial of 1st to 2nd century AD cache in SG 20, on the ridgetop immediately above Zone 2, which was buried under a 1.3 m-tall mound of mixed *nib* and soil fill sometime after ca. 135 cal AD (Prufer et al. 2011: 213-214).

Excavations continued in the center of AG3 and before reaching *nib* bedrock at 404 cmbd, a second diffuse darker layer consistent with a buried soil surface was identified ~300cmbd. This stratum also contained a few non-diagnostic ceramic sherds, indicating human use of the area before the construction of Feature 1. Two radiocarbon dates between 290-300 cmbd date this to the Late Archaic (SS11; UCIAMS-57040; 2σ: 1410–1290 cal BC; and SS10; UCIAMS-57039; 2σ, 1010–915 cal BC), and with the span between the dates suggesting the buried soil was a stable surface for as much as 500 years before being buried. This sparse deposit represents some of the earliest evidence of occupation at Uxbenká. Sediments below this exhibited strong mottling and ped faces were well coated with clays, typical of a well-developed tropical vertisol.

AG8 (3x1m) was placed about 20 m west of the main Zone 2 excavations, where the linear depression narrows and begins to conform with the topography of the hillside. Excavation revealed a similar overall pattern of strata to the units in Zone 2, as well as a portion of another sandstone alignment (Figure 3.5). The profile in the south half of the unit reveals an original hillslope surface that dipped down abruptly to form a channel, which filled in over time with successive cultural and natural sediments. At a depth of roughly 70-90 cmbs (140-160 cmbd), a stratum of reworked *nib* colluvium was encountered that capped a buried A horizon. At the base of the A horizon was a distinct charcoal-rich layer in the south half of the unit. These charcoal pieces were large (1-2 cm diameter) compared to other strata, and gave the impression of a short-fallow milpa that had been chopped and burned before being buried. Two charcoal samples, from the A horizon (110 cmbs; 180 cmbd; UCIAMS-56352) and from the charcoal layer (128 cmbs; 198 cmbd; UCIAMS-56353), produced essentially identical dates at cal AD 885-980 (2σ). These dates are consistent with the Terminal Classic, and fall in line with a date on the fill in Zone 1.

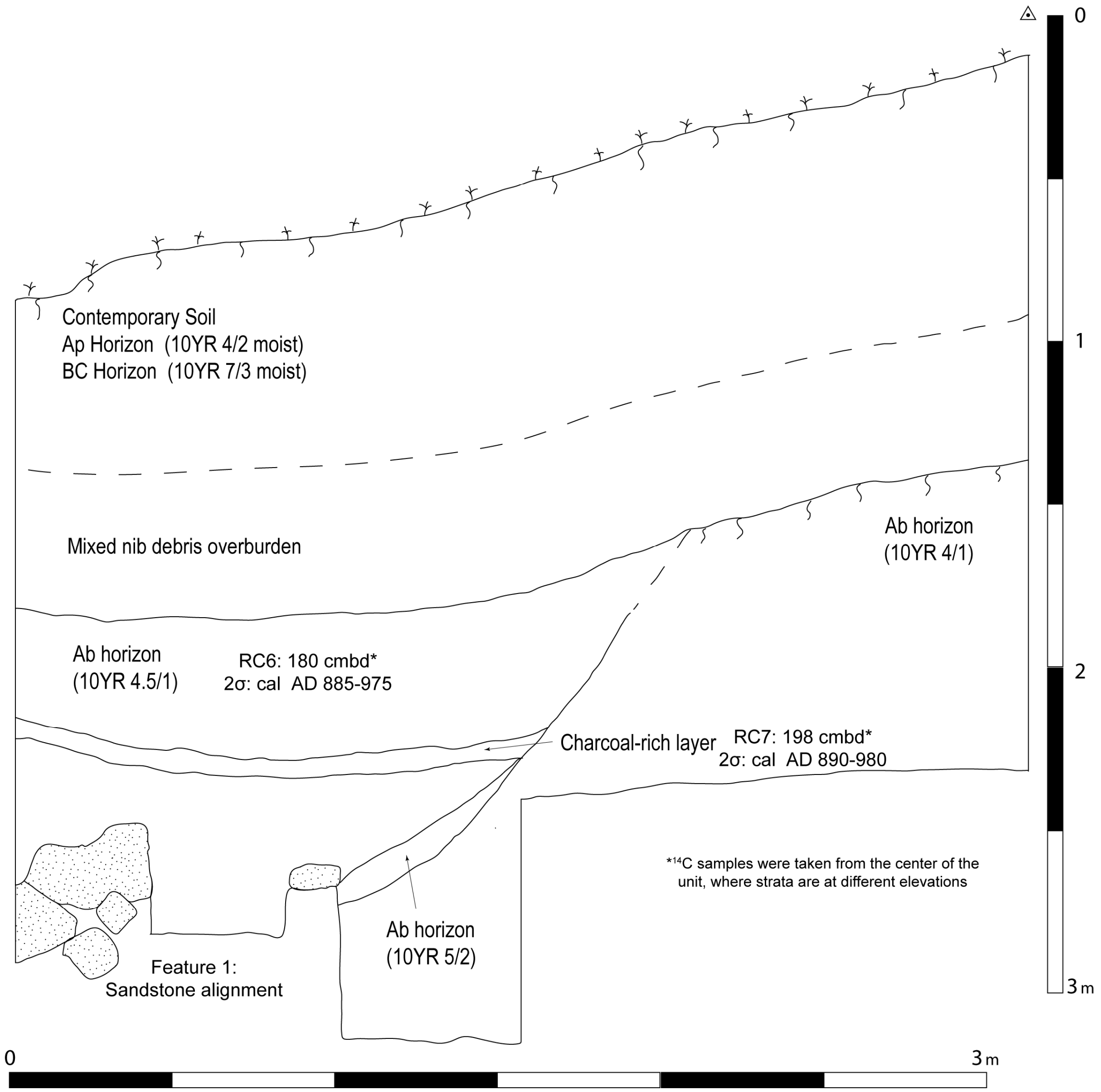


Figure 3.5. AG8 west wall profile, showing sandstone alignment (Feature 1).

Two less distinct but clearly recognizable soil surfaces were observed at ~190 cmbs (260 cmbd) and ~220 cmbs (290 cmbd). The southwest corner of AG8 cut into a portion of another sandstone alignment (Feature 1) that appears to have been constructed on top of this lowest buried soil, being made from 2-3 courses of stone in the observable section. As with the feature in the main part of Zone 2, none of the stone slabs showed signs of modification, and all appeared to be the common tabular pieces used in structures around Uxbenká. Several stones were tilted ~45° from horizontal, suggesting the feature had collapsed into the apparent depression in which fill was accumulating during the Classic period. There is no obvious relationship between the two sandstone features in Zone 2 as their function is unclear, but it seems likely that the two sandstone alignments are contemporary (i.e., dating to the Late Preclassic), and served the same purpose, whether architectural, agricultural or otherwise.

Excavations on the flat tier of Zone 3 deployed 3 trenches. AG 7 (3x1m) was placed 4 m uphill of AG8 at the head of the slope between Zone 2 and Zone 3 to investigate the relationship between the two areas in terms of soil sequences and bedrock morphology. No paleosols were identified in the unit, which appeared to contain a single stratum with A (Ap), Box, and C horizons over bedrock. Given the slope, it is likely that the soil formed in colluvium that was continually moving downslope, but without net gain or loss. The underlying bedrock in the unit was virtually horizontal, which is consistent with the observed bedding of outcrops around the Uxbenká, but also suggests there must be a fairly sharp vertical drop-off to the bedrock between AG7 and AG8. If so, Zone 2 may be flanked on the uphill side by a *nib* bedrock face similar to that exposed on its downhill side. AG10 (8x1m) was placed 6 m upslope of AG9 on the head of the slope between Zone 3 and Zone 4, which is a steep drop-off in the bedrock, covered with a thin veneer of topsoil (i.e., 5-10 cm). The excavation involved clearing the thin soil and decomposing *nib* to expose the bedrock. As elsewhere in the site core, the bedding was nearly horizontal and the vertical joints were oriented along the strike of the hill slope.

AG9 (3x1m) was placed in the center of the large flat section of Zone 3, 6 m upslope of AG7. Excavation exposed a well-developed paleosol, overlain by a layer of loose *nib* debris, in a similar sequence to that observed in AG3 and AG6 above the Late Classic strata and AG8 above the Terminal Classic stratum (Figure 3.6). An AMS ^{14}C date on charcoal from the buried 2Ab horizon (95-105 cmbd) of 1270-1080 cal BC (2σ; UCIAMS-56355) places it in the Late Archaic. As noted in the discussion of the Late Archaic paleosol in AG3, this date is bracketed by two other dates from that stratum, suggesting that the two paleosols are correlated. In the case of Zone 2 it is clear that after a period of relative geomorphic stability and soil development in the Late Archaic, Zone 2 accumulated sediments until the next evidence of occupation in the Early Classic. In Zone 3 it is not clear when the Late Archaic paleosol was buried; a few ceramic sherds were found in both the paleosol and the stratum above the *nib* debris, but were not diagnostic. If the various *nib* debris layers in other units could be correlated, it is possible that the paleosol in AG9 remained stable and available for occupation into the Classic Period. The well-developed Box horizon in the upper stratum suggests a longer period of soil development, starting before the Classic Period, leaving open the possibility that the paleosol was buried after initial land clearing by Late Archaic farmers, although this could have occurred later in the Middle or Late Preclassic period.

Zone 4 comprises a large fissure just below the ridgeline of the hill between Groups A and B. Steep eroding *nib* walls rise 2-3 m on either side above the accumulated sediment that forms its floor. The feature originates as a narrow (1 m-wide) step in the hillside at its east end (where the uphill end of AG10 begins), and broadens to 5-7 m wide at the location of AG11, roughly 30 m to the west. It continues more than 50 m, turning to follow the changing aspect of the hillslope from roughly southwest to northwest.

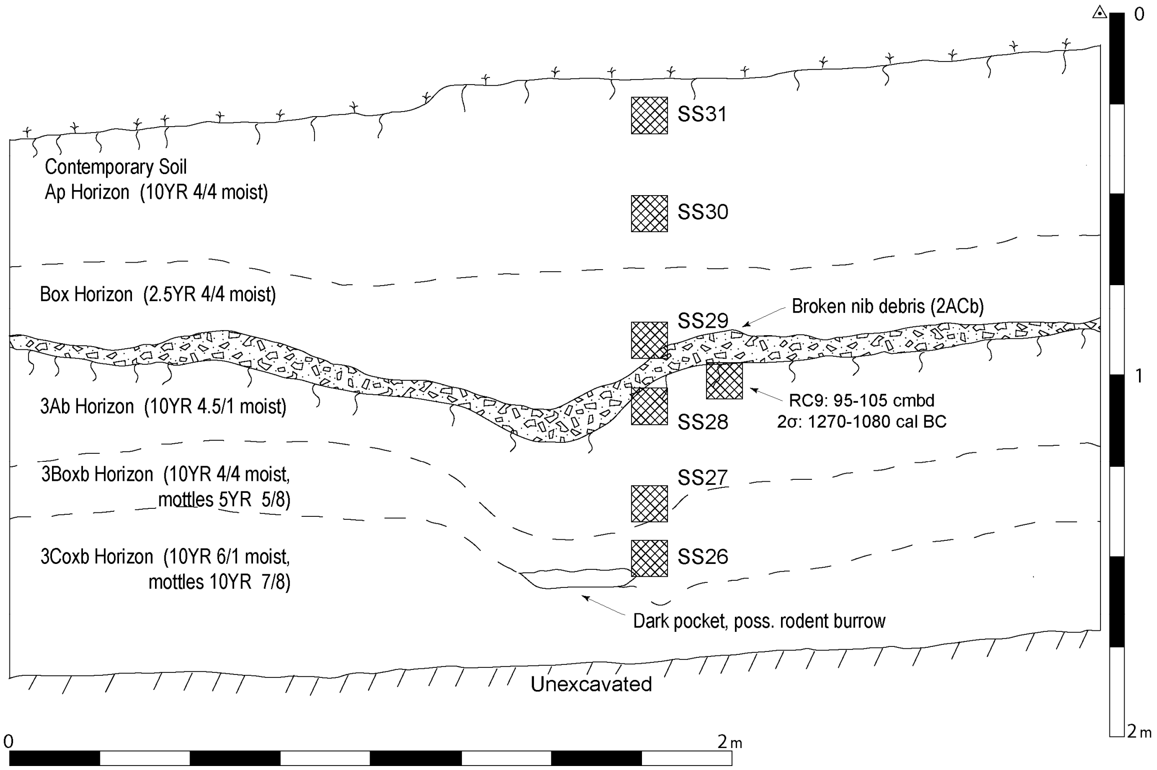


Figure 3.6. AG9 west wall profile.

AG11 was placed to cut a 1x5 m cross-section of the sediments, under the assumption that it was a larger version of the trough in Zone 2 and could possibly retain a buried cultural sequence. No distinct buried soil horizons were observed in the profile, though there were diffuse concentrations of ceramic sherds at ~200 cmbd and 210-215 cmbd, as well as more frequent but scattered charcoal at 235 and 275 cmbd. The soil remained largely structureless and consistent in color and texture despite slight variations in the amount of loose *nib* inclusions. Overall this is consistent with cumulic soil development in a continuously aggrading sediment. Two dates indicate sediment deposition was more rapid here than on the terraces below: charcoal samples from 235 cmbd (RC12; UCIAMS-56356) and 277 cmbd (RC15; UCIAMS-56357) yielded identical calibrated ages of cal AD 570-645 (2σ). These two dates are Late Classic, and are in good agreement with the date on the buried soil in AG1 in Zone 2. Given the cumulic nature of the sediments here, these two AMS dates do not reflect organic inputs associated with *in situ* soil development. They likely are derived from the erosion of a Late Classic soil upslope of the chasm some time after ca. cal AD 645.

***Excavations Northeast of the Site Core,* Cochil Bul**

Excavations were conducted to the northeast of the site core in 2009 to expand geoarchaeological work further outside of the site core (Figure 3.1B). The site on the north side of the ridge between Groups A and B was chosen for excavation after reconnaissance survey revealed a relatively flat section at the base of a hillslope bordered on the downhill margin by a linear bedrock protrusion reminiscent of that in Zone 2 in the site core. Though Group B is visible in the distance from this location, there are no known architectural features on the hills and ridge-tops immediately surrounding the basin.

Two 3x1m units and an auger probe were excavated to identify whether a similar series of buried soils was preserved in the natural sediment trap. A 4-inch dimaeter auger probe went 4 m below the present surface, encountering possible paleosols at roughly 110–130 cmbs, 200–220 cmbs, and 335 cmbs based on coloration and the presence of abandoned root channels. Bedrock was not reached by 4 mbs, indicating the potential for very early buried sediments in this area. AG12 and AG13 were laid out perpendicular to the natural rise and abutting it to the east, in the same manner as units AG1 and AG3 in Zone 2. AG12 revealed at least three discernable paleosols at ~125 cmbd, 185 cmbd and 275 cmbd, with ceramic sherds and charcoal pieces commonly dispersed in relatively low densities within them (Figure 3.7). The upper soil (from the present surface down to the 2Atb) contained very few artifacts and likely represents post-Classic/historic sedimentation from the slopes to the northeast. AMS ^{14}C dates on two individual charcoal samples from the 3Atb horizon date it to the Late Archaic period (UCIAMS-67953, 185-190 cmbd, 2σ: 1190-1010 cal BC; UCIAMS-68833, 201 cmbd, 2σ: 1005-910 cal BC), and the span of dates suggests the soil surface was stable for a period of as much as 300 years. These two dates fall in line with the ages of paleosols in the site core excavated in Zones 2 and 3, as well as the date at the base of the excavation in AG13. A date on charcoal towards the base of the unit below the 4Aoxb comes much earlier in the Late Archaic (300 cmbd, UCIAMS-67230; 2σ: 1960-1770 cal BC), though no cultural materials were recovered from within this paleosol. As such, the earliest empirical evidence for human presence at Uxbenká is found on paleosols dating a span from ca. 1200-900 cal BC in the later part of the Late Archaic period.

AG13 followed a similar course but revealed slightly more complex stratigraphy than AG12, probably attributable to local variations in colluviation and drainage. Two paleosols were encountered. The first clear paleosol (2Atb) undulated across the profile, appearing to pile up against the bedrock wall to the south end of the unit. This suggests the south half of the paleosol could be colluvium from the natural rise, or alternatively part of the 2Atb was scoured before the present soil unit was deposited. The contact between the second and third paleosols was expressed as two wedges of sediment, a grey/brown wedge associated with 2Atb in the north half of the unit and a yellow wedge in the south half. A single charcoal AMS ^{14}C date places the 2Atb soil in the Middle Preclassic, which is the first paleosol dating to that time at Uxbenká (170-175 cmbd;

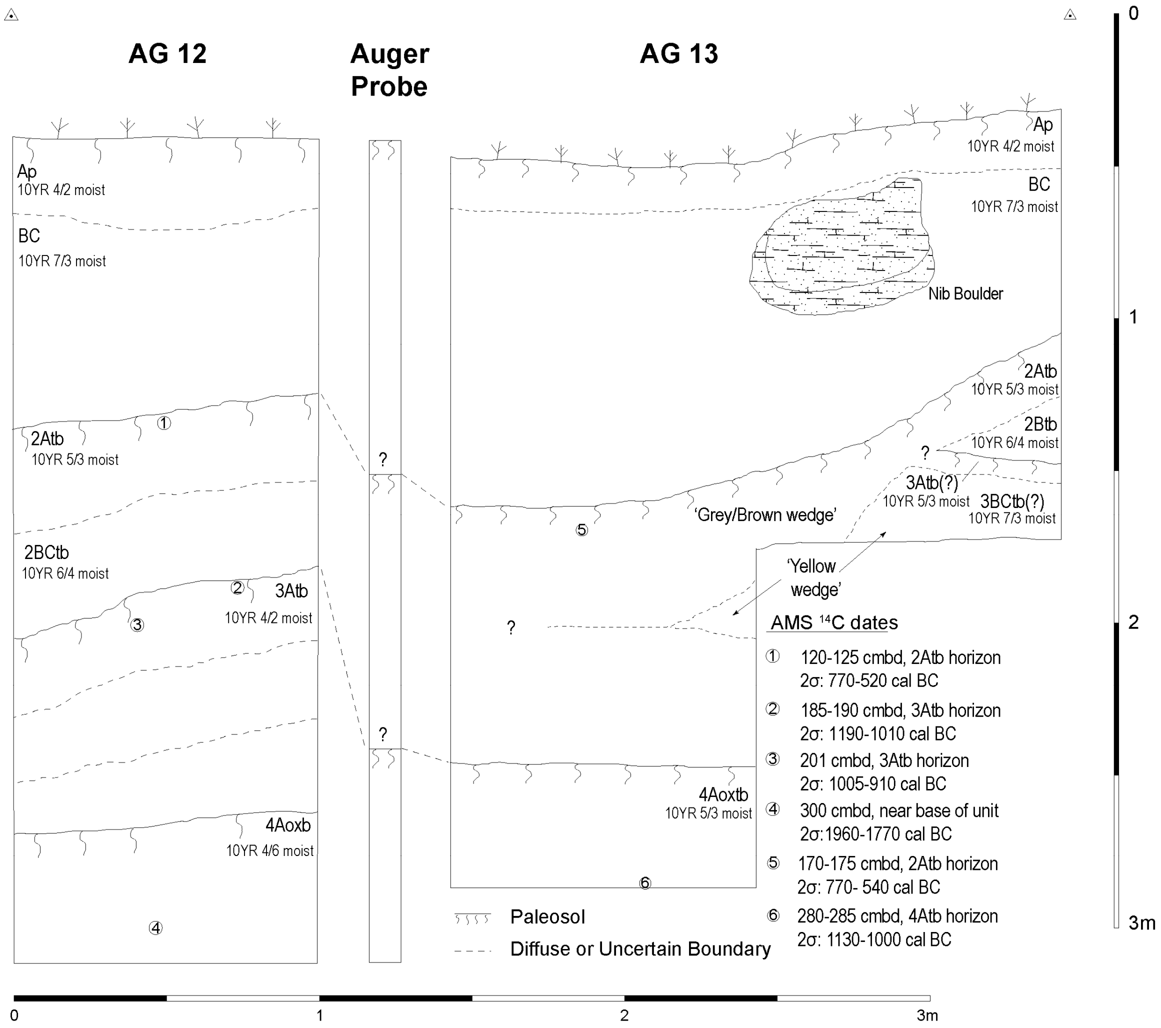


Figure 3.7. Composite profiles of *Cochil Bul* excavations AG12, AG13, and Auger Probe

UCIAMS-68834; 2σ: 770-540 cal BC). The deepest paleosol (4Aoxb) had a clear horizontal upper boundary and dispersed highly eroded ceramic sherds and charcoal. A single AMS ^{14}C date places this in the Late Archaic period (280-285 cmbd; UCIAMS-68835; 2σ: 1130-1000 cal BC) and correlates well with dates on paleosols in the site core and AG12.

Discussion

Six distinct paleosols were identified in the urban core of Uxbenká, the earliest dating to the Late Archaic Period prior to evidence for human occupation at the site and the latest dating to the Terminal Classic, a time when archaeological evidence for human presence in the region is sparse. A Bayesian model that combines stratigraphic information with AMS ^{14}C dates from within these soils is provided in Table 3.2. Age estimates and the projected duration of soil formation should be taken as a minimum given the relatively small number of radiocarbon dates on each soil and the statistical probabilities of having dated the first and last events within each soil. These were modeled as *phases* in OxCal and using the *boundary* function partly minimizes this problem (see discussion between Steier and Rom [2000] and Bronk Ramsey [2000]). The timing of the geomorphic changes is considered with respect to cultural and climatic records in the following discussion (Culleton et al. 2012; Haug et al. 2001, 2003; Hodell et al. 2005; Prufer et al. 2011; Webster et al. 2007) (Figure 3.8).

Table 3.2. Geochronology of paleosols in the Uxbenká site core.

Paleosol	Exposures	Earliest Formation (2σ)	Latest Formation/ Burial (2σ)	Dated Span Range (cal yr, 2σ)	Dated Span Mean (cal yr)
Late Archaic	AG3, AG9, AG12, AG13	1720-1280 BC	970-620 BC	320-470	390
Middle Preclassic	AG 12, AG13	970-620 BC	750-300 BC	-10-170	60
Late Preclassic	AG3, AG4, AG6	AD 10-240	AD 160-320	-5-95	30
Early Classic	AG3, AG4, AG6	AD 210-360	AD 280-610	-5-80	25
Late Classic	AG1, AG11	AD 280-610	AD 610-960	-10-180	50
Terminal Classic	AG1, AG8	AD 610-960	AD 890-1160	-5-80	35

The earliest paleosol in this series dates to the Late Archaic Period and is represented by deeply buried A horizons exposed in the site core between Groups A and B in units AG3 and AG9, and the *Cochil Bul* in units AG12 and AG13. The initial formation of this paleosol is poorly constrained between 1720-1280 cal BC, but occurs

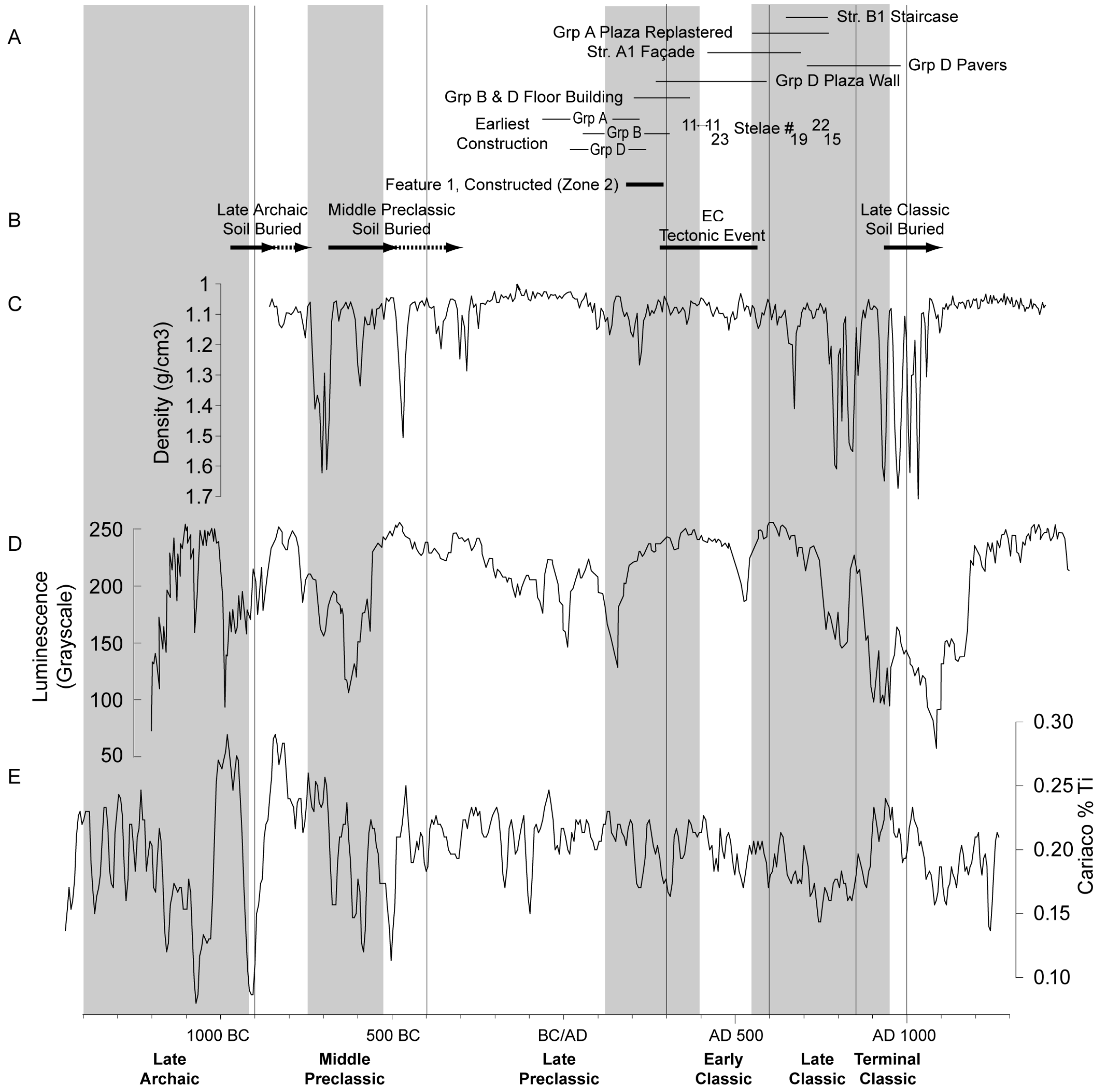


Figure 3.8. Geomorphic stability and instability at Uxbenká compared to cultural chronology and climate records. Periods of soil formation and stability as estimated from AMS ^{14}C dates are shown as grey blocks. A) Timing of major construction activities in the site core (2σ; from Culleton et al. 2012). B) Estimated onset of erosion events. C) Lake Chichancanab Core Density Record (Hodell et al. 2005). D) Macal Chasm speleothem luminescence record (Webster et al. 2007). E) Cariaco Basin core titanium record (Haug et al. 2001, 2003).

within the Late Archaic Period. There is no evidence for human activity in the surrounding area at this time and the absence of cultural material in the soil is consistent with this observation. Non-diagnostic ceramic sherds recovered from the upper portions of this soil provide the earliest evidence for human occupation within the confines of the Uxbenká site core. These sherds were most likely deposited in or on a natural soil surface and I conservatively estimate their age to be near the end of deposition (970 to 620 BC). This age represents the onset of A horizon burial. The estimated age of these ceramics falls into the early part of the Middle Preclassic Period and corresponds well with the earliest pottery found elsewhere in Belize and the Maya region more generally. Swasey, Bolay, and Cunil ceramic traditions in northern Belize are found no earlier than ca. 1000 cal BC, and sometimes appear as late as 800 cal BC (Awe 1992; Clark and Cheetham 2002; Hammond et al. 1991; Lohse 2010; Rosenswig and Kennett 2008). Lohse (2010) has noted that many of the less-securely dated contexts for early pottery occur in Late Archaic age paleosols at the base of Middle Preclassic Period excavations. Age determinations for this early pottery are often from charcoal picked from sediments directly overlying bedrock. This suggests that many of the initial ceramic components were deposited onto older surfaces and eventually mixed into the soils by natural and cultural processes.

Soil formation during the Late Archaic (~1700 - 900 BC) corresponds to moist conditions evident in the Cariaco Basin and Macal Chasm records (Haug et al. 2001, 2003; Webster et al. 2007) and this would have promoted vegetation coverage and inhibited erosion. There is also no evidence for human occupation or land use in this area until the first appearance of pottery evident in the upper portions of this deposit dating to ~900-800 BC. The coincident appearance of pottery and erosion may signal the appearance of pioneering Maya groups moving into the area and destabilizing the landscape. Deforestation, landscape destabilization, erosion, and increased sediment load in river systems is associated with the initial colonization of farmers elsewhere in Mesoamerica (Joyce and Mueller 1992; Kennett et al. 2010; Neff et al. 2006) and also in the Maya lowlands specifically (Jones 1994; Pohl et al. 1996; Pope et al. 1996, 2001). The burial of the Late Archaic soil at Uxbenká also coincides with droughts evident in both the Cariaco and Macal Chasm records at the end of the Late Archaic Period and the earliest Middle Preclassic Period and this would have exacerbated any anthropogenic impacts at this time. Although the effects of forest clearing by extensive and possibly mobile farming communities on the erosional regime in this area is difficult to estimate, the coincident appearance of pottery and increased erosion is highly suggestive. However, one cannot rule out the possibility that the destabilization of the landscape at this time was driven largely by drought. This is a topic for future work.

The Middle Preclassic paleosol is currently known from units AG12 and AG13 in the *Cochil Bul* area to the north of the site core, and so may be a fairly localized phenomenon. The burial of the Late Archaic paleosol between 970 and 620 cal BC marks the earliest possible timing for the beginning of Middle Preclassic soil formation, and, though only constrained by two AMS ^{14}C dates, would have been a stable surface until 750-300 cal BC. As with the Late Archaic paleosol, ceramic sherds and chert debitage indicate a cultural component in the vicinity of the later Uxbenká urban core in the Middle Preclassic (at least by ~300 cal BC) that predates the earliest architectural sequences at the site between ~60 BC and AD 220 (Culleton et al. 2012). Climatic conditions through this period were quite variable, with several dry episodes superimposed on a broader drying trend. The 2σ range of the two AMS dates from the paleosol, 770-520 cal BC, corresponds with two severe droughts in the Lake

Chichancanab record and the pronounced decline in precipitation in the Macal Chasm speleothem. Given the range of potential ages for the burial of this soil and variability in the climate records in the Middle Preclassic, it is possible that after a brief period of soil development it was buried by anthropogenic or drought-induced erosion at ~300 cal BC.

The series of natural and cultural strata exposed in AG3, AG4 and AG 6 in the site core are contemporary with the establishment and expansion of the urban core at Uxbenká. The estimate for the beginning of soil formation in the Late Preclassic paleosol is cal AD 10-240, by which time clearing and leveling activities had already taken place on the hilltop sites of Groups A, B, and D (Culleton et al. 2012). In addition to the accumulated cultural materials in the A horizon, it is overlain by the 3-4 course alignment of sandstone slabs (Feature 1), which is modeled to have been constructed between cal AD 180 and 340 at the end of the Late Preclassic. The deposition and occupation of an Early Classic soil and burn feature post-dates Feature 1, and initial deposition is estimated at cal AD 210-360. This soil represents the surface on which residents of Uxbenká carried out their daily activities during the Early Classic, as indicated by the presence of broken pottery, charcoal, and a relatively slower accumulation of hillslope colluvium during this time.

Based on the available data the landscape during the Late Preclassic and Classic periods was relatively stable. Agricultural systems were well established in the Maya region by the Late Preclassic and Early Classic Periods and building activities at Uxbenká suggest a thriving population that was generating enough surplus to maintain building campaigns directed by the ruling elite at this location (Culleton et al. 2012; Prufer et al. 2011). At much larger Maya sites, active building programs are associated with clear indications of intensified agriculture and soil conservation strategies in areas peripheral to the urban core (e.g., terracing at Caracol and Petexbatun; Chase and Chase 1998; Chase et al. 2011; Dunning et al. 2002; Healy et al. 1983). Conservation mechanisms do not appear to have been put in place at Uxbenká, and at face value one can assume that the natural sediment traps in the site core obviated the need for constructed terraces. However, the Early Classic paleosol is fairly thin and doesn’t appear to represent a stratum of continually aggrading slope-wash colluvium. Although the chasm in Zone 2 does act as soil retention feature there doesn’t appear to be evidence for exceptional rates of erosion and deposition there during the Early Classic. I suspect this was due to incompatibilities between civic-ceremonial activities and swidden agriculture. During the Early Classic as the Uxbenká site core developed into an urbanized landscape, regular clearing and burning for annual crops was likely relegated to more peripheral locations and closer to domestic compounds positioned on hilltops outside the city center. It seems unlikely that the urban core was allowed to return to high forest during the Classic because maintaining an open viewshed within the civic-ceremonial core must have been a priority for the ruling elites. A possible alternative would be a form of arboriculture that kept economically or ritually important species (e.g., cacao, avocado, mango, ramon) within the site core for the benefit of the elites, perhaps a version of the “forest garden” originally proposed by Puleston (1978, 1982) and more recently promoted by Ford (2005) and others (e.g., Fedick 1996c; Wyatt 2008; for persistent effects of ancient forestry practices see also Ross 2011; Ross and Rangel 2011). This change in land use led to local soil stabilization and decreased erosion even as agricultural production in the larger polity intensified during the Classic Period.

The thick wedge of mixed dark soil and bedrock debris that covers the stable Early Classic soil in Zone 2 of the site core (exposed in AG3 and AG4) suggests an episode of mass-wasting and colluviation during the Classic Period estimated to at cal AD 280-610. The colluvial deposit is generally consistent with the soil and bedrock response to forest clearing described here, where topsoil runs off and the bedrock rapidly breaks down to form new soil, but this is inconsistent with the urban setting by the Early Classic. While the dry episodes recorded in the Macal Chasm speleothem could have contributed to an erosional event toward the end of the Early Classic, evidence for a possible tectonic event (exposed in AG3 and AG4) is a more compelling trigger for landscape destabilization in an otherwise stable setting. Taken together, the disturbance to the sandstone alignment, the discontinuity in the deeper sediments and the colluvial stratum suggest an earthquake caused the bedrock to shift and the sediments to slump at some point during or after the Early Classic Period sometime between cal AD 280 and 610. The potential for rapid *nib* mass-wasting was witnessed locally after a magnitude 7.3 earthquake struck on May 28, 2009, with its epicenter off the coast of Honduras. During a survey in east of the site core the *Ha'il Ayin* drainage (cf. Figure 3.2B) two weeks later I observed multiple scree piles and displaced boulders representing hundreds of cubic meters of debris in the stream channel. It seems likely that the population of Uxbenká witnessed a similar event in the site core during the Early Classic.

The Late Classic A horizon exposed in AG1 formed in a parent material with fewer clasts than the colluvium that buried the Early Classic soil after cal AD 280-610, suggesting it was formed from gradually accumulating slopewash rather than mass-wasting. Two charcoal dates in a deeply buried section exposed in AG11 indicate the presence of a Late Classic soil that was the source of that material on the slope above it. The three dates combined into a *phase* estimate the end of soil formation during the Late Classic or into the Terminal Classic at cal AD 610-960, after which time it was buried. It was a time of increasing dryness evident in the Cariaco, Lake Chichancanab and Macal Chasm climate records and the interval was punctuated by a series of marked droughts. The chronology of construction activities in the Uxbenká site core is not well known for the Late Classic Period, but stone monuments continued to be carved and dedicated until AD 781, and architecture and artifact assemblages evident on the surface of the site indicate that it still remained an urban space devoted to civic and ceremonial functions as well as maintenance of prestige tree-crops for elite use. Slight increases in slopewash associated with the Late Classic soil probably reflect the combination of increased aridity seen in the climate records and erosion/deposition processes establishing a new equilibrium after the possible Early Classic tectonic event.

Terminal Classic deposits in the site core comprise a buried charcoal-rich layer in AG8, and a date representing in-filling of bedrock channels in Zone 1 of the site core. The stratum exposed in AG8 is formed on a sediment deposit that buried a sandstone alignment now partly exposed in the corner of the unit. Though similar to the feature exposed in AG3, AG4, and AG6, it’s impossible to say whether they are contemporaneous (therefore dating to the Late Preclassic), or shared the same obscure function. The Terminal Classic stratum is characterized by a concentration of charred 1-2 cm diameter sticks that bears a strong resemblance to a *milpa* that was then rapidly buried. The fill in the lower section of AG1 appears to have been deposited during the Terminal Classic, possibly from slopewash derived from the uphill depression. The date range constraining initial deposition is cal AD 610-960, and the burial of the deposit by later colluvium is estimated to have begun from cal AD 890 to 1160. The Terminal Classic is a period of extremely dry conditions, and it is likely that this contributed to reduced vegetation cover around Uxbenká, making the soils more prone to erosion. However, it’s unclear whether there was still a substantial population in the region by this point, as there is no clear evidence of occupation in the site core at this time and stone monument production had come to a halt. It is possible, and perhaps even suggested by the presence of the burned layer itself, that smaller groups of farmers still resided in the area during the Terminal Classic after the civic and ceremonial core was abandoned. The Terminal Classic A horizon and subsequent sediment wasting may then be the result of clearing and burning during a period of already prolonged drought that magnified the effects of swidden agriculture at that time.

Conclusions

The geoarchaeological work at Uxbenká has defined two episodes of cultural activity that precede the earliest evidence for the leveling and construction of buildings in the urban core. Non-diagnostic ceramic sherds recovered from these A horizons provide the earliest evidence for human occupation in what later became the urban center. This is currently the earliest evidence for human activity in the area and is consistent with the hypothesis that a small farming population first colonized the area between ~900 and 800 BC. This pioneering agricultural activity also occurred during a dry climatic interval that may have destabilized the landscape further. Soil stability during the Middle Preclassic (~770-520 cal BC) occurred during a drying trend that was punctuated by several severe dry periods. This suggests that the landscape is fairly resilient under naturally dry conditions. Destabilization again coincided with the appearance of pottery and stone tools in the sediments at ~300 cal BC, but also with one of the more severe drying trends that likely contributed to deforestation and erosion. I argue that the absence of agricultural terraces and other soil retention features in the area surrounding the urban core results from naturally occurring soil retention features and the rapid decomposition of the mudstone bedrock favoring soil replenishment. I further argue that the overall stability of the landscape in the urban core between ~60 BC and AD 900 resulted from the absence or reduction of swidden cultivation in what was essentially an urbanized landscape used for civic-ceremonial activities and possibly stabilized by urban gardens and the cultivation of economically valuable tree crops. An episode of mass-wasting in the urban core occurred during the Early Classic sometime between cal AD 280 and 610, and is attributed to tectonic activity and associated hillslope failure, rather than human activities in the site core. Increased erosion and the burial of the Late Classic Period landscape is coincident with increasing evidence for swidden agriculture in the site core, possibly by a remnant or returning population of farmers after the political collapse of Uxbenká that occurred in the context of climatic and social instability during the Terminal Classic Period.

CHAPTER IV

MAIZE AGROECOLOGY AND POPULATION ESTIMATES FOR THE ANCIENT MAYA POLITY OF UXBENKÁ, BELIZE

This chapter was prepared as an unpublished co-authored manuscript with Dr. Bruce Winterhalder, Claire Ebert, Dr. Prufer, and Dr. Kennett. I conducted the field work to select maize plots and to collect soil samples, quantify harvest yields, and to organize and analyze the yield and soil chemistry data. I also conducted the analyses to convert estimated maize yields into the population estimates and predictions of settlement density in the project area. Dr. Winterhalder contributed to the field research design and sampling strategy, and provided guidance on integrating aspects of demographic theory in anthropology with the maize population estimates. Claire Ebert organized the yield data in a GIS database to produce the yield rasters, landscape coverages, and summary yield calculations. Dr. Prufer oversaw field work, and Dr. Kennett provided insights into the broader application of popualtion estimates in archaeological contexts.

Any explanatory model for the development and decline of human societies must come to terms with the Malthusian problem of food limitations (Wood 1998). Whether or not models are explicitly embedded within a neo-Darwinian evolutionary framework, the role of changing population size and density are important variables in key developments in human prehistory (e.g., Dumond 1975; Johnson and Earle 1987; Turchin 2003; Weiss 1976). These include the expansion of anatomically modern humans across the globe and their concomitant ecological consequences (Burney and Flannery 2005; Erlandson 2001; Fitzhugh and Kennett 2010; Goebel et al. 2008; Kennett et al. 2006; Kirch 2000; Martin

2005; Steele 2010), the transition to agriculture and subsequent spread of agricultural populations from multiple centers (Barker 2008; Bellwood 2005; Childe 1928, 1951; Diamond and Bellwood 2006; Kennett and Winterhalder 2006; Piperno and Pearsall 1998; Smith 1998, 2001; Trigger 2003; Zeder 1991), intensification of food production and the emergence of social and technological complexity (Arnold 1992; Boserup 1965; Carniero 1970; Cohen 1977; Kennett 2005), and the integration and decline of institutions and state-level societies (Demarest 2004, 2007; Johnson and Earle 1987; Kennett and Kennett 2006).

Population change has been cited on a conceptual level as either a cause or a consequence of sociopolitical change, suggesting at a minimum a dynamic relationship between population density and sociopolitical formations (Turchin 2003). Models of Human Behavioral Ecology (HBE), including the Ideal Free Distribution (IFD) and the Ideal Despotic Distribution (IDD), formalize explicit relationships between population density and access to suitably productive habitats, and population dependent decreases in habitat suitability (e.g., Kennett and Winterhalder 2008; Kennett et al. 2009; McClure et al. 2006; Sutherland 1996; Winterhalder et al. 2010). Advances in theoretical population biology and computational modeling allow for the exploration of long-term interactions of ecological, demographic and social variables in past societies and the dynamic effects on human decision making (Lee et al. 2008, 2009; Puleston and Tuljapurkar 2008; Tuljapurkar et al. 2007). Meaningful applications of such models and simulations to a specific prehistoric context must be guided by empirical data that archeologists and human ecologists can provide about past environmental conditions, technological organization, land-use patterns, settlement structure and population.

The consideration of population dynamics in ancient Maya society is strongly dependent upon the ecological constraints of maize agriculture in the Neotropics and its relationship to the emergence of social inequality and complex political systems. The early 20th century notion of Maya polities as vacant ceremonial centers was based on the assumption that the extensive swidden system of maize production could not support substantial populations (Culbert and Rice 1990: xix). However, settlement surveys in the 1940s and 1950s brought to light large numbers of house mounds that indicated greater populations than previously thought, and by the early 1980s evidence of agricultural intensification in the form of raised fields and constructed terraces suggested the potential for higher levels of food production than had been assumed from ethnohistoric accounts (Adams 1980; Adams et al. 1981; Chase and Chase 1998; Harrison 1993, 1996; Puleston 1978; Turner and Harrison 1983). This evidence suggested that population pressure – often represented theoretically by Bosreup's (1965) model of intensified food production – was a prime mover in the emergence of Maya sociopolitical complexity. State-level development started sometime in the Preclassic Period, when the demands for centralized labor and resource management provided conditions for political hierarchies to develop (e.g., Adams 1977; Demarest 2007:162; Turner and Harrison 1978).

The role of population pressure in both the emergence and decline of ancient Maya polities (and other state-level societies) is contentious for theoretical and empirical reasons. Cowgill (1975a, b) argued that the assumption of inevitable population growth isn't borne out in ethnographically known small agricultural groups thought to be comparable to Preclassic Mesoamerican peoples. Rather, most small farming populations effectively maintain growth rates below a potential maximum through a number of biological and social mechanisms. The conditional nature of that rate is seen when populations expand rapidly in new environments or new sociopolitical contexts, but under most circumstances constant population growth cannot be assumed, and is argubaly a "non-explanation" of social change (Cowgill 1975a). At the other end of the arc of state development and collapse, Webster (1985) criticizes the idea that the economic burden of non-productive elites and specialists triggered sociopolitical tensions and the Maya collapse. The problem is defining the population size and demand for resources with respect to the productive capacity of the land and the agricultural system in place during the Classic Period. Characterizing the relationships between these variables is key to understanding the dynamic interaction between population density and sociopolitical change.

Archaeologists have estimated ancient population sizes from various lines of evidence including skeletal remains (cf. Wood et al. 1992), frequency of radiocarbon dated components (Erlandson et al. 2001; Rick 1987), summed radiocarbon probabilities (Buchanan et al. 2008; Shennan and Edinborough 2007), artifact consumption patterns, and projecting ethnographic population estimates into the past (Haviland 1969). In the Maya region settlement surveys at Tikal in the 1960s and 1970s (e.g., Haviland 1969, 1972), were used to derive population estimates from the number of domestic structures occupied through time, making assumptions about the relationship between structure size and function, number of occupants, and finally extrapolating from sampled portions of the landscape to the entire populated area of the polity (e.g., Culbert and Rice 1990, and studies therein). The settlement method of population estimation has the advantage of directly reflecting past human presence on the landscape. The connection between domestic structure density and population density across a region makes intuitive sense, but it does require a robust survey coverage that ideally employs test-pitting and artifact recovery to establish an occupational chronology (Culbert and Rice 1990; Webster et al. 2000).

Practical challenges to achieving such a settlement coverage in the Maya lowlands are many and include: 1) poor visibility of low house platforms in secondary tropical forest or scrubby bush; 2) the potential for buried components (e.g., Ashmore et al. 1990 for Quiriguá); 3) absence of datable materials or ambivalence towards chronological methods (e.g. with respect to obsidian hydration (see Braswell [1992, 1996] vs. Webster et al. [2004]); and 4) the large investment of time and financial resources necessary (Webster et al. 2000). Arguably, few ancient Maya centers have received the years of focused investigation that would be required to produce an "adequate" settlement sample, perhaps with the exception of two of the largest, Tikal and Copán (see Webster et al. 2000)

Estimating population size through study of the agricultural potential of a Maya polity's resource catchment provides another route of inquiry when settlement data is lacking. Importantly, it can serve as an independent line of evidence to test archaeologically derived estimates. One method is to iteratively model population change based on agricultural productivity, informed by in-field soil survey, estimations of erosion and recovery rates, mode of production (including fallow time and level of intensification) and other ecological variables (Kohler and van der Leeuw 2007; Wingard 1992, 1995). Simulations allow for testing the effects of individual variables to isolate and identify the most influential factors in a complex system. They are necessarily diachronic and therefore amenable to historically, processually and evolutionarily-oriented archaeological investigations. They often lead to unexpected insights into the relationships between complex sets of processes (Kennett and Winterhalder 2006; Lee et al. 2008, 2009; Puleston and Tuljapurkar 2008; Tuljapurkar et al. 2007; Webster et al. 2000; Winterhalder et al.1988; Winterhalder and Goland 1993; Winterhalder and Lu 1997).

Various authors have worked from ethnographic and ethnohistoric data on maize (or other crop) production to estimate carrying capacity of a presumed area of cultivated land around ancient Maya polities (e.g., Cancian 1965; Carter 1996; Puleston 1982; Reina 1967; Reina and Hill 1980; Stadelman 1960; Tax 1954). Applying such data to a specific archaeological setting requires careful evaluation of the comparability of the ecological zones being considered (climate, geology, soils) and the mode of production being practiced (e.g., level of mechanization, land tenure system, market engagement). The site of Uxbenká provides a unique situation where contemporary Maya farmers from the village of Santa Cruz are cultivating maize on the same lands as their ancient counterparts in a largely non-mechanized swidden subsistence system. Here I use data on maize yields collected in 2009 and 2010 to estimate overall yields for the lands around Uxbenká and the maximal population density the ancient polity could have supported at its height during the Late Classic period (AD 600-800). This effort to derive a synchronic estimate of maximal possible population at Uxbenká is not considered to be a definitive statement, but the first step towards developing more complex and demographically-informed population models in the future (e.g., Lee et al. 2008, 2009; Puleston and Tuljapurkar 2008; Tuljapurkar et al. 2007). Analysis of the local-level factors (soil characteristics, slope, planting technique, etc.) that affect agricultural yields is an equally important objective of this research. Better understanding of the causes of yield variation is also an important and generalizable result of empirical work on ancient and contemporary Maya food-production systems.

Setting and Background

The Maya village of Santa Cruz is located in Toledo District in southern Belize (Figure 1.2). Approximately 400 people live in this village, which is located between the neighboring communities of San Jose, Santa Elena and San Antonio. These reservation lands have been cultivated under a traditional communal land tenure system for many generations (Wainwright 2007). Government of Belize census data and fieldwork in 2006 by Wainwright (2007) indicate that the population is primarily Mopan (86%) and K’ek’chi (14%) Maya. The typical seasonal round of maize cultivation in Santa Cruz generally adheres to the patterns described by Wilk (1984, 1991) for other K’ek’chi and Mopan Maya subsistence farmers in the Toledo District. It begins in the driest months of the year (February/March averaging 40-70 mm/mo; Heyman and Kjerfve 1999; Wright et al. 1959) when community members decide through informal discussions where to clear land for their *milpas* (typically ranging from ~1-1.5 ha). Individuals or labor-exchange groups cut patches of secondary forest or high bush. Land is cleared primarily by hand with machetes, however in recent years a few (i.e., <5) chainsaws have been purchased by individuals and are sometimes used to fell larger trees. Ideally the felled vegetation is burned a week or two before the onset of the rainy season in May or June, and fields are planted shortly before rains are expected to begin. This crop grows through the wet summer months when rainfall ranges from 400 to 700 mm/mo (Hartshorn et al. 1984; Heyman and Kjerfve 1999; Wright et al. 1959) and cobs are dried on the stalk to be harvested starting in late September or early October.

At this time a second crop is planted in *matahambre*, which is similar to *milpa*, but the felled vegetation is left as a mulch rather than burned. The *matahambre* maize crop grows slower than the *milpa* crop due to the cooler and drier weather and it is available to harvest in February. In the ethnographic literature the term *matahambre* typically refers to a second maize crop planted on seasonally inundated floodplains and levees (e.g., Reina 1967; Wilk 1991). The wet season planting done in upland settings around Santa Cruz and other villages does not fit the classical definition of *matahambre* except in its literal Spanish sense of 'killing hunger'.

Arable soils around Santa Cruz are derived from the Toledo Beds, a series of Tertiary interbedded calcareous mudstones, sandstones and shales that are bordered to the south by a prominent Cretaceous limestone karst ridge (Keller et al. 2003; Miller 1996; Wright et al. 1959). The karst, locally known as "The Rock Patch," contains several caves that are the subject of on-going archaeological research (Prufer et al. 2011). This karst ridge dominates the drainage of the largest local stream, Rio Blanco, which flows with its tributaries over the Tertiary beds south until meeting the southwest-northeast trending ridge where it abruptly turns to the east. Eventually the Rio Blanco enters the karst at Oke'bal Ha Cave and exits as Blue Creek to the south at Hokeb Ha Cave (Miller 1996). The rock patch itself is generally considered too steep and the soils too thin for cultivation by most Santa Cruz farmers, though it is used as a source of forest products for house construction, traditional medicinal plants, and small game hunting (TMCC 1992; cf. Steinberg 1998 for similar forest use in San José village to the north).

No formal ethnopedological study has been conducted in Santa Cruz, but it is known that farmers make many fine and broad distinctions among the arable soils around the village. The broadest practical distinction is between the *box lu'um*, well-drained black clay loams largely distributed to the north of the village and at the base of the rock patch, and the *chik lu'um*, poorly-drained oxidized reds soils primarily found in the village itself and to the south within ~500-750 m of Rio Blanco. *Box lu'um* is favored for almost any crop, whereas the heavy *chik lu'um* is primarily devoted to dry rice crops and rarely for maize, which produces poorly under waterlogged conditions.

The seed stock for the *milpa* and *matahambre* crops are either saved by farmers from previous harvests, traded or purchased within the village or less often acquired from farther afield (e.g., from *cobañeros* in Guatemala). Mopan Maya farmers refer to some of these varieties as "hybrid" corn, but it is unclear if these represent industrially-bred lines, and more importantly whether they would remain true to type after multiple years of cultivation. A great deal of ethnographic work would be required to identify the many distinct land-races in circulation in Santa Cruz village, but they can be broadly characterized as either long (e.g., *shanil nul, box holoch*) or short varieties (e.g., *chaparro, bejuco*). These names simultaneously refer to both the time to harvest and the length of the husk with respect to the length of the cob. No significant differences in yields have been observed between them. The decision to plant one or the other appears to depend mainly on the farmer's estimate of when the extant household supply of dried maize will run out. Harvesting a short corn 2-3 weeks earlier may be the difference between sustenance and temporary shortfall. The timing of harvest can also be disrupted by delays in planting caused by late rains, scheduling conflicts with wage labor commitments outside the village, illness, and other factors. Selecting a short variety helps mitigate the late planting. A major disadvantage of short corn is greater susceptibility to weevils and rot because the shorter husk provides less protection than in a long corn. Unlike long varieties, short varieties cannot be saved for more than ~6 months and must be replanted with each *milpa* and *matahambre* crop to save the seed, sometimes in a small (e.g., 25 x 50 m) plot on the edge of the field.

The ancient Maya polity of Uxbenká is located on Santa Cruz lands, and the village itself is nearly superimposed on the ancient city. The urban core of Uxbenká covers an approximate area of 526 ha and comprises six plaza groups on leveled ridgelines in the hilly landscape (see Figure 2.1). Group A contains the remnants of 23 carved sandstone stela dating to the Early and Late Classic periods and is presumed to be the main ceremonial locus at the site (Prufer et al. 2011). Groups B-F are a contiguous arrangement of plazas running along a ridgeline roughly 400m to the northwest of Group A. The Group B plaza is a flattened hilltop and is surrounded by a series of range structures, a large platform mound at its northern extent, and a ballcourt stands opposite this at the south end of the plaza. A second ballcourt is located adjacent to the Group D plaza.

Construction in Uxbenká's urban core began in the Late Preclassic, with the earliest known structure in Group A dating to 60 cal BC - cal AD 220 (Culleton et al. 2012). The massive effort of leveling and expanding ridgelines to form the Group B and D plazas occurred slightly later, but still at the end of the Late Preclassic between cal AD

60-310 and cal AD 20-240, respectively. There was a flurry of replastering and plaza renovation activity until the first part of the Early Classic Period, and then less evidence for building activity between cal AD 350 and 550. Architectural modifications are documented at Groups A, B, and D after AD 550, including extensive plastering of plaza floors, laying paving stones, and the augmentation of facades on existing structures. The latest dedicatory date preserved on stelae at Group A indicates that monument carving continued until AD 781. Political disintegration and the abandonment of this city in the Terminal Classic are topics of ongoing research at Uxbenká, but there is currently no evidence for a Post-Classic (after AD 1000) occupation of the site.

Geoarchaeological investigations at Uxbenká provide evidence for early land-clearing and erosion during the Middle Preclassic Period (ca. 970-620 cal BC), general landform stability through the Classic Period (AD 300-800), and another episode of erosion during the Terminal Classic (AD 800-900). This has been interpreted as the shift from agricultural to urban land uses and back across the last several millennia (Culleton et al., nd). There is little archaeological evidence for agricultural intensification in the form of terraces or raised fields during the site's history. This may be explained by the capacity of the mudstone and sandstone bedrock to rapidly break down and form new soils when exposed to weathering, a process that contributes to the "paradoxical" fertility of the soils around Uxbenká and may play a role in the persistence of traditional swidden cultivation in the region (Culleton et al. nd; Hartshorn et al. 1984:76-77). The physical proximity of the Santa Cruz village to Uxbenká, the co-location of ancient and contemporary land-uses, and the relatively low levels of intensification or technological elaboration in the past and present farming systems provide a unique opportunity to empirically estimate present day productive capacity of the land as a means to infer the potential population supported at Uxbenká during its height in the Late Classic Period.

Methods

Arrays of 10x10 m sampling plots in planted *milpas* were selected in cooperation with farmers and village representatives in a variety of settings around Santa Cruz in June 2009 and 2010. Slope and aspect of each plot were determined in the field with combined compass and inclinometer. Slope was recorded in 5° increments and was converted to an integer scale for regression analyses (e.g., 0-5° = 1, 5-10° = 2, etc.). UTM coordinates were recorded with handheld GPS for integration with a GIS database. Working from a digitized and orthorectified soils GIS basemap, each plot was also assigned a productivity ranking based on Wilk's (1981, 1991) classification of southern Belize soil types as mapped and described by Wright et al. (1959). Following Wilk (1981), plots were ranked on a scale from 0 (unusable) to 3 (good). Soil samples were collected from each plot at a depth of 10-15 cm below the surface and analyzed for organic and inorganic carbon content through loss-on-ignition (Dean 1974; Heiri et al. 2004) at the University of Oregon, and for soil chemistry data (i.e., N, P, K, pH) at Oregon State University's Central Analytical Lab.

At the end of the growing season in late September and October, all corn within each plot was broken by hand, and the number of *suk'ub* (Mopan: plantings) and individual ears was counted. Bulk maize was weighed on a hanging scale to produce an estimate of yield in kg/ha. During the first season, in a sample of roughly half the plots (n=19 of 40), the corn was completely skinned and shelled, and the composition of edible corn, waste corn, husk and cob were determined. Waste corn mainly results from weevil infestation, rot due to fungus or bacteria, and sprouted corn. Usually only a small portion of each ear was considered inedible, and was separated during shelling and fed to pigs. The compositional data indicate a strong significant positive correlation between whole ear weight (*x*) and yield of edible corn (*y*): Pearson's $r = 0.982$; $r^2 = 0.965$; $p < 0.00001$; $y = 0.635x - 1.222$. A less strong but also significant relationship is found between whole ear weight and waste maize: Pearson's $r = 0.726$; $r^2 = 0.527$; $p < 0.0005$; $y = 0.099x + 0.138$. Additional data from 2010, when all plot samples (n=40) were completely skinned and shelled, bear out this relationship: edible maize, Pearson's $r = 0.955$; $r^2 = 0.911$; $p < 0.00001$; $y = 0.601x - 0.077$; waste, Pearson's $r = 0.415$; $r^2 = 0.172$; $p = 0.008$; $y = 0.055x + 1.051$. It is on this basis that bulk yields (kg/ha) are later converted into edible yields (kg/ha) (Figure 4.1).

Examination of the bulk yields data indicates they were strongly dependent upon planting density, or the number of *suk'ub* per plot (Pearson's $r = 0.722$; $r^2 = 0.521$; $p < 0.0001$; $y = 41.45x + 540.74$; see Figure 4.2). Planting density varies in the modern setting for many reasons: shorter maize varieties can be planted closer together than taller ones; maize intercropped with other plants (e.g., *pepitorio*) is more widely spaced to reduce overshadowing; steeper slopes may be planted more densely if they are well exposed; avoiding physical obstacles like unburned timber, rocks, or shallow soil may force the plantings further apart; and, of course, using traditional sowing techniques (i.e., digging sticks and hand-casting seed) means that each farmer's spacing differs based on the length of his gait, willingness to negotiate physical obstacles, and other idiosyncratic factors. The average number of *suk'ub* in the 100 m^2 plots is roughly 55, or a planting

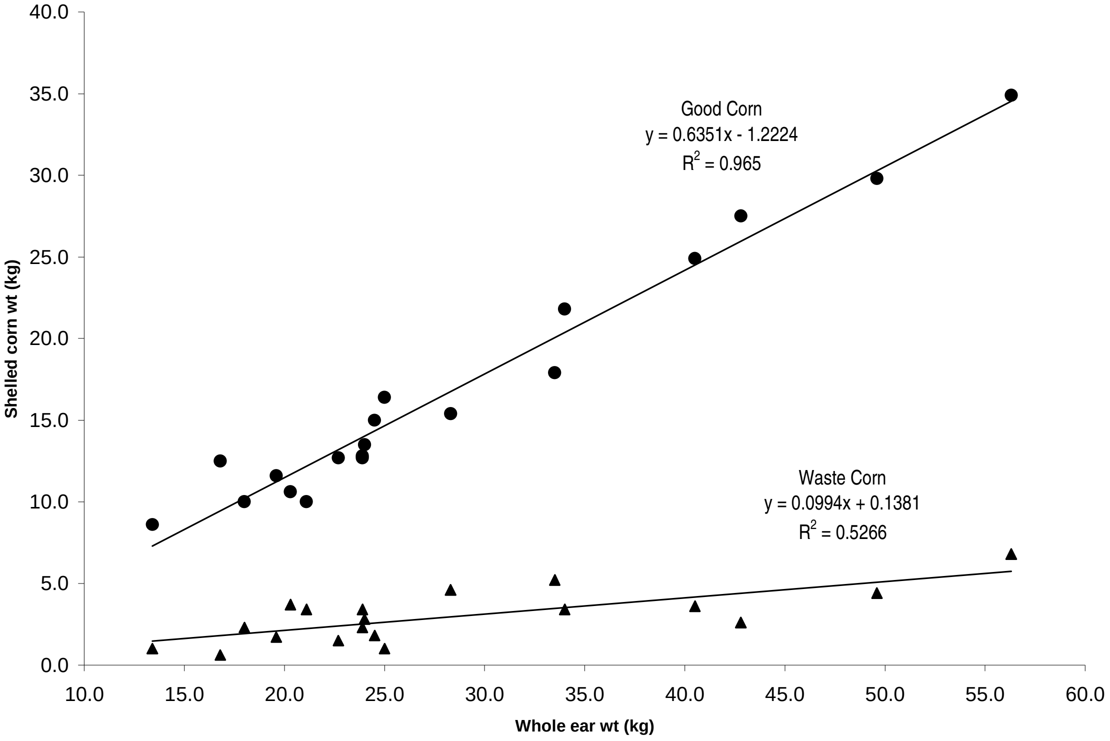


Figure 4.1. Scatterplots of edible (circles) and waste (triangle) maize vs. whole ear weight for test plots on Santa Cruz milpas.

density of 5500/ha, while the majority range between 40 and 70 *suk'ub* per plot (4000 – 7000/ha).

To remove the effects of planting density, data were normalized by conversion to yield per number of plantings (Tables 4.1 & 4.2). This indexed yield more closely reflects the underlying productivity of the soil, and so regressions of other environmental variables against this value are more likely to identify key causal variables. Although the resulting unit *kg/ha/suk'ub* makes sense as a general productivity measure it is not easily compared to other ethnographic data where yields are reported as production per unit area (bushel/acre or kg/ha; e.g., as summarized by Barlow 2002:71). To compare yields directly, values are normalized assuming an average density of 5500 suk'ub/ha.

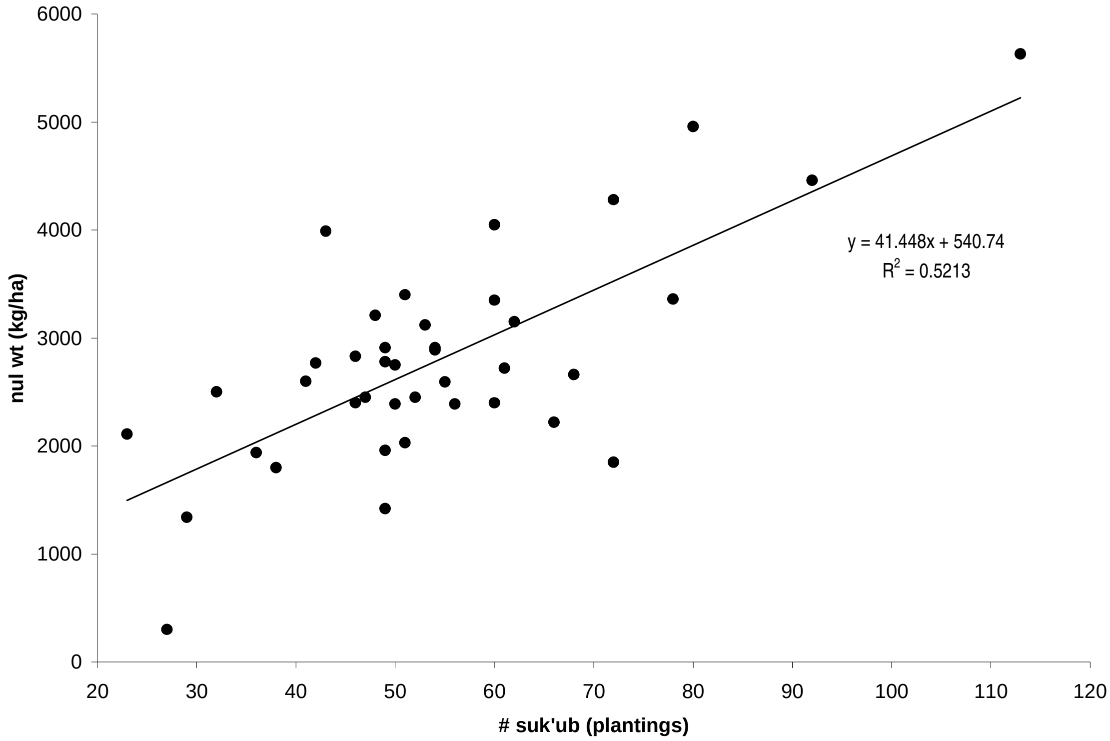


Figure 4.2. Relationship between bulk maize yield (kg/ha) and number of plantings per sample plot.

Table 4.1. 2009 bulk, edible and normalized maize yields

Lot#	Bulk Maize (kg/ha)	Edible corn (kg/ha)	Normalized Yield (kg/ha/ suk'ub)	Lot#	Bulk Maize (kg/ha)	Edible corn (kg/ha)	Normalized Yield (kg/ha/ suk'ub)
19141	5630	3574	31.63	19153	1850	1174	16.30
19142	2390	1517	27.08	19154	2889	1834	33.96
19143	3400	2158	42.32	19155	2220	1409	21.34
19144	2830	1796	39.05	19156	1420	901	18.38
19145	1800	1142	30.05	19157	2720	1726	28.30
19147	1340	850	29.30	19158	2780	1764	36.01
19148	2500	1587	49.58	19159	2600	1650	40.24
19149	1960	1244	25.38	19162	2910	1847	37.69
19150	4050	2571	42.85	19163	1940	1231	34.19
19151	2400	1523	25.38	19164	2400	1523	33.11
19152	3350	2126	35.44	19165	2910	1847	34.20
19160	2110	1339	58.21	19167	300	189	7.01
19161	2450	1555	33.08	19183	3990	2533	58.90
19178	4280	2717	37.74	19184	4460	2831	30.78
19179	4960	3149	39.36	19185	3120	1980	37.36
19180	3360	2133	27.34	19186	3210	2037	42.45
19181	2594	1646	29.93	19187	2770	1758	41.86
19191	2390	1517	30.33	19188	2750	1745	34.91
19193	2450	1555	29.90	19189	3150	1999	32.25
19194	2030	1288	25.26	19190	2660	1688	24.83

Table 4.2. 2010 bulk, edible and normalized maize yields

Lot#	Bulk Maize (kg/ha)	Edible corn (kg/ha)	Normalized Yield (kg/ha/ suk'ub)	Lot#	Bulk Maize (kg/ha)	Edible corn (kg/ha)	Normalized Yield (kg/ha/ suk'ub)
40701	4540	2740	38.06	40728	3640	1600	25.00
40702	3650	2100	34.43	40731	2580	1470	31.96
40703	1160	730	11.59	40732	3840	2040	37.78
40704	4700	3000	55.56	40733	2530	1630	31.96
40705	2650	1750	40.70	40734	4160	2560	49.23
40706	2580	1620	36.00	40737	3320	1900	29.69
40707	3900	2560	43.39	40738	3390	1920	45.71
40708	4090	2670	49.44	40739	3840	2540	44.56
40709	2630	1760	31.43	40740	2340	1420	25.36
40710	3390	2100	32.31	40741	3290	1780	34.90
40712	1330	800	14.55	40742	4580	2750	41.67
40713	2300	1530	24.29	40743	3590	1920	24.94
40714	2610	1730	31.45	40744	3640	2000	31.25
40721	3090	2000	32.26	40745	2840	1490	21.59
40722	3420	2110	30.58	40746	2730	1350	19.85
40723	1250	780	15.00	40748	1960	1180	20.00
40724	2030	1210	22.41	40749	2800	1580	27.72
40725	2490	1310	22.98	40750	4190	2700	42.19
40726	1720	890	14.83	40751	2420	1540	29.62
40727	2590	1640	26.89	40752	1880	1220	23.92

Comparing normalized whole ear weight for 2009 and 2010 maize yields show similar mean and range values despite differing planting conditions (Figure 4.3). Farmers in Santa Cruz considered 2009 a “bad” year for maize. The late onset of the dry season combined with sporadic and heavy midday rains through May kept chopped vegetation in *milpas* moist and difficult to burn. This was followed by dry conditions during the summer (rainy) growing season. By October most farmers were breaking corn in earnest, and many were clearing fields for an earlier start on the *matahambre* crop to make up for anticipated shortfalls. By contrast 2010 had a more predictable termination to the dry season and rains persisted through the summer rainy season. Farmers were less concerned with breaking *milpa* crop or clearing *matahambre* early compared with the previous year and more time and effort was instead devoted harvesting rice as a cash crop. Despite these differences the mean yields between 2009 and 2010 are statistically indistinguishable using a t-test with unequal variances (52.5 kg/ha/suk’ub in 2009 vs. 51.9 kg/ha/suk’ub in 2010; p = 0.870; Ruxton 2006). This sample is small and on-going

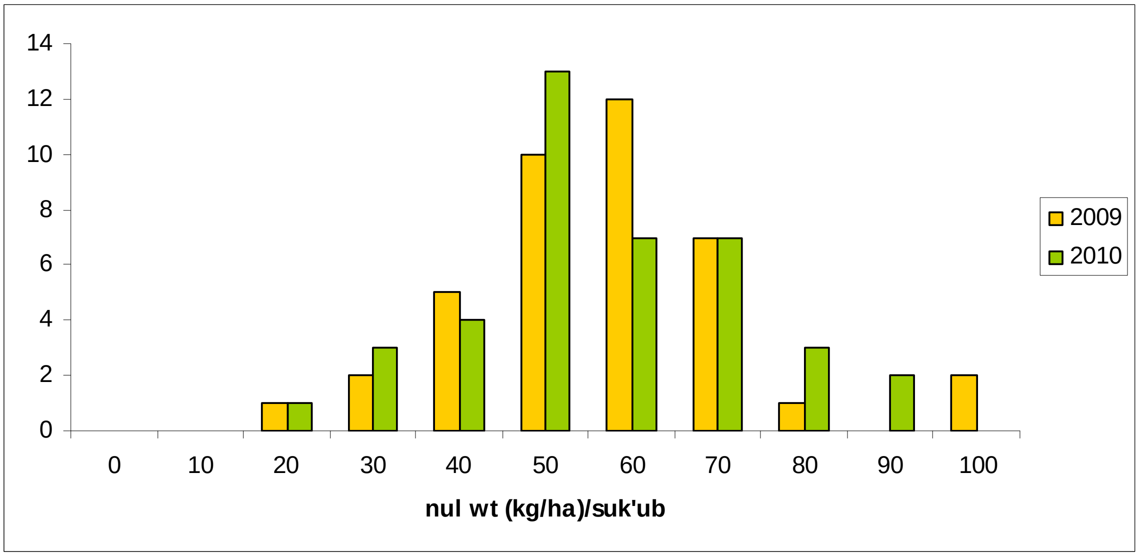


Figure 4.3. Comparison of 2009 and 2010 density-normalized maize yields. Means are statistically indistinguishable using a t-test with unequal variances (2009 = 52.5 kg/ha/suk'ub; 2010 = 51.9 kg/ha/suk'ub; p = 0.870).

work is focused on determining how the timing of the dry and rainy season rains may impact crop yields. Rain and temperature gauges have recently been installed in Santa Cruz village and are starting to provide quantitative meteorological data that can be compared with land-clearing and planting schedules. The data currently available suggest that a wide variety of variables act in concert to produce the observed more-or-less normally distributed range of yields across the landscape and over time.

Spatial variability in the productivity of maize on lands surrounding Santa Cruz and Uxbenká are detailed in the next section. I also compared edible maize yields in kg/ha and density normalized yields in kg/ha/suk'ub against multiple environmental variables (i.e., soil nutrients, pH, slope, aspect, and distance from Santa Cruz village Figures 4.4 and 4.5). Regressions made against log-transformed, density-normalized data show no correlations between yields and these variables for each year with the exception of a weak correlation between K (potassium) and yield in 2010 (Tables 4.3 and 4.4).

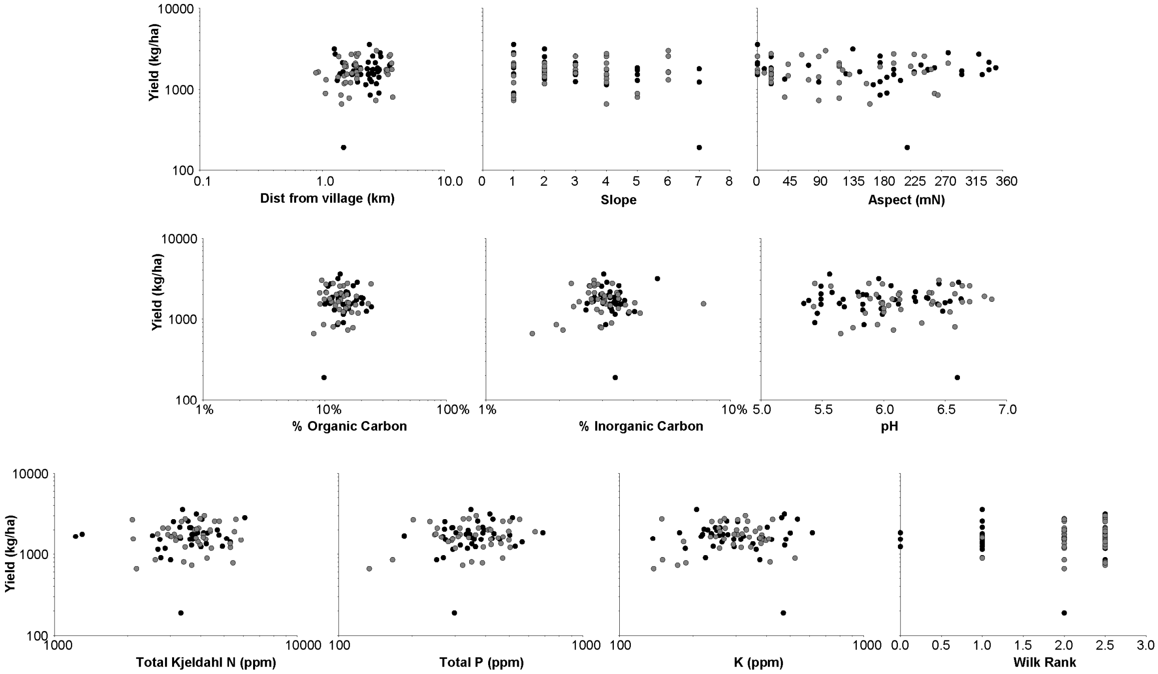


Figure 4.4. Scatterplots of bulk maize yields (black circle: 2009; grey circle: 2010) vs. environmental variables, showing the range of scatter and lack of correlation.

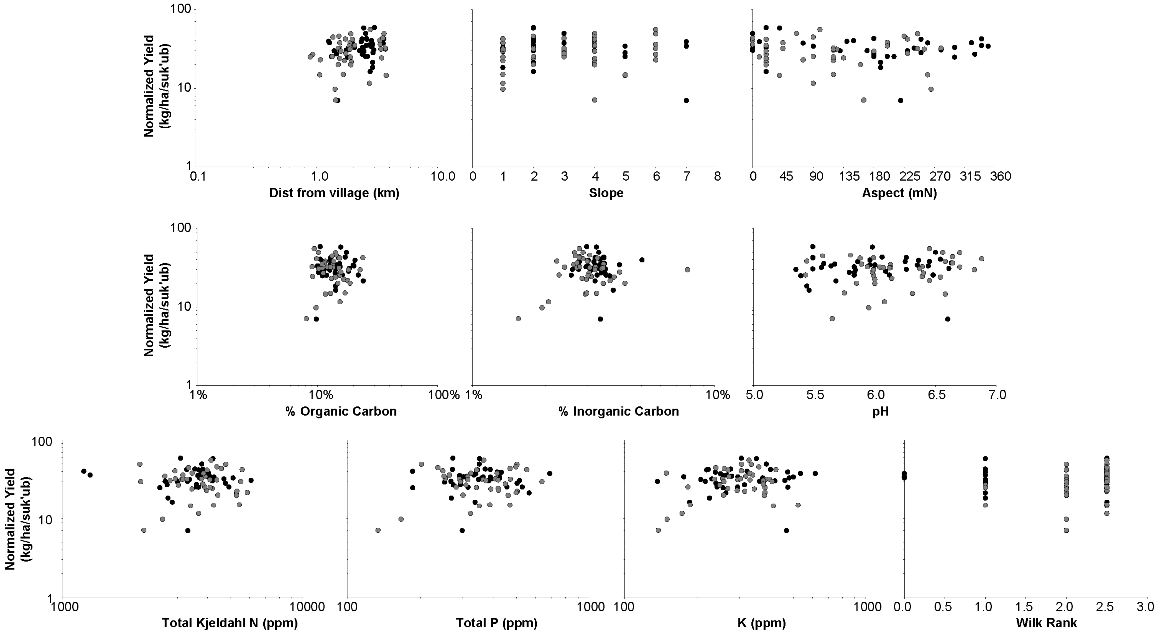


Figure 4.5. Scatterplots of density-normalized maize yields (black circle: 2009; grey circle: 2010) vs. environmental variables, showing the range of scatter and lack of correlation.

The two-year aggregated data show also show a weak correlation between K and yield (Table 4.5).

Table 4.3. Regression of 2009 log-transformed maize yield normalized for planting density with respect to environmental variables.

Edible maize (kg/ha/suk'ub) vs.	Pearson's r	r^2	p-value	regression equation
Distance from Santa Cruz (km)	0.227	0.051	0.159	y =0.29x + 1.60
Slope Index	0.172	0.030	0.287	y = -0.10x + 1.73
%OC	0.073	0.005	0.656	y = 0.11x + 1.79
%CO_3	0.042	0.002	0.803	y = -0.12x + 1.52
pH	0.015	<0.001	0.928	y = 0.08x + 1.64
K (ppm)	0.005	0.003	0.753	y = 0.05x + 1.56
TKN (ppm)	0.017	<0.001	0.916	y = 0.02x + 1.63
TP (ppm)	0.048	0.002	0.764	y = 0.06x + 1.53

Table 4.4. Regression of 2010 log-transformed maize yield normalized for planting density with respect to environmental variables.

Edible maize (kg/ha/suk'ub) vs	Pearson's r	r^2	p-value	regression equation
Distance from Santa Cruz (km)	0.122	0.015	0.451	y = 0.13x + 1.64
Slope Index	0.207	0.043	0.201	y = 0.13x + 1.62
%OC	0.073	0.005	0.658	y = 0.12x + 1.78
%CO_3	0.264	0.070	0.104	y = 0.44x + 2.35
pH	0.216	0.047	0.179	y = 1.47x + 0.51
K (ppm)	0.403	0.162	0.010	y = 0.54x + 0.35
TKN (ppm)	0.096	0.009	0.556	y = 0.15x + 1.14
TP (ppm)	0.287	0.082	0.073	y = 0.36x + 0.76

Table 4.5. Regression of 2-year aggregated log-transformed maize yield data normalized for planting density with respect to environmental variables.

Edible maize (kg/ha/suk'ub) vs	Pearson's r	r^2	p-value	regression equation
Distance from Santa Cruz (km)	0.173	0.030	0.125	y = 0.19x + 1.63
Slope Index	0.031	<0.001	0.783	y = 0.02x + 1.68
%OC	0.082	0.007	0.473	y = 0.13x + 1.80
%CO_3	0.187	0.035	0.103	y = 0.36x + 2.23
pH	0.094	0.008	0.403	y = 0.56x + 1.25
K (ppm)	0.231	0.053	0.039	y = 0.27x + 1.01
TKN (ppm)	0.048	0.002	0.669	y = 0.07x +1.45
TP (ppm)	0.187	0.035	0.097	y = 0.24x + 1.07

Maize Yields and Modern Populations

Geographic Information Systems (GIS) were used to interpolate the productivity of the lands surrounding Santa Cruz and Uxbenká (bulk yields normalized to planting density).

The locations of *milpas* sampled in 2009 and 2010 were plotted in ArcGIS 10.0 along with archaeological settlements and the architecture within the Uxbenká site core. The normalized yield or yield index *(kg/ha/suk'ub)* was interpolated between plots with the Spatial Analyst toolset using a Nearest Neighbor method that assigns values to locations based on the surrounding measured values. Each 18.5 m 18.5 x 18.5 m (0.034225 ha) cell has an associated yield index value ranging from 11.8 – 92.9 kg/ha/suk'ub, with an average value of 47.9 kg/ha/suk'ub (Figure 4.6). The distinction between the more fertile *box lu'um* and the less favorable *chik lu'um* soils influences the raster in two ways. The general north to south gradient of greater to lesser maize yields does map on to the known distribution of the soils in Santa Cruz described earlier, with the *chik lu'um* located primarily between the village and the Rio Blanco. At the same time, there are relatively few maize plots on the *chik lu'um* because *milpas* in this zone are typically planted in dry rice and samples are therefore difficult to obtain. A t-test assuming unequal variances run on the 3 *chik lu'um* samples vs. the majority of the plots positioned to the north of the village on *box lu'um* soils (n = 75-77 depending on the variable) does show a significant difference between the sample means in % organic carbon ($p < 0.002$; *chik lu'um* mean = 9.2%; others = 14.2%). Further soil sampling will be directed towards the area south of the village in future field seasons.

The exact political boundaries of Santa Cruz are in the process of being determined by local community leaders, but Santa Cruz village lands are estimated to be approximately 16.08 km^2 for the purposes of this study based on the recent history of land use practices. *Milpas* are not planted in a buffer zone of ~0.5 km around the village, corresponding to the range that domestic pigs will travel to forage. Removing this 1.63

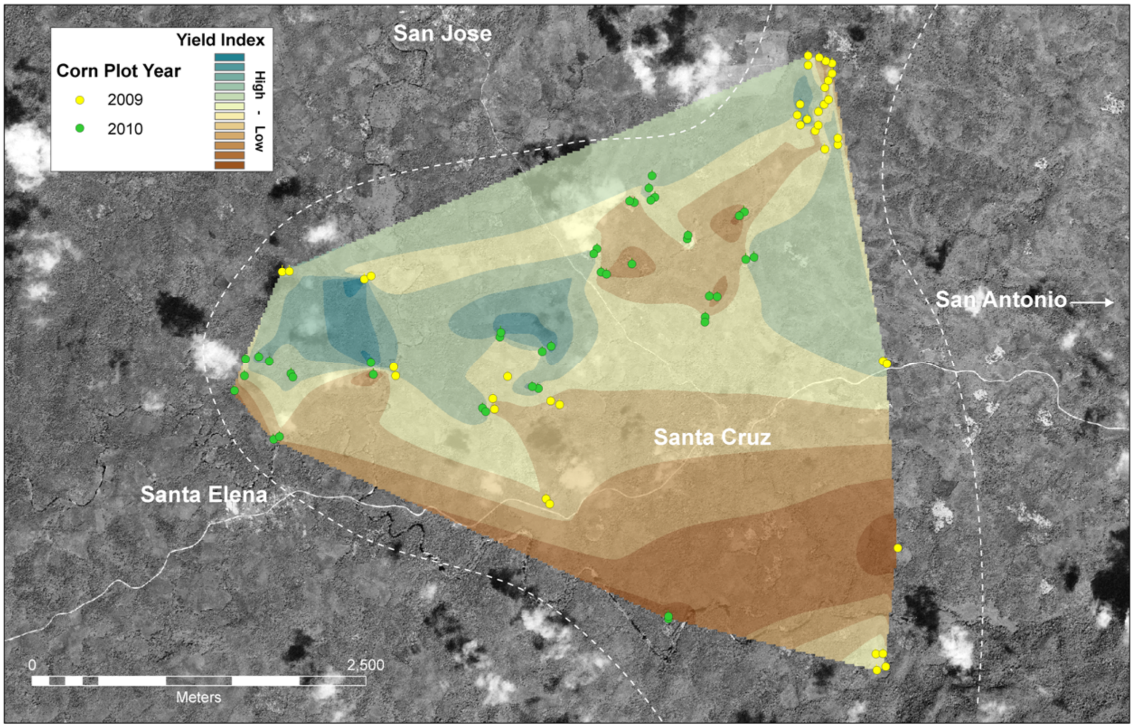


Figure 4.6. Interpolated raster of maize yields around Santa Cruz village (image created by C. Ebert).

km^2 area from analysis, total arable land available to farmers in Santa Cruz is estimated to be 14.45 km^2. The total area of Santa Cruz land cultivated in 2009 and 2010 was estimated from a satellite image (Worldview II) taken in April 2010 that covers a 100 km^2 around Santa Cruz/Uxbenká. This image provides ~60 cm resolution and is composed of 8 multispectral bands that include Red Edge (705 - 745 µm) and Near infrared (IR) bands (760-900 µm). The color IR image (including the red edge band) was used for photo interpretation due to its broader spectral resolution that allowed cleared agricultural plots to be distinguished from the surrounding vegetation. A total of 134 fields were identified and digitized for both years totaling 209.88 ha, an average of 104.94 ha of land cultivated each year. The total cultivated land comprises both *milpa* and *matahambre* cultivation of subsistence crops such as maize, beans, and ground foods, as well as cash crops including dry-field rice and seed pumpkins (*pepitorio*). A total of 111 *milpas* fall into the raster area and represent a total area of 168.52 ha.

As discussed earlier, the yield index is a normalized value that accounts for the influence of planting density on potential yields expressed as kg/ha/*suk'ub*. The average yield index for the raster is 47.86 kg/ha/*suk'ub*. Taking representative values of 4000, 5500, and 7000 *suk'ub*/ha (see above), the yield index can be converted to bulk yield (kg/ha) to model low, medium, and high yield scenarios. Note that for heuristic purposes these scenarios could also be used to approximate variation caused by weather conditions, pest activity, theft, etc.

To get a sense of how realistic the interpolation and average yield index might be for estimating the ancient population at Uxbenká, I converted the yield index into absolute yields based on the area currently cultivated by farmers (i.e., 104.49 ha) to compare these modeled results with the census data from Santa Cruz village. Absolute yields in kg were converted to edible corn using an empirically-derived conversion from whole ear weight to kernel weight (0.60), and then multiplied by 0.95 to account for the estimated difference in equilibrium moisture content (EMC) for October maize in Belize (~19% w/w) versus the dry weight EMC of stored US maize (~14% w/w). Absolute yields of dry corn are converted to yield in kcal assuming 3650 kcal/kg for dry maize (USDA Nutrition Database).

Positing an average daily caloric requirement of 2500 kcal/day for Santa Cruz villagers based on adult caloric needs is a simplifying but conservative assumption when calculating population. Working from FAO/WHO/UNU (1991) estimates, 2500 kcal/per day is the rough average of an adult male subsistence farmer (2780 kcal/day; FAO et al.

[1991], Table 10) and a ‘rural woman in a developing country’ (2235 kcal/day; FAO et al. [1991], Table 14). Assuming an equal sex ratio this average person leads to a relatively conservative population figure, as children and the elderly have lower caloric demands in general.

Based on these model assumptions I estimate the village population at between ~460 and 800 people, higher than the current census of 400 people (Wainwright 2007; Table 4.6). Since not all cultivated land is devoted to subsistence, and not all subsistence crops yield caloric returns equal to maize, these figures can be corrected assuming different proportions of land devoted to maize (Table 4.7). Additional work is needed to determine the percentage of maize consumed on average, but an estimate of 70-80% maize cultivation seems reasonable based on informal observation in Santa Cruz throughout the year and considering that two crops of maize are grown per year and dry field rice, beans and ground foods tend to be grown less frequently. Assuming 70-80% maize cultivation, then ~105 ha would support a village population closer to ~440-500people (per year). Taking the total arable land around Santa Cruz as 1445 ha, this suggests an average of 7.2% of land cultivated each year and an average fallow period of 13.8 years. This average for the entire area appears reasonable considering some fields are routinely cleared every 5 years, and more distant forest stands can remain in fallow for 20 years or more (e.g., some higher stands of forest at the foot of the rock patch, and section to the northwest towards *Ya’ax Ha*).

Table 4.6. Estimated annual maize yield and potential population of Santa Cruz village (values rounded for clarity)

Planting Density (*suk'ub*/ha)	Gross Yield (kg)	Edible Corn (kg)	Dry weight (kg)	Total Energy (kcal)	Population @ 2500 kcal/day
4000	200910	120540	114520	417985130	460
5500	276250	165750	157460	574729550	630
7000	351590	210950	200400	731473980	800

Table 4.7. Estimated potential population of Santa Cruz village assuming % of land devoted to maize (values rounded for clarity)

	Population @ 2500 kcal/day				
Planting Density (*suk'ub*/ha)	60% Maize Cultivation	70% Maize Cultivation	80% Maize Cultivation	90% Maize Cultivation	100% Maize Cultivation
4000	270	320	370	410	460
5500	380	440	500	570	630
7000	480	560	640	720	800

Population Estimates for the Uxbenká Polity

Without the current political boundaries limiting the available arable land and no evidence of ancient political boundaries, the potential catchment for Uxbenká can be modeled as a series of concentric rings radiating out from the site core. In this study the catchment area is centered on Group B (Structure B1; Figure 4.7) and arable land area was calculated in 1 km radii subtracting the 526 ha site core that was probably not cultivated with maize crops during the Classic Period (Chapter III; Culleton et al. nd). These concentric rings were also truncated at the edge of the high karst “rock patch” to the south because this rugged terrain is not suitable for agriculture. The interpolated yield raster does not cover the entire extent of land potentially under cultivation by the inhabitants of Uxbenká, so the average index value is assumed for the entire area. Estimated potential population for each catchment is presented in Table 4.8, assuming low, average, and high planting density and varying the proportion of maize cultivation. These values are calculated as person-years, or the number of people that could be fed for a year if the entire area was put under cultivation.

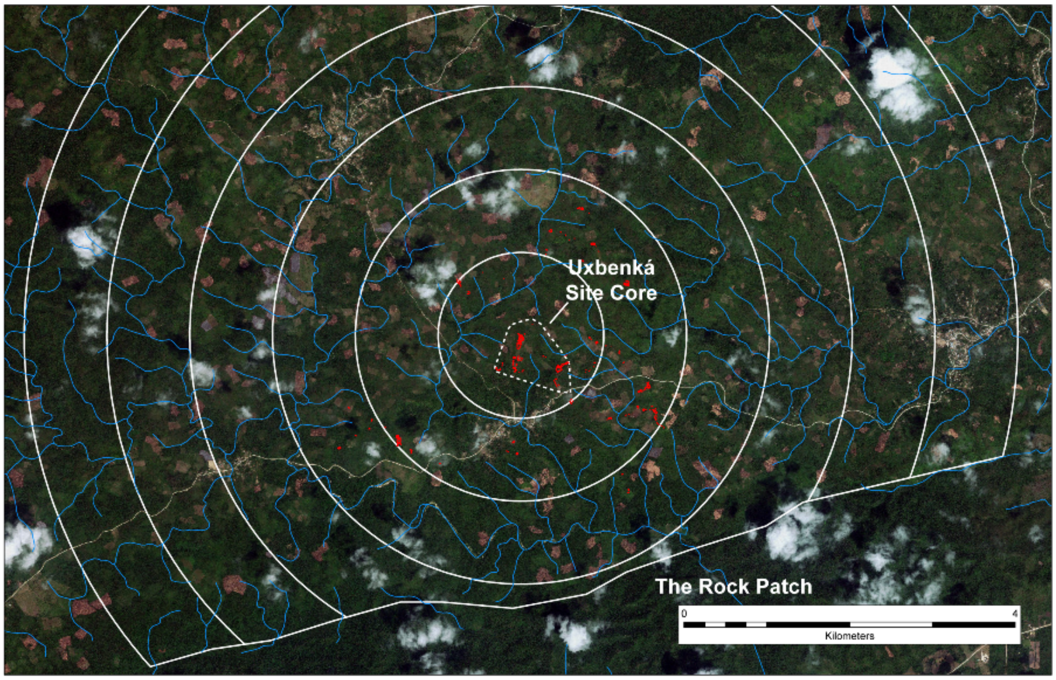


Figure 4.7. Hypothetical catchments centered on Uxbenká used to estimate the total maize production for each additional 1 km radius (image created by C. Ebert).

Since these values are time-dependent, the maximum carrying capacity at Uxbenká can be calculated under varying fallow cycles. For this calculation, assume that 75% of the land is devoted to maize cultivation, and for the sake of simplicity assume similar yields at each fallow length. The population at each fallow level is presented in Table 4.9, and ideally represents the population that could be sustained indefinitely at a given intensity of land clearing. These numbers are also translated into number of households, assuming an average of 5 persons per household, a commonly applied estimate for Mesoamerican nuclear families (e.g., Culbert and Rice 1990, and papers therein; Webster et al. 2000).

Table 4.8. Estimated maximum population for Uxbenká assuming different catchment areas (values rounded for clarity).

3 km (2774.79 ha)			**person-yr @ 2500 kcal/day**					
Suk'ub/ha	**kcal**	**% maize**	**50**	**60**	**70**	**80**	**90**	**100**
4000	10910590890		5980	7170	8370	9570	10760	11960
5500	15002062470		8220	9860	11510	13150	14800	16440
7000	19093534050		10460	12550	14650	16740	18830	20920

4 km (4613.34 ha)			**person-yr @ 2500 kcal/day**					
Suk'ub/ha	**kcal**	**% maize**	**50**	**60**	**70**	**80**	**90**	**100**
4000	17829013530		9770	11720	13680	15630	17580	19540
5500	24514893600		13430	16120	18810	21490	24180	26870
7000	31200773670		17100	20520	23930	27350	30770	34190

5 km (6633.03 ha)			**person-yr @ 2500 kcal/day**					
Suk'ub/ha	**kcal**	**% maize**	**50**	**60**	**70**	**80**	**90**	**100**
4000	25847963050		14160	17000	19830	22660	25500	28330
5500	35540949190		19470	23370	27260	31160	35050	38950
7000	45233935340		24790	29740	34700	39660	44610	49570

6 km (8948.46 ha)			**person-yr @ 2500 kcal/day**					
Suk'ub/ha	**kcal**	**% maize**	**50**	**60**	**70**	**80**	**90**	**100**
4000	35005955910		19180	23020	26850	30690	34530	38360
5500	48133189370		26370	31650	36920	42200	47470	52750
7000	61260422840		33570	40280	46990	53710	60420	67130

Discussion

The results suggest that within the area of arable land potentially under the political influence of Uxbenká, i.e., the area within 6 km (to a point equidistant from Lubaantun, the nearest regional center during the Classic Period) and excluding the karst ridge and lands to the south, ~7500-13,000 people could have been supported on a 5-year fallow cycle (Table 4.9). At longer fallow cycles requiring more available land the potential population is proportionately less. Wilk (1984, 1991) assumed that land cleared for swidden cultivation would need 30 years of fallow to return to high (primary) forest

Table 4.9. Estimated population of Uxbenká at various catchments and fallow length assuming 75% maize cultivation (values rounded for clarity).

3 km (2774.79 ha)	***Population at Fallow (yr)***					**Households (5 person/family)**				
Suk'ub/ha	**5**	**10**	**15**	**20**	**30**	**5**	**10**	**15**	**20**	**30**
4000	2390	1200	800	600	400	480	240	160	120	80
5500	3290	1640	1100	820	550	660	330	220	160	110
7000	4180	2090	1400	1050	700	840	420	280	210	140
4 km (4613.34 ha)	***Population at Fallow (yr)***					**Households (5 person/family)**				
Suk'ub/ha	**5**	**10**	**15**	**20**	**30**	**5**	**10**	**15**	**20**	**30**
4000	3910	1950	1300	980	650	780	390	260	200	130
5500	5370	2690	1790	1340	900	1070	540	360	270	180
7000	6840	3420	2280	1710	1140	1370	680	460	340	230
5 km (6633.03 ha)	***Population at Fallow (yr)***					**Households (5 person/family)**				
Suk'ub/ha	**5**	**10**	**15**	**20**	**30**	**5**	**10**	**15**	**20**	**30**
4000	5670	2830	1890	1420	940	1130	570	380	280	190
5500	7790	3890	2600	1950	1300	1560	780	520	390	260
7000	9910	4960	3300	2480	1650	1980	990	660	500	330
6 km (8948.46 ha)	***Population at Fallow (yr)***					**Households (5 person/family)**				
Suk'ub/ha	**5**	**10**	**15**	**20**	**30**	**5**	**10**	**15**	**20**	**30**
4000	7670	3840	2560	1920	1280	1530	770	510	380	260
5500	10550	5270	3520	2640	1760	2100	1060	700	530	350
7000	13430	6710	4480	3360	2240	2690	1340	900	670	450

based on a model of sustainable village size for K'ek'chi farmers in southern Belize. Fallow times short of that were assumed to lead inevitably to declining yields over the longer term as soil nutrients become depleted and the spread of grasses and weeds inhibit the re-establishment of arboreal species. Wilk found that this eventually forced people to use more intensive cultivation strategies via increased labor or soil augmentation (e.g., fertilizer). However, if uncleared forest was available the hypothetical village could relocate and start anew elsewhere.

Although some aspects of Wilk's heuristic model are not directly analogous to the Uxbenká case (particularly the assumption that sub-climax conditions are inherently unsustainable; cf. Hartshorn et al. [1984] and the “paradoxical fertility” of the Toledo Beds) these assumptions provide a starting point to model the population size at the 30-year fallow cycle. Assuming a 3 km radius catchment and average planting density, these lands could support a hypothetical village of roughly 550 members. A 5 km catchment (a default village catchment size in Wilk’s analysis) could support a population of 1300. In the contemporary setting, village populations in the area range between 300 and 500 people (excluding the largest Maya town of San Antonio) and catchments are closer to a 3-4 km radius. Fallows are also much shorter than 30 years. Given that the sustainability of farming systems should be considered over generations, it is difficult to say that the shorter fallows observed today will lead to the negative consequences predicted by Wilk’s analysis for subsistence farmers in the region. The population estimates made here will inevitably be improved by long-term data collection designed to establish the linkage between length of fallow and productivity. These data will be required to make the model more dynamic and applicable to analyzing diachronic processes.

The population estimates presented here give a sense of what level of intensified food production may have been practiced in the Uxbenká environs. Because these population estimates are based on maize yields per area, they indirectly assume a constant population density per area for any given planting density and fallow length. For a 5-year fallow as shown in Table 4.9, planting density of 4000 *suk’ub*/ha supports a population density of 65.5/km^2, 5500 *suk’ub*/ha supports 90.0/km^2, and 7000 *suk’ub*/ha supports 114.6/km^2, regardless of size of the catchment area under consideration (though longer fallows would decrease the population density by decreasing overall production at a given planting density).

These figures, which do not include calories and nutrients from other crops or wild foods may well be conservative. Nonetheless, they are generally consistent in magnitude with, if somewhat lower than, several of the broader areal population densities based on residential structures from Rice and Culbert's (1990) summary for Lowland Maya centers (see Table 4.10): e.g., the Copan Valley in total, 43.2/km^2 (Webster and Freter 1990); rural areas within 10km of Tikal, 153.1/km^2 (Culbert et al. 1990); Guatemalan lake basins and the Yaxha Polygon, 163.2 – 260/km^2 (A. Chase 1990); Nohmul, 150.5/km^2 (Pyburn et al. 1990).

Translating the Uxbenká population densities to household densities assuming 5-persons per household gives a range of 13.1 – 22.9 households/km^2, with each household having an average of 4.4 - 7.6 ha for cultivation over the long term (assuming some form of usufruct land tenure). The current settlement survey indicates that most of these households would have been located on hilltops or extended across ridgelines throughout the hilly and steeply incised landscape. Assuming a 5-year fallow and an annual plot size of 1.5 ha (as with the contemporary situation) ancient households at this settlement density would be on the cusp of choosing between planting in more distant outfields to acquire more land, decreasing fallow time (e.g., a 1.5 ha/yr in a 3 yr fallow over 4.5 ha), or increasing the planting density on the same amount of land. These are among the simplest and presumably earliest strategies employed along the spectrum of agricultural intensification (in the sense of Boserup 1965). They are strategies that would leave little trace in the archaeological record. Low-level agricultural intensification is in general accord with the lack of evidence for substantial soil management features at Uxbenká, those that would signal large labor inputs to mitigate declining productivity or would put

Table 4.10. Population estimates for Lowland Maya sites, after Rice and Culbert (1990: Table 1.3)

Site	Area (km^2)	Estimated Population	Density (range, pop/km^2)	Density (pop/km^2)[a]
Late Preclassic Period				
Seibal				
Center	1.6	1644		1027.5
Peripheries	13.6	7974		586.3
Total	15.2	9618		632.8
Komchen	2	2500-3000	1250.0-1500.0	1375.0
Late Classic Period				
Copan				
Urban core	0.6	5797-9464	9661.7-15773.3	12717.5
Copan pocket, rural	23.4	9360-11,639	400.0-497.4	448.7
Outside Copan pocket, rural	476	3010-3725	6.3-7.8	7.1
Copan Valley, Total	500	18,417-24,828	36.8-49.7	43.2
Quirigua (center)	3	1183-1579	394.3-526.3	460.3
Tikal				
Central 9km^2	9	8300		922.2
Next 7km^2	7	4975		710.7
Remainder within boundaries	104	45720		439.6
Total within boundaries	120	62000		516.7
Rural within 10km	194	29696		153.1
Macanche-Salpeten Basin	27.9	7262		260.3
Yaxha-Sacnab Basin	29.5	6253		212.0
Quexil-Petenxil Basin	23.5	3836		163.2
All lake basins	78.3	17351		221.6
Yaxha Polygon	237	42047		177.4
Tayasal				
Spine	8	6861-10,400	857.6-1300.0	1078.8
Outer Ring	18	7719-11,000	428.8-611.1	520.0
Periphery	64	7371-11,172	115.2-174.6	144.9
Total	90	21,951-32,272	243.9-358.6	301.2
Late/Terminal Classic				
Nohmul	22	3310		150.5
Sayil (by mounds)	3.4	8148-9990	2396.5-2938.2	2667.4
Sayil (by chultuns)	3.4	4900-10,000	1441.2-2941.2	2191.2
Late Postclassic				
Santa Rita	5	4958-8722	991.6-1744.4	1368.0

a: Mean density is given for sites with a range of estimates.

more proximate marginal land into production (e.g., terraces, raised fields, or simply demarcated fields; Culleton et al. nd). More work on both the food production system and the settlement archaeology remains to be done but these initial population estimates suggest that the area conceivably under the political influence of Uxbenká could have supported 7500-13,000 people without resorting to archaeologically obvious intensive agriculture strategies.

Classic Period Lowland Maya city centers are thought to support densities between 6 and 100 times the average for the broader landscape (Culbert and Rice 1990), the latter extreme representing architectural intensification that most contemporary city dwellers would have no trouble recognizing as urban. Investigations characterizing the residential nature of the Uxbenká site core are underway, but the current data from survey and excavations suggest that it is much closer to the lower end of the urban density spectrum. Assuming 5 times the average population density with a 5 year fallow in an area of 0.526 km^2, gives an estimate of ~237 people living in the site core, or ~475 at 10 times the density. Based on Webster's (1985; Webster et al. 2000) assumption of a maximum of 10% of ancient Maya populations being elites and specialists (i.e., those not involved in food production; at most 5% belonging to each group), and a population of 10,550 for the 6 km radius around Uxbenká at a 5-year fallow, we derive a non-producing population of 1055 people at Uxbenká at its height. If only the elite segment resided in the site core, this gives a maximum estimate of ~525 people, which is reasonably close to the larger estimate of 475 based on relative population density.

Translating elite population estimates into numbers of households is less straight forward than for the broader population of Uxbenká because of differences in the ways elite households were constituted as social and economic entities. Polygyny among elite families is well-attested, and the inclusion of retainers, specialists, and slaves could increase the houshold size considerably (Webster et al 2000: 158-160, 165). Working from the assumption of a 5-person household, the two density-based estimates for the site core population translate to 47 to 95 households in the core, respectively, and the elite proportion estimate suggests a maximum of 105 households. Using a hypothetical average household size of 20, the core would have been composed of ~12 to 24 households, or 26 households using the elite proportion of the overall population. These estimates can be developed into testable predictions about the number and types of structures that should be found by ongoing household investigations in the site core, keeping in mind that “elite” structures and burials cover a spectrum from modest to elaborate (Webster et al. 2000: 165). Results of those studies will provide an independent test of the assumptions involved in this population reconstruction, and highlight specific areas for revision and refinement.

Conclusions

The agricultural productivity of the present-day landscape was used to estimated the maximum potential population size for the ancient Maya center of Uxbenká. Maize yields in *milpas* planted by farmers around the village of Santa Cruz were quantified during the 2009 and 2010 harvest seasons, and compared with environmental variables including soil nutrients (e.g., N, P, K, pH, organic and inorganic carbon) and landscape attributes (e.g., slope, aspect, distance from the village). Maize yields were found not to correlate with measured variables, except for a very weak positive correlation with distance from the site core. Planting density, which varies with the type of maize planted, was found to heavily influence yields and is dependent upon intercropping with other cultivars and the presence of physical obstacles in cleared *milpas*. The lack of correlation between yields and a range of environmental variables is consistent with other ethnographic studies on maize production that suggest a range of confounding factors (e.g., soil, weather, maize variety, pests, and farming experience) ultimately dictate the outcome at harvest.

Yield values were controlled for planting density and incorporated into a geospatial database to interpolate a productivity raster of the lands surrounding Uxbenká. Taking the average maize yield per area and assuming daily caloric needs for ancient inhabitants, the maximum sustainable population of the Uxbenká polity during the Classic Period is estimated to be between 7500 and 13,000 people within a 6km radius. This population is modeled at a five-year fallow period, just on the cusp of a short fallow system suggestive of a low level of agricultural intensification. The lack of archaeological evidence for intensive farming strategies (e.g., terracing, field demarcation, irrigation systems) in the vicinity of Uxbenká is consistent with this model result. Assuming the elite population resided in the urban core of the site and that it was 5% of the total population, the model predicts the presence of ~525 elites, though the number of elite households is difficult to reliably estimate because of their unique social and economic makeup. Productivity-derived predictions of population size and household density within the ancient Uxbenká polity provide expectations for the material record that can be tested through future work in household, settlement and landscape archaeology.

CHAPTER V

THE IDEAL FREE AND DESPOTIC DISTRIBUTIONS AND ANCIENT MAYA SETTLEMENT AT UXBENKÁ, BELIZE

This chapter was prepared as an unpublished co-authored manuscript with Dr. Winterhalder, Ms. Ebert, Mr. Ethan Kalosky, Dr. Prufer, and Dr. Kennett. I conceived of the settlement models that incorporate data on productivity derived from modern maize yields (see Chapter IV), hydrology and proximity to the site core, and also conducted settlement excavations and ceramic analyses at two settlement groups to expand the chronological dataset. I processed the radiocarbon dates that form the overall settlement chronology. Dr. Winterhalder provided guidance on the application of the Ideal Free and Despotic Distributions and gave valuable feedback on the implementation and interpretation of these models. Ms. Ebert summarized data on productivity, hydrology and proximity for each settlement group catchment using the GIS database, as well as providing overall map coverages and elements of key figures. Mr. Kalosky directed and conducted much of settlement survey and mapping that forms the settlement database for the analysis presented here, and graciously shared preliminary results of a least-cost path analysis of the project area. Dr. Prufer oversaw the original settlement field work and provided access to the settlement and chronological data, and provided useful discussion on the interpretation of the model results. Dr. Kennett helped with organization and presentation of the data and the model design, as well as providing critical feedback on interpretive aspects of the models.

The florescence of ancient Maya culture from the Late Preclassic through the Classic Period was marked by increased social differentiation and institutionalized status hierarchy, agricultural intensification, elite control of water resources, expanded trade and exchange, interpolity conflict, organized warfare, and environmental degradation (Demarest 2004; Fedick 1996a; Lentz 2000; Scarborough 2003; Schele and Freidel 1990; Webster 2002). The processes of polity formation, settlement expansion, and political decline in the ancient Maya Lowlands involved the dynamic interaction of social and ecological factors influencing each other on multiple spatial scales, from the broadest scale of political cooperation and conflict between multiple polities, to smaller scales of interaction between factions or even individual commoner households within polities.

The connection between population increase, intensive food-production, and environmental degradation is central to ecologically based explanations of the emergence and decline of ancient Lowland Maya societies. However, many explanatory narratives of the rise and fall of Maya polities take for granted that one or more of these processes is operating without demonstrating it, or take evidence of one as a proxy for the others. Demarest’s (2004:258, Figure 10.10) causal model for the collapse of Late Classic Petexbatún, for example, placed population growth during the Late Preclassic as a prime mover that also influenced the shift to shorter and shorter fallow times during the Classic Period. He argued that increased intensification led to environmental degradation and undermined the resource base that was rapidly overshot by a growing population. This resulted in increased warfare for prime agriculture lands, social upheaval, and settlement disruption through immigration and abandonment.

Cowgill (1975a, 1975b) has cogently argued against the assumption of intrinsic population growth and the inevitable response of agricultural intensification (*contra* Boserup 1965), but it is clear in the Maya region that population *densities* were greater at many centers during the Classic Period compared with 2000 years earlier in the Preclassic. There are also plausible causal linkages between population density, land-use practices, resource availability and social behaviors of household settlement and production that can be empirically demonstrated. So attempting to develop coherent models of the consequences of changing population densities within an ecological framework and applying them to archaeological data is a reasonable theoretical endeavor.

A set of models developed in Human Behavioral Ecology provide a framework that incorporates explicit relationships between population density, habitat quality and human decision-making that can be used to investigate the dynamic process of settlement expansion. Specifically, the Ideal Free Distribution and related Ideal Despotic Distribution (Fretwell 1972; Fretwell and Lucas 1969; Sutherland 1996) show great potential for exploring the causal connections between socioecological conditions and human behavior at multiple spatial and temporal scales. The scalar flexibility of these models makes them particularly well-suited to addressing archaeological problems on local and regional scales over decades, centuries or millennia.

The Ideal Free and Despotic Distributions

The Ideal Free Distribution (IFD) is a formal habitat choice model developed in population ecology that incorporates density-dependent and density-independent environmental factors of habitat suitability to generate testable predictions about settlement behavior (Fretwell 1972; Fretwell and Lucas 1969; Sutherland 1996). The IFD assumes that all members of a population are equal competitors for resources, have equal ability to evaluate all available habitats (which implies a sort of theoretical omniscience of the landscape for individuals), will always choose the most suitable habitat to settle (the *ideal* of the IFD), and are able to relocate to any habitat at will (the *free* of the IFD). Settlement locations or habitats are ranked by their relative suitability, a summary of overall resource richness within a given area (Figure 5.1A). The IFD predicts that the most suitable habitat (*H1* in Figure 5.1A) is occupied first, and as population grows, suitability in this habitat drops due to density-dependent resource depletion or interference arising from competition. When suitability declines to that of the second-ranked resource patch *H2* at population density *A*, further population growth will be divided between them. This process continues as population density increases and habitat suitability declines to that of the lowest ranked habitat *H3* at population density *B*. The tempo and mode of this process may be affected by changes in suitability that affect all habitats (e.g., climate change, adoption of novel technology, etc.). Another variation of the IFD includes the Allee effect (Figure 5.1B), in which habitat suitability initially increases with population density. Typical examples of the Allee effect in human groups include: greater availability of suitable mates; increased food production due to collective effort in construction and maintenance of raised fields, terraces, or irrigation systems; and better opportunities for collective defense of resources. In either version, an equilibrium population distribution is achieved between all habitats.

The freedom of any individual to relocate to a more favorable habitat at will is conceivable among groups at relatively low regional population densities and high

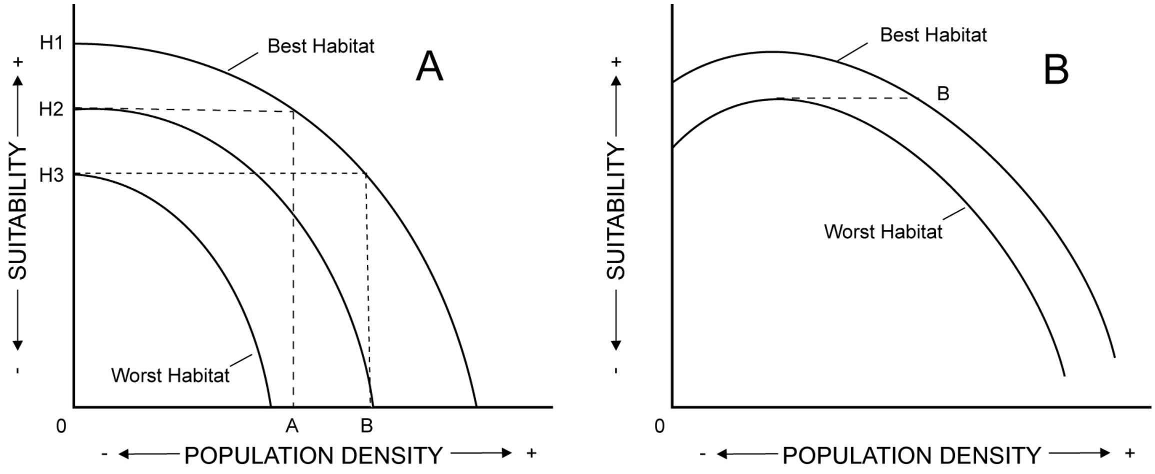


Figure 5.1. Habitat rankings under assumptions of A) the Ideal Free Distribution, and B) with the Allee effect (after Kennett et al. 2006, 2008; Sutherland 1996).

residential mobility, but less likely in more socially stratified or territorially circumscribed populations. A variation of the IFD that assumes unequal competitive advantage, and hence the ability of some individuals (or groups of individuals) to exclude others from a habitat, is the Ideal Despotic Distribution (IDD). Under the IDD individuals still seek to settle in the highest ranked (i.e., *ideal*) habitat, but the presence of groups with competitive advantage prevent immigration to these habitats. This has the effect of mitigating density-dependent declines in habitat suitability within the best habitats, and pushes others into lower ranked areas sooner than predicted by the IFD. In contrast to the IFD, when IDD conditions exist, the process of competitive exclusion leads to an equilibrium population distribution with disproportionately greater population densities in lower ranked habitats. Such distributions are familiar to contemporary urban dwellers – the *favelas* outside of Rio de Janeiro can be considered an extreme example of this outcome – and so commonplace that one’s intuitive sense might be that IDD conditions are a more likely default expectation than IFD conditions in human settlement. In fact, the IFD is often taken as a null hypothesis in population ecology models against which the effects of competition and unequal access to resources can be measured (Kennett and Winterhalder 2006:89; Sutherland 1996).

The IFD and IDD are sufficiently general in formulation to allow them to be adapted to a broad range of social and environmental settings to make predictions about the processes of settlement and resource exploitation in past and present human populations. “Habitat suitability” is an index of all social and ecological variables that could bear on individual fitness (however that is conceived) and therefore can be defined for specific research questions informed by a knowledge of relevant ecological variables, mode of food production, and degree of technological complexity or status differentiation. This flexibility makes the IFD and IDD amenable to starting with very basic models that incorporate one or two key variables (e.g., access to water and abundance of shellfish beds among coastal hunter-gatherers in an arid environment), testing the model predictions against archaeological observations, and then refining the concept of habitat suitability to include other predictive social or ecological variables. In this way, developing and testing an IFD model iteratively can serve as a tool for identifying relevant variables that have not been recognized or fully accounted for. Or, as noted above, the failure of an IFD model to predict the observed distribution of settlements may indicate the presence of interference competition, suggesting an IDD condition prevails, and thereby focusing research on explaining the emergence and maintenance of despotic conditions.

Another aspect of the IFD and IDD models that makes them productive for archaeological inquiry is their dynamic and diachronic formulation, which opens up useful avenues for explaining both stability and change in the archaeological record over long periods. Many models in the evolutionary sciences begin as thought experiments premised upon a time-transgressive narrative where competition under certain conditions leads to a specific set of Evolutionarily Stable Strategies (ESS) for individuals, such as classic models like the Prisoner's Dilemma, Hawks vs. Doves, and so on (Kennett 1998; Kennett and Clifford 2004; Smith 2000; Smith and Winterhalder 1992). The implied time scale under which these strategies evolved (i.e., in the literal sense of the biological evolution of innate behavioral tendencies, not the figurative or metaphorical usage of evolution as any change or development in a group or individual) is typically assumed to be on the order of $>10^5$ years in the Environment of Evolutionary Adaptiveness (EEA) and to have already resulted in what we observed today as the distinct set of ESS for a given species in its habitat. There is rarely a sense that the initial stages of the process could ever be observed directly among living populations, except as they are recapitulated by undergraduate test subjects in evolutionary psychology laboratories around the world.

Similarly, for population biologists the diachronic aspect of the IFD and IDD largely serves to provide a framework for understanding the equilibrium (or non-equilibrium) population distributions observed in the present, i.e., the synchronic view of a target population studied in the field. The scenario described by the IFD and IDD is essentially the colonization of an unoccupied habitat by a novel species, a process difficult to observe and describe over short timescales of years or decades of fieldwork, but one that is represented in the centennial- to millennial-scale archaeological records of much of the world. Assuming an adequately sampled and temporally-resolved record, archaeologists have the opportunity to consider the diachronic aspects of the IFD and IDD, as well as to take synchronic snapshots at specific points in culture history to explore abrupt and discontinuous processes of societal change such as the development of new technologies and food production techniques, resource intensification, migration, colonization, and the emergence of social inequality.

Archaeological Applications of the IFD and IDD

Most applications of IFD and IDD models to archaeological problems have been carried out by D.J. Kennett, B. Winterhalder, and their colleagues, primarily applied to hunter-gatherer groups on California's Northern Channel Islands (Kennett 2005:32-36, 229-233; Kennett et al. 2009; Winterhalder et al. 2010), to agricultural societies in Polynesia (Kennett and Winterhalder 2008; Kennett et al. 2006), and to diachronic patterns of trade and interactions between coastal and island populations along the west coast of North America (Fitzhugh and Kennett 2010). Although these case studies are largely in island contexts at scales ranging from individual islands (e.g., Rapa) to small nearshore groups (e.g., California's Channel Islands) to multiple and geographically dispersed groups (e.g., Polynesia), the IFD and the IDD are equally applicable to mainland continental settings as an early application of the IFD model to colonization and expansion of Neolithic populations in Spain has demonstrated (McClure et al. 2006).

On California's Northern Channel Islands, the IFD and IDD models have been articulated with principles of Central Place Foraging theory (which guides habitat definition by characterizing the size and content of resource patches; Orians and Pearson 1979; Stephens and Krebs 1986) to explore the process of settlement expansion through the Holocene in terms of resource intensification, technological innovation, and emergent social inequality. In the earliest work, predictions of an IFD model for the Channel Islands that evaluated settlement location (habitat suitability) in terms of access to fresh water (using drainage size as a proxy), extent of shellfish-rich rocky intertidal zones foraging locales, and area of kelp forest for fishing, indicated that the earliest occupation sites should be located at the mouths of the largest drainages on the islands and these should also host most persistent settlements (Kennett 2005). Early and persistent settlements at Arlington Canyon, Cañada Verde, Lobo Canyon, and Old Ranch Canyon on Santa Rosa, and Central Valley and Prisoner's Harbor on Santa Cruz conform to these predictions (Kennett 2005:230). Establishment of other primary village sites on the islands appears by the middle Holocene in what would be secondary habitats: those associated with moderately sized drainages and less access to marine foraging patches. A process of infilling tertiary habitats on the islands appears to have occurred by the Middle-Late Period Transition (~1500 BP) when the islands entered the period of highest population density since their colonization in the Terminal Pleistocene. This was a time of great social and technological change, when a shell bead currency emerged, and use of the more seaworthy *tomol* plank canoe and fishing technologies both increased trade with the mainland and led to intensive exploitation of offshore fisheries (Arnold 2001; Kennett 2005). Along with resource intensification and increasing diet breadth come signs of growing status differentiation, increased evidence for interpersonal violence, and osteological evidence of nutritional stress (Lambert 1994).

Kennett argued that the expression of social conflict, as reflected by lethal and sublethal violence, as groups colonized the lowest ranked habitats is more consistent with the despotic variant of the IFD (Kennett 2005; Kennett et al. 2009; Winterhalder et al. 2010). Thereby the emergence of social inequality is tied directly to population density, resource intensification, and technological change at a specific point in cultural history. The original Channel Islands model has since been further refined with better integration of ecological, temporal and spatial data in a GIS system (Kennett et al. 2009), and by incorporating a Bayesian approach to the chronological and geographic sampling that minimizes the effect of missing data in the record (Winterhalder et al. 2010), indicating directions for applications in other archaeological settings and geographic scales.

The record of episodic expansion of Polynesian peoples across the Pacific has also been explored in terms of the IFD (Kennett et al. 2006) and the IDD (Kennett and Winterhalder 2008), with population pressure, agricultural intensification and ecological degradation considered as key factors in both triggering pulses of migration and the emergence of status differentiation in the form of hereditary chiefdoms. As summarized by Anderson (2001), the initial colonization of Polynesia is signaled by the spread of Lapita culture into Fiji and West Polynesia between ca. 1300 and 600 BC, which is considered part of a broader dispersal of speakers of Austronesian languages (Diamond and Bellwood 2003). Archaeologically, Lapita culture is recognized by the presence of distinctive dentate-stamped pottery that is distributed into Remote Oceania as far as Tonga and Samoa, and early footholds on these islands are primarily associated with coastal rather than interior settlements (Anderson et al 2001; Kirch and Hunt 1988). Further expansion appears to have stalled for roughly 1600 years before the earliest documented settlements in East and South Polynesia (AD 1100-1000; e.g., Society Islands, Marquesas, Hawai'i), with more remote islands such as Rapa Nui (Easter Island), Rapa, and New Zealand settled by about AD 1200 (summarized in Kennett and Winterhalder 2008).

Kennett et al. (2006) view the hiatus as the result of a period of demographic infilling in the islands of Fiji and West Polynesia as colonizing populations increased over time. Evidence for increasing population density is inferred from a range of archaeological indicators: larger site sizes; decreased residential mobility; settlement expansion into island interiors; and agricultural intensification indicated by terracing and irrigation systems (Kennett and Witnerhalder 2008). Considering this process at the scale of individual islands, this settlement progression is consistent with predictions of the IFD. In a mixed foraging/agricultural economy, coastal settlements that offer optimal access to both marine and terrestrial resources would be higher ranked than interior habitats, and therefore should be occupied first. When population densities increased to the point where habitat suitability declined for the highest ranked habitats the disadvantages of interior settlements became less significant, and migration occured. As Kennett et al. (2006) note, and Kennett and Winterhalder (2008) develop more fully, this process also likely involved some aspects of despotism as well, pointing to Kirch's (2000) inference from linguistic evidence that hierarchical sociopolitical traditions existed among Lapita groups. Access to the best settlement locations in such a society could be effectively restricted by certain individuals or groups (and also vigorously contested through intra-group conflict), leading to a population distribution and land-use pattern more consistent with the IDD. Another crucial aspect of density-dependent declines in habitat suitability in the Polynesian case is the environmental consequence of resource intensification that led both to loss of island flora and fauna targeted by foragers, and increased soil erosion in agricultural contexts. As Lapita populations in-filled the islands, some prime settlement locations became restricted, and more marginal ones became degraded; as equilibrium population distributions – *free* or *despotic* – were reached after more than a millennium in West Polynesia. Within this context, another wave of exploration and migration to new island habitats began. Conceived of in this way, the tempo and mode of Polynesian expansion can be understood through the integration of ecological, cultural and ideological factors using a generalizable model that is at once diachronic, spatially scalable, and open to inclusion of a variety of new archaeological and ecological observations (Kennett and Winterhalder 2008; Winterhalder and Kennett 2006).

Applying the IFD to Household Settlement at Uxbenká

At Uxbenká in southern Belize the establishment of household settlement groups should proceed from the highest ranked habitats in the Late Preclassic and Early Classic into lower ranked habitats as the landscape fills through the Classis period. Because settlement mobility becomes reduced due to political and social circumscription throughout the Classic Period, intensive strategies will be employed to offset climatically-driven and density-dependent habitat degradation around settlement groups. The model predicts that higher ranked settlement groups will have earlier initial dates of occupation and longer periods of occupation, and those lower ranked will have later dates of initial occupation and will have been occupied for a shorter period. Chronological data to test these predictions are drawn from a combination of archaeological and chronometric research, including: AMS ^{14}C radiocarbon dated samples recovered from excavations; Bayesian modeling of selected sequences from Groups A and B (Culleton et al. 2012); temporally diagnostic ceramics recovered from deposits; dedicatory dates on stelae (Group A); and the presence of architectural features such as ballcourts, which are typically assigned to the Late Classic Period. These data for the large civic-ceremonial architectural groups and the domestic settlement groups (SG) are summarized in Table 5.1. Cases where the archaeological data contradict the model expectations will point to other factors affecting settlement choices that need to be considered, such as the role of competition and social dominance described by the despotic variant of the IFD (Kennett et al. 2006, 2008).

Table 5.1. Chronological data on 22 settlement groups (SG) and core groups considered in IFD modeling.

SG	**Latest Preclassic (AD 1-300)**	**Early Classic I (AD 300-425)**	**Early Classic II (AD 425-600)**	**Late Classic (AD 600-800)**
1	C	C	C	C
3			R	
4	R	C	C,R	C
5	R		R	
20	C,R			
21	R			R
23				R
24			R	
36	-	-	-	-
38			R	R
39				R
50	-	-	-	-
51	-	-	-	-
53	-	-	-	-
54				R
55	-	-	-	-
56	-	-	-	-
57	-	-	-	-
Core Group				
A	R	D,R	D,R	D,R
B	R	R	R	A,C,R
G	-	-	-	-
I	R	R	R	A

Chronological attribution based on : A. architecture (e.g., ballcourt); C: diagnostic ceramics; D: dedicatory date on stela; R: radiocarbon date or modeled event; -: no data for site.

Key environmental parameters influencing settlement decisions around Uxbenká are considered to be agricultural potential, hydrology (i.e., access to freshwater), and linear distance from the site core as measured from Group A (specifically the peak of Structure A1). Similar to the approach of Kennett et al. (2009), the selection of these particular model variables is supported by knowledge of ancient and modern Maya land use and custom, as well as personal experience on the landscape during several years of fieldwork. Each variable is discussed below to develop the decision-making context and provide a rationale for its inclusion in the IFD model. All of the environmental data were incorporated into a GIS for quantification and analysis along with the settlement survey data gathered by the Uxbenká Archaeological Project since 2005 (Figure 5.2).

Agricultural Productivity

The ancient Maya inhabitants of Uxbenká, like their contemporary Maya counterparts in the village of Santa Cruz, were primarily subsistence farmers who relied heavily upon maize as a staple crop along with secondary crops such as manioc, beans, squash, and cacao. As such, proximity and access to the most productive lands is expected to be one of the main criteria for household site selection (or extended household group). A measure of soil productivity around Uxbenká has been developed from empirical data on maize yields in the contemporary *milpas* cleared and planted by Santa Cruz farmers in 2009 and 2010 (see Chapter IV). Yields from each plot (expressed as bulk maize yields normalized to account for planting density; kg/ha/planting) were used to interpolate the productivity across the landscape with the Spatial Analyst toolset in ArcGIS using a Nearest Neighbor method. The result is a raster surface with a

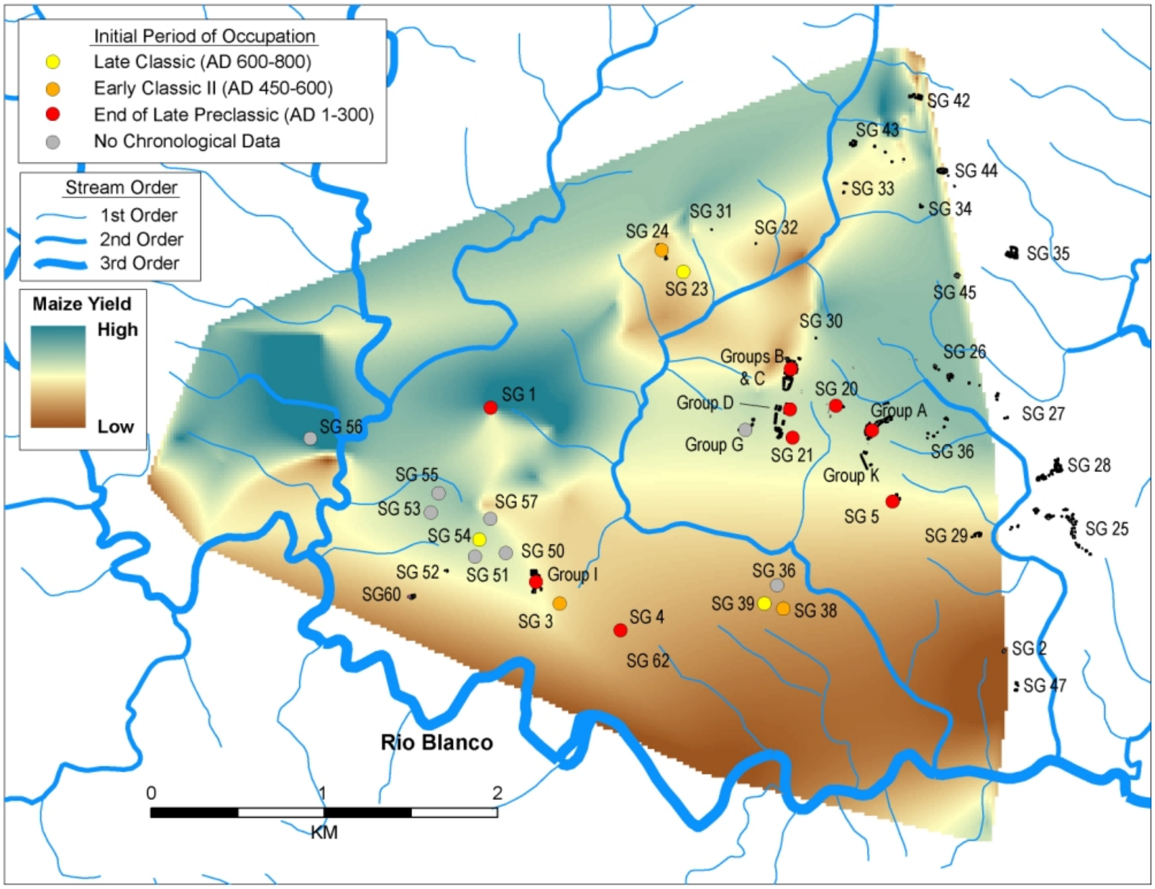


Figure 5.2. Composite showing ecological variables incorporated into the IFD model of settlement at Uxbenká: agricultural productivity (raster gradient); hydrology; and distance from the site core. Periods of earliest occupation for settlement and core groups are noted where data exist (image created by B. Culleton and C. Ebert).

resolution of 18.5 m where each 18.5 x 18.5 m (0.034225 ha) cell has an associated yield index value ranging from 11.8 – 92.9 kg/ha/suk'ub, with an average value of 47.9 kg/ha/suk'ub (see Chapter IV). There is a clear north to south gradient of greater to lesser maize yields and this maps on to the known distribution of more prized *box lu'um* (dark soils) and less productive *chik lu'um* (red soils) as described by modern farmers in Santa Cruz village. The *chik lu'um* is located primarily between the village and the Rio Blanco. A 0.5 km-radius catchment was defined around each settlement group and core group completely within the raster coverage, and the individual yield index value for each cell

(~2300 cells within each catchment) was compiled in a database and the average yield value was used to rank each SG and Core Group in terms of agricultural productivity. Agricultural productivity is assigned a 50% weighing in the determination of overall rank due to its perceived importance.

Hydrology

Compared to California's Northern Channel Islands, access to freshwater in tropical southern Belize is considered a less crucial but still important factor in settlement decisions. The presence of the relatively large drainage of Rio Blanco and some of its main tributary streams would provide access to water even during the depths of the dry season and the time and effort involved in transporting water during the driest times of the year would still make locations near larger streams more favorable for settlement, all other things being equal. To quantify the hydrologic potential of each SG and Core Group, all of the stream segments in the Uxbenká vicinity were ordered according to the Strahler's (1957) method. The locations of these streams (and by extension, what is defined as a stream) are taken from a digitized and orthorectified hydrologic GIS layer derived from the 1950s British Ordnance Survey maps for Belize. Stream-ordering is a convenient approach for characterizing the relative discharge between drainages and watersheds from essentially analog geographic data, especially in the absence of a higher-resolution digital elevation model (DEM) from which the areas of watersheds could be more accurately defined and quantified. The approach is as follows. Any stream in the broader hydrological system with no tributaries (i.e., those at the headwater of any-sized drainage) is designated a 1st order stream. Where two 1st order streams join the segment downstream from the confluence is designated a 2nd order stream. When two streams of differing order meet, the downstream segment remains the higher order of the two. Where two equally ordered segments meet, the downstream segment is of the next highest order. For example, if a 1st and 3rd order stream meet, the next segment remains 3rd order; if two 3rd order streams meet the downstream segment is 4th order.

After ranking each segment, the same 0.5-km radius catchment was applied to each SG and Core Group, and the length of streams of each order was quantified. Though Strahler's (1957) method does not perfectly correlate with overall discharge or watershed area in every case, a hydrological value was devised that weighted stream lengths geometrically by order to reflect the geometric nature of both hydrological cross-section and watershed area, and their relationship to discharge. Length of 1st order streams was weighted at ×1, 2nd order at ×2, and 3rd order at ×4 (i.e., $\times 2^0$, $\times 2^1$, $\times 2^2$) and summed, and the sites were ranked in terms of hydrology based on this value. It is worth noting that only two sites, SG 56 and Group I, both to the west of the site core, had a 3rd order stream within their catchment. Hydrology is given a 30% weighting in the overall rank for each location.

Distance from the Site Core

Proximity to the site core is a variable that incorporates both social and ecological aspects of settlement decision-making into the model, and presumes an added resource potential provided by the urban center of Uxbenká (or any urban center) and what this offered people in terms of social, commercial, ideological, or subsistence opportunities, and their desire to be located near them. Some of the attractions an urban center held would likely be greater access to: 1) rarer goods not produced in household economies, such as salt, cacao, obsidian, or finer pottery in markets; 2) the exchange of information and maintenance of social ties among commoners; and 3) participation in social and religious events conducted by elites and specialists (a “theater state”; Demarest 2004:149-160; Zimmerman Holt 2009). On the broader regional scale, closer proximity to the site core could offer households greater protection from aggression by outside groups. At the same time, we should keep in mind the possible desire of some individuals to settle farther from the reach of ruling elites and their ability to extend physical, economic and social influence over commoners. Proximity to the site core was measured as the linear distance of each SG or Core Group to the peak of Structure A1, the largest structure in Group A, which is the location of the earliest known activities at Uxbenká (Culleton et al. 2012). Sites were then ranked in ascending order according to distance from Structure A1. The choice of linear distance in this hilly and incised landscape rather than a least-cost path is justified by a comparison of established farmers’ roads (i.e., trails) emanating from nearby Santa Cruz village with a series of least-cost paths generated using the 30 m-resolution DEM for the area (E. Kalosky, pers. comm., 2010). The roads, which farmers travel on foot to reach distant *milpas* (often backing loads in excess of 50 kg), radiate as nearly linear paths from the village and ignoring slope and terrain features, contrary to what would be predicted from an slope/elevation derived least-cost model. Practical experience cutting trails through bush with these farmers also indicates that most will choose the shortest path in terms of distance rather than the one with the gentlest slope and I suspect that the same strategy was used by the ancient Maya as they traversed this landscape. Distance from the site core is assigned a 20% weighting in the overall rank for each location.

The Model

Values and rankings for each of the three variables, and the overall rank for each SG or Core Group location are presented in Table 5.2. Overall rank is calculated as the weighted average of each rank where:

$$\text{Weighted Score} = (\text{Productivity Rank} \times 0.5) + (\text{Hydrology Rank} \times 0.3) + (\text{Distance Rank} \times 0.2).$$

Examples of high-and low-ranked settlement groups are depicted in Figure 5.3.

The highest ranked site location in the available sample is Group A itself, which ranks in the first quartile for productivity (at 4) and proximity to the site core (at 1), and at the top of the second quartile for hydrology (at 6). The proximity rank is problematic, since Group A is the datum from which all the other distances are measured, so obviously it’s the closest site to itself. Other settlement groups close to the site core are also ranked relatively high, such as SG 20 (ranked #3), which is located on the ridge between Groups A and B and contains a late Preclassic deposit buried under a large mound of fill (Prufer et al. 2011; cf. Chapter III), and SG 21 (ranked #6), which is a small settlement group set on a finger ridge near Group F. In these two cases proximity to Group A also maps onto the northerly distribution of highly productive soils and this contributes to their high rank along with proximity. In contrast SG 5, located immediately to the south of Group A and ranked 4th in proximity, is on poorer land that is only ranked 16th in this sample (i.e.,

Table 5.2. Environmental parameters used to rank settlement groups and core groups at Uxbenká.

	Maize Productivity		Hydrology, Length of Ordered Streams					Distance from Group A		Overall	
SG	**Bulk kg/ha/ planting**	**Yield Rank**	**1st Order (m)**	**2nd Order (m)**	**3rd Order (m)**	**Wtd Value**	**Rank**	**km**	**Rank**	**Wtd Score**	**Rank**
1	63.37	1	536.5	638.3	0.0	1813.0	8	1.73	12	5.3	2
3	40.63	18	649.9	0.0	0.0	649.9	17	2.06	15	17.1	20
4	36.52	19	572.8	0.0	0.0	572.8	18	1.86	13	17.5	22
5	47.08	16	1237.1	0.0	0.0	1237.1	13	0.45	4	12.7	14
20	54.38	5	1731.7	0.0	0.0	1731.7	9	0.38	2	5.6	3
21	50.73	10	1280.1	0.0	0.0	1280.1	11	0.44	3	8.9	6
23	47.47	15	1084.3	840.7	0.0	2765.7	4	0.82	7	10.1	9
24	50.74	9	981.7	518.4	0.0	2018.4	7	1.00	8	8.2	5
36	36.51	20	604.2	1158.9	0.0	2922.1	2	1.06	9	12.4	12
38	34.09	22	625.6	1101.9	0.0	2829.3	3	1.17	10	13.9	15
39	34.73	21	517.4	1046.2	0.0	2609.8	5	1.20	11	14.2	16
50	47.70	14	390.4	0.0	0.0	390.4	22	2.23	18	17.2	21
51	48.09	13	512.9	0.0	0.0	512.9	20	2.41	20	16.5	18
53	52.80	6	1299.1	45.9	0.0	1390.8	10	2.59	21	10.2	10
54	50.01	11	572.7	0.0	0.0	572.7	19	2.36	19	15	17
55	54.61	3	1119.0	0.0	0.0	1119.0	15	2.16	17	9.4	8
56	61.85	2	806.6	774.6	1489.9	8315.4	1	2.82	22	5.7	4
57	51.18	7	500.4	0.0	0.0	500.4	21	1.94	14	12.6	13
Core Group											
A	54.55	4	2047.3	221.2	0.0	2489.7	6	0.00	1	4	1
B	51.01	8	1179.8	0.0	0.0	1179.8	14	0.60	5	9.2	7
G	49.72	12	1276.4	0.0	0.0	1276.4	12	0.73	6	10.8	11
I	43.63	17	385.7	0.0	128.7	900.4	16	2.13	16	16.5	19

close to the bottom of the third quartile). In general, sites to the north are ranked higher than those to the south reflecting the heavier weighting of productivity in the overall model.

The predictions of this model are that if IFD conditions prevailed during the establishment and settlement expansion of Uxbenká, then the earliest settlements should be found in the highest ranked habitats in terms of agricultural productivity, hydrology (i.e., access to freshwater), and proximity to the site core. Furthermore, the highest ranked sites should show more persistent occupation throughout the Classic Period.

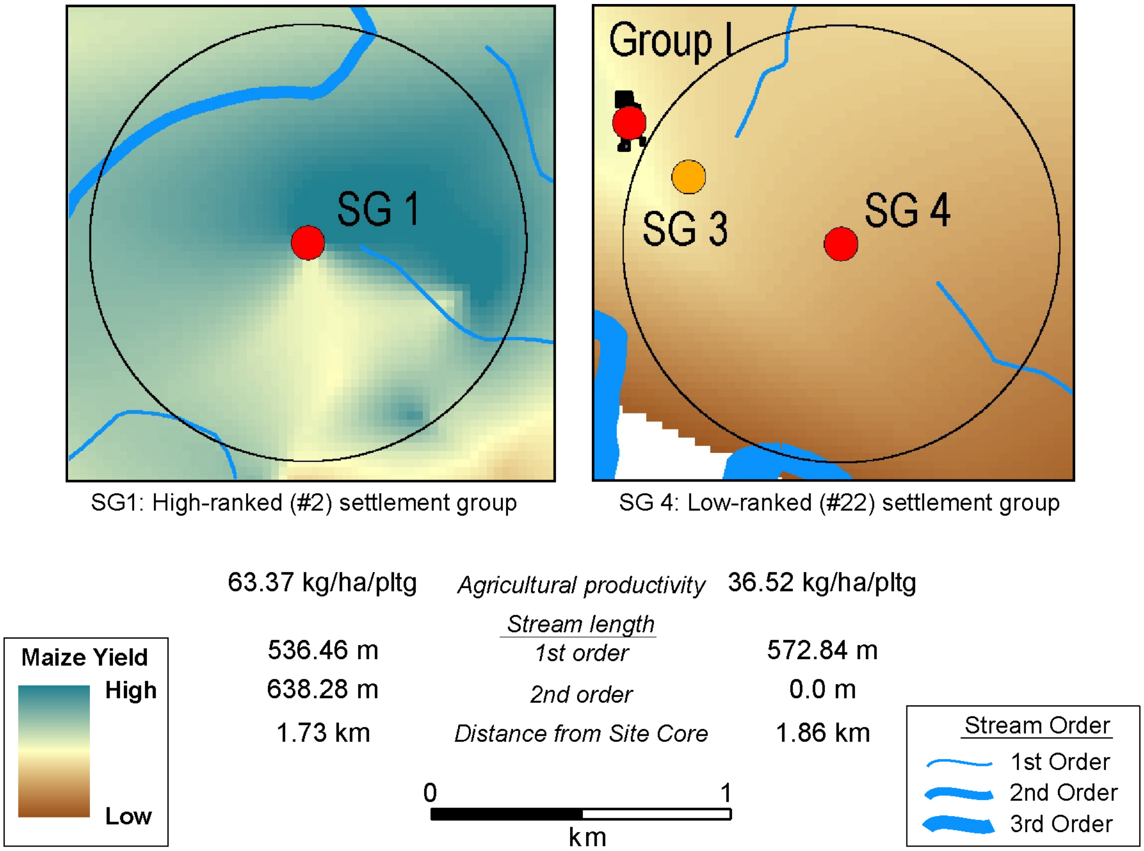


Figure 5.3. Examples of high and low ranked settlement groups based on the ecological variables within a 0.5 km catchment radius.

Chronological data to test these predictions were summarized above in Table 5.1, and is integrated in with the habitat rankings in Table 5.3 below to allow for comparisons between individual variables and composite rankings.

In Table 5.3, a settlement chronology consistent with IFD predictions would be represented as the earliest and most continuously occupied sites to the left (highest ranked), and sites occupied later in time to the right (lower-ranked). That is, the dots in each matrix would tend to fall above and to the left of a diagonal from bottom left to upper right. The overall picture of habitat suitability proposed here is somewhat

Table 5.3. Chronological data and site rankings by individual variables and overall rankings.

Ranked by Yield	First Quartile					Second Quartile						Third Quartile						Fourth Quartile				
Late Classic	●	-	-	●		-	-	●		●	●	-	-	-	●		●		●	-	●	●
E Classic II	●	-	-	●		-	-	●	●			-	-	-		●	●	●	●	-		●
E Classic I	●	-	-	●		-	-	●				-	-	-			●		●	-		
L Preclassic	●	-	-	●	●	-	-	●		●		-	-	-		●	●		●	-		
SG or Group	**1**	**56**	**55**	**A**	**20**	**53**	**57**	**B**	**24**	**21**	**54**	**G**	**51**	**50**	**23**	**5**	**I**	**3**	**4**	**36**	**39**	**38**
Ranked by Hydrology																						
Late Classic	-	-	●	●	●	●		●		-	●	-		●	-	●		●	●	-	-	-
E Classic II	-	-	●			●	●	●		-		-	●	●	-	●	●	●		-	-	-
E Classic I	-	-				●		●		-		-		●	-	●		●		-	-	-
L Preclassic	-	-				●		●	●	-	●	-	●	●	-	●		●		-	-	-
SG or Group	**56**	**36**	**38**	**23**	**39**	**A**	**24**	**1**	**20**	**53**	**21**	**G**	**5**	**B**	**55**	**I**	**3**	**4**	**54**	**51**	**57**	**50**
Ranked by Dist to Core																						
Late Classic	●		●		●	-	●		-	●	●	●	●	-		●	-	-	●	-	-	-
E Classic II	●			●	●	-		●	-	●		●	●	-	●	●	-	-		-	-	-
E Classic I	●				●	-			-			●	●	-		●	-	-		-	-	-
L Preclassic	●	●	●	●	●	-			-			●	●	-		●	-	-		-	-	-
SG or Group	**A**	**20**	**21**	**5**	**B**	**G**	**23**	**24**	**36**	**38**	**39**	**1**	**4**	**57**	**3**	**I**	**55**	**50**	**54**	**51**	**53**	**56**

Late Classic Period, AD 600-800; Early Classic Period II, AD 450-600; Early Classic Period I, AD 300-450; L Preclassic, Latest Preclassic Period (AD1-300). ●: Evidence for site use;
-: no chronological information for the site.

Table 5.3. (cont.) Chronological data and site rankings by individual variables and overall rankings.

Ranked by Yield and Hydro, Unwtd	First Quartile					Second Quartile						Third Quartile						Fourth Quartile				
Late Classic	-	●	●			-	-	●	●	●	-	-	●	●	-		●	-	●		-	●
E Classic II	-	●	●		●	-	-			●	-	-	●		-	●		-	●	●	-	●
E Classic I	-	●	●			-	-			●	-	-			-			-	●		-	●
L Preclassic	-	●	●	●		-	-		●	●	-	-			-	●		-	●		-	●
SG or Group	**56**	**1**	**A**	**20**	**24**	**53**	**55**	**23**	**21**	**B**	**36**	**G**	**38**	**39**	**57**	**5**	**54**	**51**	**I**	**3**	**50**	**4**
Overall Rank, Unweighted																						
Late Classic	●		●	●		-	●	●	-	-		●	-	●	-	-	●	●		●	-	-
E Classic II	●		●		●	-		●	-	-	●	●	-		-	-		●	●	●	-	-
E Classic I	●		●			-		●	-	-			-		-	-		●		●	-	-
L Preclassic	●	●	●	●		-		●	-	-	●		-		-	-		●		●	-	-
SG or Group	**A**	**20**	**1**	**21**	**24**	**56**	**23**	**B**	**G**	**36**	**5**	**38**	**55**	**39**	**53**	**57**	**54**	**I**	**3**	**4**	**51**	**50**
Overall Rank, Weighted																						
Late Classic	●	●		-		●	●	-	●	-	-	-	-		●	●	●	-	●		-	●
E Classic II	●	●		-	●		●	-		-	-	-	-	●	●			-	●	●	-	●
E Classic I	●	●		-			●	-		-	-	-	-					-	●		-	●
L Preclassic	●	●	●	-		●	●	-		-	-	-	-	●				-	●		-	●
SG or Group	**A**	**1**	**20**	**56**	**24**	**21**	**B**	**55**	**23**	**53**	**G**	**36**	**57**	**5**	**38**	**39**	**54**	**51**	**I**	**3**	**50**	**4**

Late Classic Period, AD 600-800; Early Classic Period II, AD 450-600; Early Classic Period I, AD 300-450; L Preclassic, Latest Preclassic Period (AD1-300). ●: Evidence for site use;
-: no chronological information for the site.

more mixed, suggesting that unaccounted factors need to be considered. The earliest occupied sites documented at Uxbenká are the main Groups A, B, D (not ranked here), and I, and settlement groups 1, 4, 5, 20, 21, all of which indicate occupation during at least the latest phase of the Late Preclassic, ca. AD 1-300 (Culleton et al. 2012; Prufer et al. 2011). As noted, several of these are relatively close to the site core (SG 5, 20 and 21), which would suggest that proximity predicts habitat suitability fairly well. However, SG 1, SG 4 and Group I are located relatively distant from Group A, suggesting that these earlier sites were selected for reasons other than proximity to Group A during the Preclassic Period. SG 1 is ranked highest in terms of yield, and in the top quartile in weighted and unweighted overall ranks, suggesting that the choice to settle there was guided largely by agricultural concerns rather than association with the core area. Group I and the nearby SG 4 are located to the west of the site core, and rank in the lowest quartile overall, largely due to the low ranking in productivity and hydrology, but also affected by distance from the core. The early settlements near the site core are consistent with the IFD model, but Group I and SG 4 do not simply conform poorly to the model predictions, their low rankings contradict the model outright. This leads to several considerations of the model and the specific nature of Group I as a main architectural group.

The large, highly visible architectural groups that are concentrated in the core of Uxbenká (Groups A-G and K) are practically contiguous along two ridgelines within sight of each other. Groups A and K form the eastern complex, and Groups B-G form the western complex. Bayesian analysis of the radiocarbon evidence from Groups A, B, and D indicate that initial clearing and construction at these sites occurred during the latest part of the Late Preclassic. In contrast, Group I appears from the present survey of the area to be a rather isolated group, but definitely a substantial one with an elite presence (Reith et al. 2011). AMS dates on early deposits suggest a Late Preclassic date for initial construction, i.e., probably contemporary with the construction of groups in the core area, and dates on a tomb containing finely made ceramics vessels, jade beads and earspools indicate an elite presence there during the Early Classic Period. A ballcourt suggests that Group I served as a locus of civic and/or ceremonial activities during the Late Classic period as well (Reith et al. 2011). The picture that emerges from these data is of a detached center developed during the Late Preclassic by, perhaps, a group competing with those that established and expanded the main core area of Uxbenká. From this perspective, Group I's lower-ranked location would be more consistent with a despotic distribution, suggesting that individuals involved in settling and elaborating the core groups prevented these people from establishing themselves in the core during the Late Preclassic. That is, the early presence of Group I in a relatively marginal habitat is consistent with the IDD more so that the IFD. Aside from the lack of known stelae at Group I, similar features of elite expression are found at Groups A, B and I throughout the Classic Period, suggesting that status rivalry and competition persisted between the core and this detached faction after the Preclassic Period. However, nothing is known about the political history of this inferred rivalry, and it is possible that the elites living in the site core established and maintained hegemony over the Group I faction at various points during the Classic Period.

If such a rivalry existed including proximity to Group A as a variable in the IFD model should be reconsidered. If some form of despotic behavior existed during the Late

Preclassic and it constrained free settlement then, proximity to a detached center like Group I might figure more prominently in settlement decisions. Although Group I is less extensive and elaborate than the groups in the core area, it likely would have offered similar benefits of social, economic, and ideological interaction for people at settlements more distal to the site core. Accounting for this sort of "social gravity" in the model could be done by proposing the presence of Groups, A, B, I and so on, *a priori* during the Late Preclassic, and reckoning settlement group distances from the nearest main group, rather than only Group A. This would help explain the early and persistent occupation of a site like SG 4, whose proximity to an already established Group I would raise its habitat suitability. Under this revised model, the early settlement of SG 1 would still be primarily explained by the highly ranked agricultural potential of its relatively remote location.

It is also possible that other factors influencing site selection need to be considered to explain the relatively early establishment of Group I and SG 4. The three factors involved in the proposed IFD model are primarily oriented towards evaluating habitat suitability with respect to internally-oriented criteria. Maize productivity relates most directly to the commoner household subsistence economy, and then secondarily toward the broader polity as surplus maize is given in tribute to elite functionaries or bartered for other goods. Hydrology, or water availability, is also directly tied to the concerns of the household economy in terms of labor required to obtain suffiencient water for daily needs. Distance from the site core, as described above, touches on several social and economic advantages of access to the concentration of civic and ceremonial power that made Uxbenká a sociopolitical entity – a small city – in and of itself. Turning to interactions with people and polities outside of Uxbenká, peripheral outposts might offer individuals the opportunity to observe and mediate access to the site core along transport routes between other polities. Group I and SG 4 are on either side of the existing San Antonio-Jalacte Road to the west of Santa Cruz village, and least-cost models of area suggest that the same route would have been favored for travel to and from what is now eastern Guatemala (K. Prufer, pers. comm. 2012). The ability to influence commerce and diplomacy by restricting trade routes is a possible factor that might raise the habitat suitability of the Group I locality despite generally lower agricultural productivity. If the area served as one of the entrances to the polity, however, it seems more likely that the elites at Group I would have been politically integrated with the elite apparatus in the site core, rather than a competing rival faction. This line of thinking also raises the question of whether there would have been other potential routes to access the core area – e.g., across the Rock Patch to the south towards Pusilha, or to the northeast towards Lubaantun and Nim Lit Punit - and whether there are similar outposts or garrisons controlling access there as well.

Further Work towards Understanding the Ideal Free and Despotic Settlement Models for Uxbenká

A focus of ongoing work at Uxbenká is augmenting the chronological records for many of the sites in the sample. It is clear that Groups A, B, and I have longer records of occupation than most settlement groups. Much of this is owed to better documentation at those locations because of the larger effort devoted to their excavation over the years, as well as the greater frequency of secure contexts within large structures from which to collect radiocarbon samples to establish absolute chronology (e.g., pit features, plaster floors, rebuilding events, tombs; Culleton et al. 2012; Prufer et al 2011). Smaller settlement groups with less elaborate architecture and simpler construction histories often do not provide adequate contexts for sampling because Late and Terminal Classic deposits, if they exist, are also mixed by bioturbation and other processes into the present-day A Horizon (Culleton et al. 2012; Webster et al. 2004). There is no way around this obstacle for radiocarbon dating in many settlement groups, but the problem may be ameliorated through the ongoing research of ceramic types present in these deposits. Preliminary work on the ceramic assemblages of SG 1 and SG 4, for example, documents components attributed to the Late Preclassic Period through the Classic Period. This is also supported by AMS ^{14}C dates from the site. Further refinement of the diagnostic ceramic sequence will help flesh out the settlement chronology and provide a stronger test of the IFD model presented here.

Additional fieldwork is being conducted to expand the database of maize yields surrounding Uxbenká and Santa Cruz. These new data may alter the rankings for individual settlement groups, but the general pattern of greater productivity in the north and lower productivity to the south will likely remain unchanged. The broader areal coverage will, however, extend the yield raster and allow for additional known settlement groups with existing chronological data to be included in the sample of sites considered in this analysis. With a larger sample of sites further complexities in the settlement history of Uxbenká can be explored within the IFD and IDD models developed here.

Conclusions

An IFD/IDD model of habitat suitability and settlement expansion was developed for the ancient Maya center of Uxbenká and tested against settlement data from the end of the Late Preclassic Period (AD 1-300) through the Late Classic Period (AD 600-800). A sample of 22 known civic/ceremonial architectural groups and household settlement groups was ranked in terms of three variables: agricultural potential, access to potable water, and proximity to the site core. These variables were quantified from empirical data on contemporary maize yields in the area, stream ordering, and linear distance from the core area, incorporated into a GIS database along with archaeological survey coverages of known settlement sites. These variables were combined into a weighted overall ranking of habitat suitability for each settlement location in the sample. The prediction of the IFD model is that the highest ranked habitats should be settled first, and as population density increases, settlements will expand into less favorable habitats over time.

Comparison of the existing archaeological chronology with settlement ranks shows a general conformity with the IFD, in that several of the earliest (i.e. Late Preclassic) settlements are found in high-ranked locations near the site core (e.g., SG 5, SG 20, and SG 21), and in the most agriculturally productive areas away from the site core (e.g., SG 1). Two other Late Preclassic settlements – civic-ceremonial Group I and a smaller household settlement SG 4 – defy the predicted pattern and are found in much lower-ranked (3rd and 4th quartile) habitats to the west of the Uxbenká's urban core. The presence of these sites in marginal habitats early in the settlement history of Uxbenká may be interpreted as evidence for early despotic behaviors practiced by elites seeking to exclude certain segments of the population from establishing settlements near the site core. If so, this suggests that competition and status rivalry developed between at least two competing elite groups: one located in the site core and the other in the detached center at Group I. Alternatively, Group I may have been positioned to mediate access to the site core from travellers outside of the polity, and functioned as a garrison or outpost. In that case, the Group I population was more likely to have been politically integrated with core elites, rather than a competing rival faction. Further work is needed to improve the archaeological chronology and incorporate more sites into the analysis, but the results demonstrate the utility of formal IFD and IDD models for exploring the ecological and social factors affecting population distributions in the past and for identifying and explaining instances of status competition in the archaeological record.

CHAPTER VI

CONCLUSIONS AND PROSPECTS

The archaeological research presented in this dissertation is the outcome of several years of collaborative work with colleagues in the field and lab with the aim of understanding the connections between land use, ecology and settlement at the ancient Maya center of Uxbenká, Belize. It is the result of the kind of interdisciplinary effort that marks the higher ambitions of archaeological research, which, as van der Leeuw and Redman (2002) argue, is to place “archaeology at the center of socionatural studies.” Doing so means attempting to bridge methodological, theoretical and cultural gaps between disciplines, and a willingness to share our data, expertise, and to help shoulder the burdens of interpretation and analysis. My work at Uxbenká is a small contribution to the larger on-going research project there, and to Maya archaeology in general, but several of the approaches outlined here may show promise for broader application as collaboration continues.

The Bayesian chronology developed here provides new insights into the developmental history of Uxbenká’s urban core and provides a statistical framework for future chronological refinement. The earliest leveling and clearing at Group A (the Stela Plaza) began during the Late Preclassic at cal 50 BC – AD 220, roughly 100-200 years earlier than previously thought (Prufer et al. 2011). This was followed by similar landscape modifications at Group D (cal AD 20-240) and Group B (cal AD 60-310) and a period of multiple plastering and remodeling episodes in both plazas. The leveling and construction during the Late Preclassic and the Early Classic that established the nascent urban core of Uxbenká preceded all evidence for dated stone monuments at the site, as the earliest known stela was dedicated in AD 378. Based on the available evidence there is relatively little construction in the site core that dates after the Early Classic Period from ca. AD 400-600. However, the Group A plaza was substantially replastered in the Late Classic at cal AD 550-770 along with the construction and dedication of a staircase in Group B (Structure B1; cal AD 650-770). These events coincide with the dedication of stela at Uxbenká and the appearance or expansion of other regional polities (e.g., Pusilhá, Lubaantun, Nim Li Punit) that is possibly tied to increased interaction with the Petén region in Northern Guatemala (e.g., Tikal). Secure Terminal Classic contexts have been difficult to identify, but remain a focus of ongoing investigations at Uxbenká.

The geoarchaeological work at Uxbenká has defined two episodes of cultural activity that precede the earliest evidence for the leveling and construction of buildings in the urban core. Non-diagnostic ceramic sherds recovered from these A horizons provide the earliest evidence for human occupation in what later became the urban center. This is currently the earliest evidence for human activity in the area and is consistent with the hypothesis that a small farming population first colonized the area between ~900 and 800 BC. This pioneering agricultural activity also occurred during a dry climatic interval that may have destabilized the landscape further. Soil stability during the Middle Preclassic (~770-520 cal BC) occurred during a drying trend that was punctuated by several severe dry periods. This suggests that the landscape is fairly resilient under naturally dry conditions. Destabilization again coincided with the appearance of pottery and stone tools in the sediments at ~300 cal BC, but also with one of the more severe drying trends that likely contributed to deforestation and erosion. I argue that the absence of agricultural terraces and other soil retention features in the area surrounding the urban core results from naturally occurring soil retention features and the rapid decomposition of the mudstone bedrock favoring soil replenishment. I also argue that the overall stability of the landscape in the urban core between ~60 BC and AD 900 resulted from the absence or reduction of swidden cultivation in what was essentially an urbanized landscape used for civic-ceremonial activities and possibly stabilized by urban gardens and the cultivation of economically valuable tree crops. An episode of mass-wasting in the urban core occurred during the Early Classic sometime between cal AD 280-610, and is attributed to possible tectonic activity and associated hillslope failure, rather than human activities in the site core. Increased erosion and the burial of the Late Classic Period landscape is coincident with increasing evidence for swidden agriculture in the site core, possibly by a remnant or returning population of farmers after the political collapse of Uxbenká that occurred in the context of climatic and social instability during the Terminal Classic Period.

The results of the geoarchaeological work suggest further avenues to explore. The presence of pottery in the early paleosols is currently the earliest evidence for ceramics in southern Belize. They are Middle Preclassic in age and this is consistent with the relatively late adoption of ceramics elsewhere in the eastern Maya Lowlands. The lack of diagnostic slip or discernable vessel form leaves these sherds as tantalizing evidence of a human presence, but with no indication of cultural or geographic origin. Thin-section studies and element analysis of the ceramic paste holds the possibility of identifying a local or exotic origin for the pieces, and might allow their age to be confirmed by comparison to better preserved specimens from areas such as the Petén or the Belize

River Valley. Also the interpretation of changing land use in the site core, from agricultural to urban during the Classic Period, and returning to swidden cultivation from in the Terminal Classic might be tested through palynological and paleobotanical studies on sediments recovered from the paleosol sequences. Shifting land use in the site core should be identifiable by changing abundances of arboreal and disturbance taxa, and by the presence or absence of economic cultivars throughout the sequence. Finally, the development of a high precision speleothem precipitation record from Yok Balum Cave in the karst ridge roughly 1.5 km south of Uxbenká may clarify the relationship between the climate change and landscape stability that is somewhat obscured by the contradictions in the three existing climate records considered in this study.

Contemporary Maya subsistence practices and maize productivity in the area were used to estimate maximum population potential for the ancient Maya center of Uxbenká. Maize yields in *milpas* planted by farmers around the village of Santa Cruz were quantified during the 2009 and 2010 harvest seasons, and compared with environmental variables including soil nutrients (e.g., N, P, K, pH, organic and inorganic carbon) and landscape attributes (e.g., slope, aspect, distance from the village). Maize yields were found not to correlate with measured variables, with the exception of a very weak positive correlation with distance from the site core. Planting density, which varies with the type of maize planted, was found to heavily influence yields and is dependent upon intercropping with other cultivars and the presence of physical obstacles in cleared *milpas*. The lack of correlation between yields and a range of environmental variables is consistent with other ethnographic studies on maize production that suggest a range confounding factors of soil, weather, maize variety, pests, and farming experience that ultimately dictate the outcome at harvest.

Taking the average maize yield per area and assuming daily caloric needs for ancient inhabitants, the maximum sustainable population of the Uxbenká polity during the Classic Period is estimated to be between 7500 and 13,000 people within a 6 km radius. This population is modeled at a five-year fallow period, just on the cusp of a short fallow system suggestive of low level agricultural intensification. The lack of archaeological evidence for intensive farming strategies (e.g., terracing, field demarcation, irrigations systems) in the vicinity of Uxbenká is consistent with this model result. Assuming the elite population resided in the urban core of the site and that it was 5% of the total population, the model predicts the presence of ~525 elites.

A productivity-derived prediction of household density within the ancient Uxbenká polity provides expectations that can be tested with future archeological work. The factors affecting maize yields will continue to be investigated by a new cohort of anthropologists working with farmers in Santa Cruz village. Further directions for research into past population size include incorporation of more realistic demographic profiles for the ancient population (i.e., accounting for the distribution of the age and sex classes of the modeled population with life tables), and the development of more complex computational models of demographic change over centuries and millennia of land use and social change.

An IFD/IDD model of habitat suitability and settlement expansion was developed for the ancient Maya center of Uxbenká and tested against settlement data from the end of the Late Preclassic Period (AD 1-300) through the Late Classic Period (AD 600-800).

A sample of 22 known civic/ceremonial architectural groups (n=4) and household settlement groups (n=18) was ranked in terms of three variables: agricultural potential, access to potable water, and proximity to the site core. These variables were quantified from empirical data on contemporary maize yields in the area, stream ordering, and linear distance incorporated into a GIS database along with archaeological survey coverages of known settlement sites. These variables were combined into a weighted overall ranking of habitat suitability for each settlement location in the sample. The prediction of the IFD model is that the highest ranked habitats should be settled first, and as population density increases, settlements will expand into less favorable habitats over time.

Comparison of the existing archaeological chronology with settlement ranks shows a general conformity with the IFD, in that several of the earliest (i.e. Late Preclassic) settlements are found in high-ranked locations near the site core (e.g., SG 5, SG 20, and SG 21), and in the most agriculturally productive areas away from the site core (e.g., SG 1). Two other Late Preclassic settlements – a civic-ceremonial group (Group I) and a smaller household settlement (SG 4) – defy the predicted pattern and are found in much lower-ranked (3rd and 4th quartile) habitats to the west of Uxbenká's urban core. The presence of these sites in marginal habitats early in the settlement history of Uxbenká may be interpreted as evidence for early despotic behaviors practiced by elites seeking to exclude certain segments of the population from establishing settlements near the site core. If so, this suggests that competition and status rivalry developed between at least two competing elite groups, one located in the site core and the other in the detached center at Group I. However, it is also possible that peripheral settlements that exhibit less favorable habitat suitablity rankings in the proposed model may offer other advantages in the broader sociopolitical context that have not been accounted for. Peripheral settlements located at points of strategic access to the site core may have served as points from which to observe and mediate travel and trade between other regional polities, possibly serving as garrisons or checkpoints. In such a scenario, the existence of a relatively substantial elite presence at Group I may be interpreted as an extension of elite political control throughout the Uxbenká area rather than the center of a competing rival faction.

Further work is needed to improve the archaeological chronology of the settlement groups around Uxbenká so that a larger sample of sites in a broader range of habitat types can be incorporated into the analysis to test model predictions. Further methodological refinements would include the use of Bayesian sampling techniques to develop finer chronological resolution in the order of settlement expansion, and also to account for the effects of incomplete settlement survey coverages. Even so, the results of a relatively simple model formulation demonstrate the utility of formal IFD and IDD models for exploring the ecological and social factors affecting population distributions in the past and for identifying and explaining possible instances of status competition in the archaeological record. A broader application of ecologically-based formal models holds promise for addressing questions of ancient Maya human-environment interactions over a range of temporal and spatial scales.

Broader Relevance to Lowland Maya Archaeology

The work presented here on the archaeology of land use at Uxbenká is fundamentally aligned with the research tradition of cultural ecology in the Maya Lowlands, while also incorporating more recent theoretical developments in Human

Behavioral Ecology (HBE). As outlined by Demarest (2003:22-24), cultural ecology and economic approaches to understanding Maya culture history, and Mesoamerican archaeology in general, were widely adopted in the 1960s and influenced research designs and objectives heavily into the 1970s and early 1980s. The emphasis on ecological constraints on cultural adaptations as well as attempts to employ hypothesis testing in research agendas characterized much of Mayanist archaeology during those decades, leading to an expansion of data-driven empirical work on settlement patterns, paleodemography, and food production systems at Lowland Maya sites. By the late 1980s critiques of cultural ecology as being overly deterministic in explanatory power, and perceived inability to address or explain apparently non-ecological features of ancient Maya society, such as the ceremonial-religious apparatus of Maya rulers and their elites, gained ground as an element of the broader post-processual backlash within Americanist archaeology. The desire to understand the political and social aspects of Maya society that at first glance are less empirically tractable - but clearly crucial to explaining the emergence, maintenance and eventual decline of Classic Period Maya polities – drove research into the arena of political economy of theather states (Demarest 2004; Masson and Freidel 2002).

As ecological approaches to Mayanist archaeology were gradually being de-emphasized from the early 1990s on, advances in climate science led to more precise climate records (primarily lake cores) recovered from Central America. The role of climate change, specifically drought, in the decline of Maya civilization came to the fore again (e.g., Hodell et al. 1995), bouyed by the increasing concern about the social consequences of environmental change among natural and social scientists, political entities, funding agencies, and the general public. This shift back towards ecological explanation continues to the present, but poses a challenge for archaeologists to collaborate effectively with climate scientists that desire their work to have broader social relevance, but may not (yet) be well versed in anthropological theories of societal change.

Much of my research at Uxbenká has attempted to develop the site’s temporal and ecological context to bridge the gap between archaeological and environmental histories, so that the effects of human land use and ecological change can be better understood. Working in collaboration with members of the Uxbenká Archaeological Project and Maya Socioeconomic Dynamics project, I have helped build the Uxbenká site chronology using Bayesian techniques, studied the unique geoarchaeological setting of the area, investigated contemproary maize yields and their implications for past population and land use, and incorporated these data into a preliminary settlement decision model using concepts of the Ideal Free and Despotic Distributions from population ecology. This work complements and augments the more strictly archaeological and ecological work being conducted by the broader research teams. The approach is not new to Mayanist archaeology, but can be seen as part of the growing return of ecologically oriented research of past decades into contemporary research agendas, while employing new analytical techniques to the study of human environment interactions.

As climate records gain resolution through advances in chronology and sampling techniques, periods of rapid climate change come into focus and understanding human responses to them have become more pressing topics of study. Improving the chronological resolution of Maya culture histories is key if they are to be comparable to newer climate records so that cause and effect relationships between environmental and cultural change may be properly understood. The use of Bayesian chronology building at Uxbenká is one example of how existing chronometric and archaeological data can be integrated to improve site chronologies, and these may be more widely applied throughout the Maya Lowlands. While ceramic seriation and epigraphic texts have formed the backbone of Maya site chronologies for decades, better integration with high resolution AMS ^{14}C dating in a Bayesian framework may yield much tighter absolute chronologies that are required to test hypotheses of climate-driven social change throughout the Preclassic and Classic Periods. Given the large body of existing chronometric data from these various sources at hundreds of Maya centers, there is great potential to re-evaluate Maya culture history using Bayesian analysis.

The geoarchaeological work at Uxbenká has demonstrated the importance of site-specific geology and soil formation processes, as well as the value of conducting off-site investigations. When discussing the ecological setting of the Maya Lowlands, reference to the limitations of thin limestone soils for maize farmers is extremely common, and of course it is a broadly accurate description of much of the Maya Lowlands. However, the mudstone- and sandstone-dominated Toledo Beds on which Uxbenká sits produce relatively thick soils, and appear to be fairly resilient in the face of swidden agriculture. That, coupled with the presence of deep joints and fissures in bedrock that act as soil-retaining structures, appears to have obviated the need for heavy investment in constructed soil management features during the site's history. Without excavating trenches in areas away from the main architectural groups at Uxbenká, the special nature of the local soils and geology were understood in a way that would have remained unknown. Further, the record of geomorphic stability and instability in response to land use and climate change was produced in an area where other local proxies of land use – specifically lake sediment cores – are unavailable or poorly resolved. Off-site work is extremely valuable for providing proximate records of landscape response when making comparisons to environmental records derived from other parts of Mesoamerica or further abroad. Humans respond to the local effects of global environmental change, and local proxies serve as a test for hypotheses of social change derived from more distal or regional records.

Interest in estimating ancient Maya population sizes has waned since the early 1990s as a result of the shift away from the larger settlement surveys required when estimating population from known structural remains, itself part of the general decline of ecological approaches to Mayanist archaeology. In so far as estimates of population size and density directly relate to questions about capacity for food production and level of agricultural intensification, they are crucial for developing the context in which climate change (e.g., periods of drought) could have altered the economic basis of ancient Maya societies. The fact that the lands around Uxbenká are currently being farmed by the modern Maya community of Santa Cruz offered the opportunity to gauge the productive capacity of the land in a non-mechanized swidden farming system today, and from that develop maximum population estimates for the ancient polity. The results provide further predictions about potential settlement densities that can be tested in the course of the ongoing settlement survey and excavation work by the Uxbenká Archaeological Project. By estimating possible fallow periods at the site's peak during the Classic Period, I suggest that the population may have been just on the cusp of needing to shift to more intensive agricultural practices, and were engaging in a level of intensification that would typically leave very little archaeological trace. This opens the question of how intensive Maya agriculture was at any given polity that lacks obvious signs of constructed terraces, raised fields, and similar adaptations. The lack of such features does not necessarily equate to extensive land use, but indicates the spectrum of intensification possible, and the margin of land use flexibility and adaptability inherent in the Maya farming system to cope with human-induced and external environmental change. Likely many secondary polities without elaborate soil management structures were indeed still making land use decisions within that archaeologically obscure margin of intensification.

The application of HBE models to land use and settlement decisions in the Maya Lowlands is a new approach to understanding land use decisions and dynamics of social and ecological change. Viewed as an outgrowth of earlier Cultural Ecology paradigms it offers explicit connections between the socioeconomic context in which individuals operated and allows predictions of the outcomes of their decision-making process for the archaeological record. By focusing on individuals, HBE models have the potential for addressing issues of agency among the commoners that comprised the bulk of ancient Maya society. Further, by emphasizing the ecological context of human decision making the integration of HBE into Mayanist archaeology has the potential to bridge archaeological and anthropological data and theories with those of other natural sciences including tropical ecology, hydrology, geomorphology, and climate systems. In this sense HBE may serve as a crucial tool for the broader interdisciplinary endeavors that are required to address current problems of human responses to enivronmental change by providing a mutually intelligible framework for communication between disparate aspects of collaborative projects. The ability to accomodate aspects of climate change with the complexities of human social behavior - particularly in the case of the ancient Maya where cultural features of religion, ceremony and statecraft may seem ecologically intractable and therefore inexplicable – is key to understanding the dynamics of the emergence, maintenance and dissolution of ancient Maya sociopoltical sytems. HBE offers the potential for broader application and multiple spatial and temporal scales and should be a productive vehicle for future work in the Maya Lowlands.

The Archaeology of Uxbenká and the Community of Santa Cruz

My work at Uxbenká and the surrounding lands has been conducted with the permission and and assistance of the Maya community of Santa Cruz, on whose land the ruins of the ancient polity are found. The Uxbenká Archaeological Project has developed an excellent working relationship with community members, and helped develop a community-based organization for the management of cultural tourism related to the lands and the ruins of Uxbenká, the Uchbenkah K'in Ajaw Association. Because of the close collaboration with the community members I have been mindful of what contribution my work could make to the people of Santa Cruz, beyond providing the short-term economic benefits of wage labor during surveys and excavation. It is a vexing problem in any circumstance to argue for the practical benefit of archaeological knowledge for society as a whole, but more so when those benefits to society may appear to be largely abstract and refer to Euro-American Enlightment goals rather than practical applications for indigenous farmers.

The men that did the bulk of the physical work excavating with me at Uxbenká are all farmers engaged in subsistence and cash cropping, and we spent a great deal of time talking about farming and soils. The aspects of my work that deal with soils and maize productivity probably have the most direct relevance to their concerns as farmers and householders. One issue that they confront is the long-term sustainability of shifting swidden agriculture on their communal lands, which they won the right to in the Supreme Court of Belize in 2007. The geoarchaeology of Uxbenká suggests that since at least the Middle Preclassic Period, people have engaged in a form of swidden agriculture at various times and with varying intensity, and that the land responded with periods of erosion and stability depending on climatic conditions and local land use decisions. This record exists because the character of the local bedrock provides what are essentially sediment traps that retain large volumes of soil that today must contribute to the overall productivity and resilience of the soil to swidden farming and the effects of erosion and slopewash. In addition, when the mudstone and sandstone bedrock is exposed by forest clearing it quickly breaks down to form new soil, so that topsoil is relatively rapidly replenished. Together these aspects of the Santa Cruz lands lend themselves to what Hartshorn et al. (1984) referred to as the "paradoxical fertility" of the Toledo Beds.

There is not yet enough data to argue that this resilience will persist indefinitely under current land use practices, which would be one way of defining sustainability. Longer term study of the local ecology, fertility, dynamics of forest succession and recovery will be needed to make this argument. However, I would note that the continued ability to grow maize, rice and other crops on Santa Cruz lands without the emergence of a grassy wasteland, as feared by Wilk (1991) in the region, is suggestive. Wright et al.'s (1959) land use recommendation for the area was to log the remaining stands of forest, clear the bush for pasture and graze cattle for several years, and then devote the land to tree crops such as citrus. He argued that there was very little potential for other economic uses. By the time of Wright’s contribution to the Hartshorn et al. (1984) field study, he apparently recognized the aforementioned paradoxical fertility of the region. However, almost 30 years later it appears that the resilience of the area’s soil to current land use practices continues. Again, this is attributed to a balance between the advantages of the local geology and the nature of the communal land use practices, and can’t be said to apply to every part of southern Belize. However, the geoarchaeological evidence suggests the capacity of the land to continue to support swidden farming around Santa Cruz with communal decision-making regarding land use practices. The ongoing work of archaeologists, ethnographers and ecologists in the Santa Cruz community can draw upon the geoarchaeological presented here as a baseline for comparing the effects of modern land use over the longer term. In a small way, perhaps this work can also offer the community a sense of their place in the longer historical legacy of peoples that have been making a living farming the land over the last 3000 years in southern Belize.

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