



The Classic Period Maya transition from an ideal free to an ideal despotic settlement system at the polity of Uxbenká



Keith M. Prufer^{a,*}, Amy E. Thompson^a, Clayton R. Meredith^a, Brendan J. Culleton^b, Jillian M. Jordan^a, Claire E. Ebert^b, Bruce Winterhalder^c, Douglas J. Kennett^b

^a Department of Anthropology, University of New Mexico, United States

^b Department of Anthropology, The Pennsylvania State University, United States

^c Department of Anthropology, University of California-Davis, United States

1. Introduction

More than eleven hundred years of settlement history at Uxbenká, a Classic Period Maya polity (ca. 300 BC to AD 900) located in southern Belize (Fig. 1), conform to a patterned shift from an ideal free to a despotic distribution, coincident with a change toward habitat suitability increasingly dependent on anthropogenic features of the landscape. To demonstrate this claim, we document the development and geospatial organization of the settlement systems at Uxbenká using differential GPS and LiDAR data associated with extensive survey and excavations (Prufer et al., 2015). We also chronicle the development of the built landscape; a major trade corridor, neighborhoods, districts, and the ceremonial center being the prime features under consideration. Finally, we assess the relationships between the spatial patterns as populations in-fill to political developments within the framework of two population ecology models: the Ideal Free Distribution (IFD) and Ideal Despotic Distribution (IDD).

1.1. Setting, objectives and questions

Uxbenká (Fig. 1) was a moderately sized Maya center during the Classic Period (AD 250–900), comparable to nearby sites such as Pusilhá and Lubaantun but small when compared to the major centers of Tikal and Caracol to the northwest. Since 2005 the Uxbenká Archaeological Project (UAP) has conducted extensive survey and excavations in the settlement zone surrounding Uxbenká, with a focus on building a precise absolute chronology for the development of the community and its environmental context (Culleton et al., 2012; Prufer et al., 2011, 2015; Prufer and Thompson, 2016). Cultural ecological studies conducted in parallel are documenting the agro-ecology of contemporary subsistence tactics in the nearby community of Santa Cruz (Baines, 2015; Culleton, 2012). We draw on both sources of information in our analysis.

In agrarian communities, residential settlements are the primary social unit and location of human interactions that articulate with broader economic and political processes (Ashmore, 1981;

Willey, 1968). Despite their importance they remain understudied and poorly dated in the Maya area (See Supplement S-1). For instance, little research has examined the precise chronological histories of settlements surrounding Classic Period Maya centers. This leaves us unable to answer basic anthropological questions: Why were people more successful in some locations compared to others on a landscape? How did population growth, the natural environment, and the built environment influence status disparities of settlements through time? What are the relationships between settlements, which generate agricultural and other resources, and the consolidation and differential control of those resources by emerging political elites?

We explore fundamental questions in the development of settlement systems in the Maya Lowlands and beyond: What organizing principles and socio-environmental factors guide residential settlement decisions in agricultural societies when the environment is an open access frontier? How do these initial choices change with the growth and development of low-density urban environments? And, what are the long-term consequences of these initially open but increasingly constrained settlement options? We identify and assess the relative importance of social and environmental variables that may have been important to human decision-making in a bounded, community-centered landscape. Furthermore, we examine how those decisions were reflected in the relative success of residential compounds over centuries of growth.

In pursuit of answers to these and related questions, we (a) present a high precision AMS ¹⁴C chronology for the development of the Uxbenká settlement system; (b) identify and describe neighborhoods (loci of daily household interactions) and districts (local seats of power and authority) as organizing principles for the distribution of households and local economic and political control across the landscape; (c) develop population estimates and a model of demographic growth; (d) analyze factors affecting decisions about household location; and (e) offer an evolutionary anthropology model, drawing on behavioral ecology, to help explain why some households and neighborhoods were larger, longer-occupied, and apparently more successful over the 1150 year occupation of the polity. Our evidence and interpretation together document an increasingly stratified relationship

* Corresponding author.

E-mail address: kmp@unm.edu (K.M. Prufer).

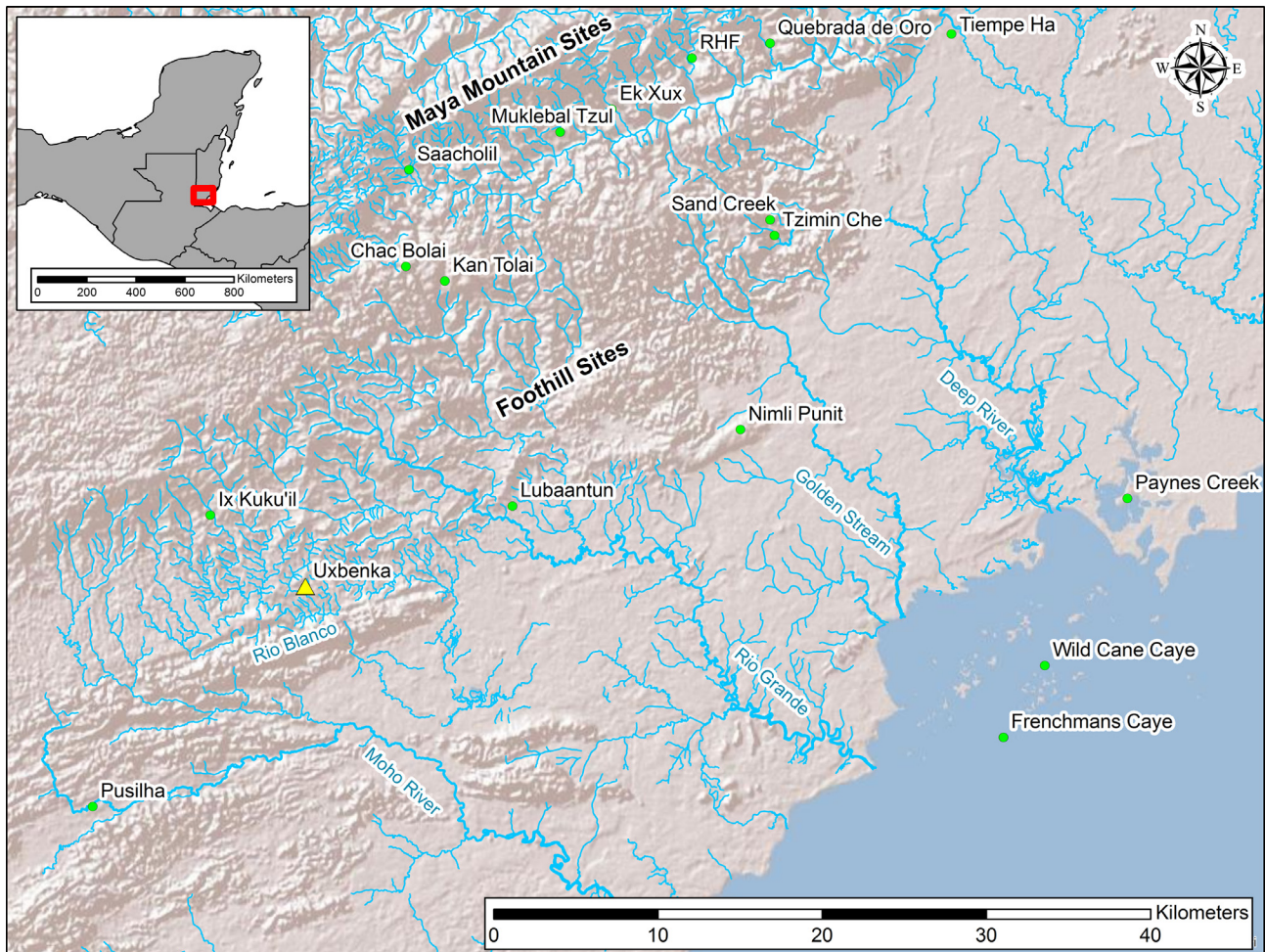


Fig. 1. Regional map of southern Belize showing known archaeological sites and relief features as well as major watercourses discussed in the text. Aside from Uxbenká, Ek Xux, and Nimli Punit, all other sites are primarily Late and Terminal Classic centers.

among households, reflecting their distribution relative to ceremonial centers and differential access to socio-economic resources.

1.2. The ideal free and ideal despotic distributions

We propose that the settlement history at Uxbenká is consistent with two related models derived from Human Behavioral Ecology (Fretwell and Lucas, 1969; Sutherland, 1996). Initially, it agrees with core predictions of the Ideal Free Distribution (IFD). Given a ranking of settlement locations – call them habitats – by their suitability, the IFD predicts that immigrants will settle first in the best open location and then, as density and competition there reduce the effective suitability, further growth will spill over into the second ranked habitat, and eventually into the third. In effect, the distribution of people across a landscape is density-dependent; freely moving individuals will cease to move at an equilibrium that entails equal suitability across all occupied locations (Kennett, 2005; Kennett et al., 2006; Winterhalder et al., 2010).

For early colonizers settling in locations highly ranked for their environmental suitability we presume that competition for resources is low and status differences are small (Kennett et al., 2009). The IFD typically assumes negative density dependence – suitability declines with increasing density. However, human opportunities for cooperative endeavors such as investment in landscape capital (e.g., terraces or agroforestry), and development of

economies of scale and division of labor, not to say more effective collective action for defense, may actually elevate effective suitability as the founding population begins to grow. This is known as the Allee effect (Allee et al., 1949). Subsequent declines in per capita suitability will arise from interference (theft, or boundary conflict) or exploitation (depletions of resources) competition. Declining effective suitability results in movement of people to nearby but lower ranked habitats.

The basic IFD neglects features we would want to include in the analysis of early complex societies. In these cases, status differentials may facilitate defense of resources by elites and relocation decisions may be limited and movement may be constrained in politically organized agricultural landscapes (Ebert et al., 2016) due to occupied frontiers or hostile neighbors (McClure et al., 2006). In Classic Period Maya polities there were marked status differences between individuals. The ability of some actors to control a disproportionate share of resources and labor and kin reckoning among descent groups was likely a major factor in how status differences were organized. We address this more complex setting with the Ideal Despotic Distribution (IDD). The IDD assumes that actors differ in their ability and willingness to accumulate and defend a disproportionate share of resources, including prestige (Kennett and Winterhalder, 2008) and elites may be able to impede emigration. The IDD assumes that those able to defend resources will occupy the highest ranked habitats, and will do so at lower densities, pushing spillover population growth into lower

ranking locations. In the IDD suitability no longer is equalized over the whole population, as habitat specific densities are no longer strictly proportional to resource potentials.

Our use of the IDD entails the definition of despotism used in evolutionary biology: one or more individuals in the population is able to sequester and control a disproportionately large share of the factor or factors determining habitat suitability (see also Summers, 2005: 106). Unconstrained and equal resource access and defendability (IFD) gives way to control and unequal access and defendability (IDD). The relevant suitability factors may be as diverse as size of a territory, resource and environmental amenities, access to mates and labor, or socio-economic advantages stemming, for instance, from contiguity with a desirable trade route or religious shrine. While differential control over such resources is a condition for social stratification and political control (D'Altroy et al., 1985), this is a narrower definition of despotism than that adopted by social scientists, including some archaeologists (cf. Malley, 2012; Bahrani, 2010), who more typically follow Wittfogel (1957) in implying to some degree an absolutist, managerial state. We assume the potential for an emergent, managerial centralization based in differential resource control, and ask what factors were likely to promote its development toward state-level organization.

In the IDD model, subordinates will remain in an oppressive environment, one in which elites claim part of their production, if the elites make concessions sufficient to outweigh the costs and uncertainties of migration (Bell and Winterhalder, 2014). Those concessions can include access to subsistence and other material resources, but can also be construed as the benefits and security of group membership. Examples might be access to market economies and goods and services, promises of collective security, redistribution of goods as a form of reciprocity, and access to public events to reinforce group identity. If elites are able to elevate local suitability – by providing amenities such as (a) solutions to coordination problems, (b) better defense, or (c) access to sacred sites and ritual opportunities – they may actually encourage immigration. Even subordination may be advantageous if the alternative is worse. Similarly, if elites can impede out-migration by control of borders, they can raise the cost of flight and retain a high density of subordinate producers subject to greater exploitation.

IDD suitability can also allow for reproductive skew (Clutton-Brock, 1998; Johnstone, 2000; Cant and English, 2006), in which individuals increase their inclusive fitness by enhancing the direct reproductive fitness of kin, a hallmark of despotism (Summers, 2005). Reproductive skew models developed originally to explain “helpers at the nest,” whence newly adult avian individuals who, rather than dispersing to their own nesting sites, appear to sacrifice their reproductive opportunity in order to help their parents fledge the next generation. This kind of behavior grows in likelihood as the relatedness of the helper to the beneficiaries increases, enhancing kin selection benefits, and as the likelihood of successful independent reproduction diminishes. We take reproductive skew to indicate that allegiance to kin and locale increases with relatedness and with diminishing prospects associated with dispersal.

In societies in which descent is recognized, individuals are likely to favor kin in the allocation of resources, leading over time to the concentrations of resources in the hands of particular descent groups. This is a key difference between egalitarian and despotic societies (Buston and Zink, 2009), one associated with intergenerational land-tenure (Kushnick et al., 2014) and other kinds of wealth transmission (Borgerhoff-Mulder et al., 2009). Control by elites of access to high quality arable land is one means by which dominants can make concessions to subordinates in exchange for a share of what is produced. Coincidentally, they also gain a socially amenable pool of laborers for capital projects. This social dynamic may be particularly important in the context of

low-density peri-urban settings, in which agricultural, residential and public spaces coexist in close proximity on the landscape.

1.3. Regional setting

Southern Belize was a frontier region of the Maya Lowlands (Fig. 1), circumscribed by the Maya Mountains to the west, swampy *bajos* to the south, the Caribbean Sea to the east and inhospitable pine-barrens to the north. Despite these biogeographic constraints, the area was economically and politically connected to the rest of the Maya world (Prufer et al., 2011). Occupation dates at least to the Late Archaic (Culleton, 2012), suggesting that early populations coalesced into farming communities and eventually a series of well-developed polities. The earliest known communities are Ek Xux, located in the Maya Mountains, and Uxbenká, in the foothills; both occupied by the end of the Late Preclassic (400 BC–AD 250). Several small coastal trading communities first date to around the Late Preclassic/Early Classic boundary (ca. AD 200–250). Other centers did not develop until the end of the Early Classic (ca. >AD 400, Nimli Punit, Pusilhá and Quebrada de Oro) or the Late Classic (ca. >AD 700; Lubaantun, Xnaheb, Muklebal Tzul and a host of smaller centers). By AD 750 there were at least 20 centers with public architecture in southern Belize with largely independent rulers and significant populations dispersed across the agriculturally rich hills and valleys.

These communities are distributed across four different ecological zones, each of which likely was crucial to their respective success. Ek Xux, Quebrada de Oro, and Muklebal Tzul are located in tributary valleys of the Bladen River, an area hosting important mineral resources and rich agricultural soils derived from the underlying volcanic bedrock of the Maya Mountains (Dunham and Prufer, 1998). Pusilhá is located along a navigable upper section of the Moho River, with access to rich alluvial soils (Braswell and Prufer, 2009). The coastal sites enjoyed marine trade routes and resources (Robinson and McKillop, 2013). Finally, Uxbenká, Lubaantun, and Nimli Punit are located along an unusually fertile 25 km long hilly relief feature composed of interbedded Tertiary calcareous mudstones, sandstones and shales (Keller et al., 2003) extending from the Maya Mountains to the north, to the coastal plain in the south (Hammond, 1975; Prufer et al., 2011). Two general points are consistent with the evidence: First, settlements in the region appear to conform to local topographic conditions and, second, they are closely tied to important resources such as productive farmland. For example, Pusilhá, Quebrada de Oro, and Ek Xux are located on deep alluvial soils ideal for agriculture; these centers were highly nucleated. In contrast, Uxbenká, Lubaantun, Nimli Punit, and Muklebal Tzul were positioned in high-relief hilly environments with settlements spread across ridges and hilltops in clearly differentiated groups.

1.4. The IFD and IDD at Uxbenká

We propose that the eleven centuries of continuous occupation at Uxbenká illustrate a shift from an IFD to an IDD type of settlement system, as the suitability of natural resources that guided initial settlement choices became increasingly imbued with socio-political value that shaped their ranking. The initial settlements likely were part of a small agricultural community living in hamlets with a reasonably open landscape and few neighboring communities. Early settlers located themselves in the most suitable locations for subsistence, social interaction and economic security (Prufer et al., 2011). We assume that the long-term locations and social structure of these early settlements reflect lineal principles of kinship (McAnany, 1995), as descendant groups established control of settlement locations. The presence of elaborate and serially used tombs in the largest and longest occupied settlements at

Uxbenká likely indicates exclusionary rights to land by lineage groups, as has been proposed generally for the Maya lowlands (Gillespie, 2002; McAnany, 1995; Vogt, 1970; Welsh, 1988).

As the polity of Uxbenká grew and became more socially and politically differentiated, those early locations maintained their prominence, reflected archaeologically in the presence of larger and more specialized architectural groups. Their residents were able to mobilize a greater share of resources and labor relative to other and later-settled locations on the landscape. AD 200 and 400 is the key period of rapid growth and initial social differentiation at Uxbenká, the beginning of public architecture (Culleton et al., 2012), emergent leadership strategies (Moyes and Prufer, 2013; Moyes et al., 2016), and the expansion of settlement groups most closely associated in space with public architecture. Following AD 550 we see continued growth but at outlying settlements that are smaller, more impoverished and located at greater distances from the larger initial settlements and site centers. Both the political core and the larger outlying groups, up to 2 km distant, continue to be occupied and grow until they were abandoned after AD 850. We further develop and generalize this model in terms of the IFD-IDD transition in the Discussion.

2. Results and analyses

2.1. Settlement studies at Uxbenká

Ancient Maya cities have been described as low-density urbanism (Awe et al., 2014; Isendahl and Smith, 2013) characterized by residential groupings interspaced with open agricultural zones distributed across the landscape. The residential groupings functioned as urban neighborhoods, zones that emphasized significant face-to-face interaction and are distinctive on the basis of spatial characteristics (Robin, 2003; Smith, 2010, 2011). Home to the vast majority of people and the nexus of social relations, they shaped political, economic and religious structures within a community (Ashmore, 1981).

With 10 years of survey, our methods for studying settlements at Uxbenká have changed over time. We integrate the varying approaches in this paper. Initial research in 2005–2007 focused on walking transects to identify and map architectural groups. However, we quickly determined that the traditional use of linear transects to identify settlements was not a productive strategy. No settlements were located in low-lying areas and thick, secondary growth vegetation made this method time consuming and expensive. We adjusted to target ridges and hilltops, aided by the local agricultural cycle. Each year Mopan Maya farmers from the nearby village of Santa Cruz select new field locations in secondary growth on slopes and hilltops for slash and burn (*milpa*) agriculture. In doing so, they provide a moving opportunity to explore with relative ease previously unexamined portions of the landscape. By 2011 we had located and mapped 57 residential compounds using this approach and had conducted excavations in 37 of these settlement groups (Kalosky and Prufer, 2012).

In 2011 the UAP acquired Light Detection and Ranging (LiDAR) data for a 132 km² area centered on Uxbenká in collaboration with the National Center for Airborne Laser Mapping. We averaged approximately 20 laser returns per square meter in key areas, allowing us to build a Digital Elevation Model (DEM) of approximately 1 m resolution (Prufer et al., 2015). By combining pedestrian survey and analysis of LiDAR data we have increased the number of documented settlements groups to 94, representing 408 individual structures. All of these groups have been visited and mapped using handheld GPS, tape and compass and then overlaid and wiggle matched onto the LiDAR derived digital terrain (DTM, or bare earth) and slope models.

For spatial analyses, we sample all of the 408 structures and 94 settlement groups. For our statistics we include the 48 settlement groups for which we have chronological data (See Supplement Tables 1 and 2). These 48 groups vary in size, layout and architectural complexity and, because we had the goal of collecting chronological data from the widest possible range of settlement groups regardless of distance from core or architectural complexity, they are relatively evenly distributed across the entire study area. We define a settlement group (SG) as consisting of 1–36 buildings on a single modified landform (i.e., ridge line or hilltop), separated from other residential groups by drainages or saddles, and with a clearly defined unoccupied space separating the groupings.

Settlement patterns at Uxbenká suggest a central, elite-focused core with administrative, political, religious, and residential functions, prominently located on a series of ridges and hilltops and encompassing 2 km². A dispersed and economically heterogeneous population of households is spread out across the landscape surrounding this core (Prufer et al., 2011). Settlements include both large residential compounds and smaller hinterland households located up to 2.5 km from the site core; they cover a 20 km² area.

2.2. A multiproxy chronology for the Uxbenká settlement zone

The settlement chronology presented here builds on previous AMS ¹⁴C chronological studies of the site core (Aquino et al., 2013; Culleton et al., 2012; Prufer et al., 2011) and is consistent in bracketing the history of the site between 300 BC and AD 850. Our sample consists of 55 high-precision AMS ¹⁴C radiocarbon dates (Supplemental Table 1) from excavations in 22 settlement groups. In most cases, deeper excavations into larger settlement structures (>1 m tall) produced remarkably useful and consistent dates (Fig. 2). However, excavations into smaller household structures (<0.25–1 m tall), some of which are buildings represented by only one to two courses of stone, and into the upper levels of some larger buildings, produced suspect charcoal and a raft of post-AD 1950 (bomb) dates. These bomb dates can be attributed to long-term slash-and-burn farming that has contaminated all but the best sealed contexts. Because of this, we consider the upper most post-AD 700 dates to be underrepresented. To supplement these late, difficult to date contexts, we also employ a lower resolution ceramic chronology, independently developed and anchored to AMS ¹⁴C dates (Jordan and Prufer, 2014).

All dates presented are 2σ calibrated age ranges from securely documented and carefully selected contexts. We do not attempt to analyze within group chronologies but instead we are concerned with the total, or summed, occupation of each settlement group.

Settlement were modeled in OxCal v2.4 as a single sequence “settlements at Uxbenká” using the INTCAL13 calibration curve (Bronk Ramsey, 2009; Reimer et al., 2013). When building this model, dates that we consider informative but also outliers were excluded. They include several post AD 1000 and Historic period dates, which suggest a residual post-collapse population (n = 4) as well as earlier Archaic and pre-300 BC formative dates (n = 2). We also excluded modern (bomb) dates (n = 7) attributed to recent agricultural activity.

The lower boundary (Fig. 3) of the sequence suggests that initial settlements in stone or dirt platform buildings at Uxbenká first appear between 305 BC and AD 61 (95.4% probability, which can be slightly constrained to 305–168 BC, 79.5% probability). This is three centuries prior to the first public architectural complexes. This early date pushes back previously published assessments of site chronology by over a century, but it is consistent with geomorphological studies in the site core that suggest land clearing for agricultural activity prior to the 300 BC (Culleton, 2012). The radiocarbon data, particularly the summed probability density

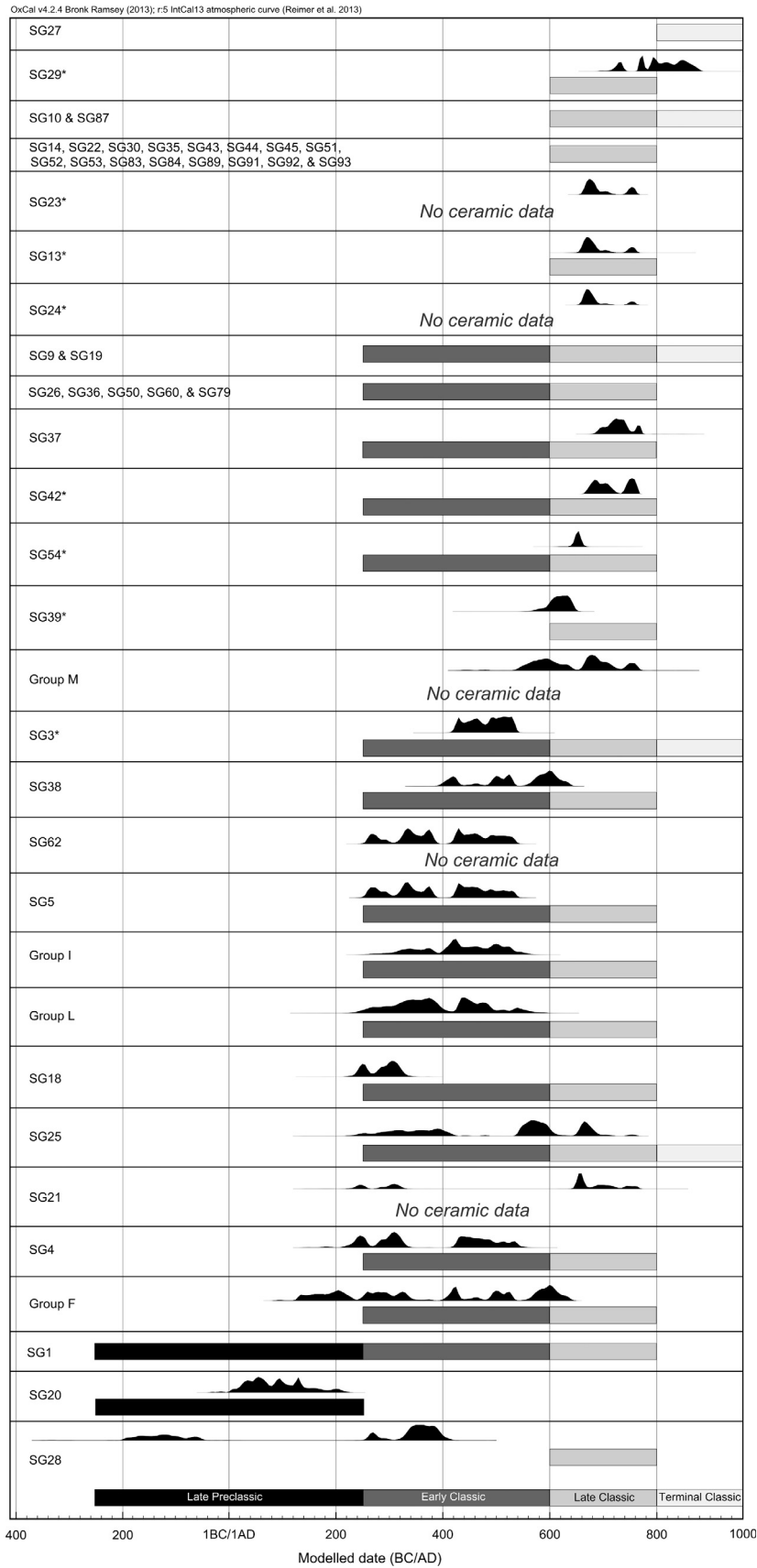


Fig. 2. Combined AMS ^{14}C radiocarbon and ceramic chronology for all settlement groups (SGs) at Uxbenká. Within each row the area in black represents the summed density distribution of AMS dates for each SG at 2σ while the bars represent the overall ceramic chronology by time period. SG numbers indicated by a * have only a single date which is represented at 2σ . All dates were calibrated and modeled in Oxcal using the Intcal 2013 atmospheric curve (Reimer et al., 2013).

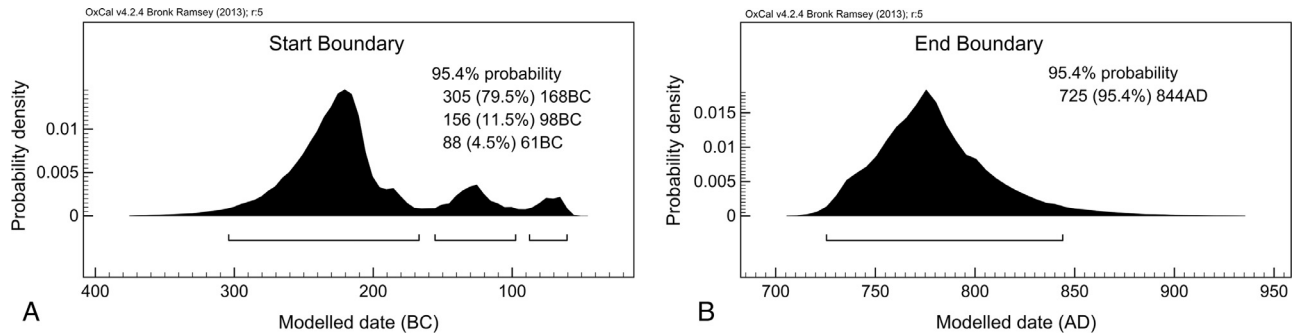


Fig. 3. Summed probability densities of (A) start and (B) end boundaries for AMS ¹⁴C dates from the entire settlement sequence at Uxbenká.

distribution of all acceptable dates at 2σ , suggest that AD 200–400 was a period of major growth at Uxbenká, including heavy investment in modifying hilltops in the larger settlement groups (Fig. 4). This growth is coincident with expansion of the site core (Culleton et al., 2012) and with the massive landscape modifications required to accommodate platforms and public architecture, activities that would have required significant, likely *corvée*, labor (Prufer and Thompson, 2016).

At AD 400 this steady growth is supplanted by the first of several possible moderations in settlement activity, the largest of them coming somewhat later (AD 600–660). These gaps in the radiocarbon record likely are not due to sampling inconsistencies; both intervals are bracketed by high densities of dates. Instead, they probably represent brief lulls in settlement construction.

Settlement activity resumes after each of these pauses and continues until the early 9th century, when the AMS ¹⁴C model shows an end boundary (Fig. 3) for the settlement sequence bounded at between AD 725–844 (95.4% probability). However, as noted above, we believe that these dates underrepresent the final occupation sequence due to bioturbation and modern agricultural activity that deter us from dating these later deposits by ¹⁴C. In fact, our AMS ¹⁴C grounded ceramic chronology suggests a terminal population well into the 9th century AD. Both Culleton et al. (2012) and Aquino et al. (2013) place the abandonment of the site core after AD 850 based on both site core AMS ¹⁴C derived chronologies and epigraphic information. Terminal occupation of Uxbenká in the late 9th century would be consistent with proposed regional political abandonment in southern Belize (Braswell and Prufer, 2009).

2.3. The Identification of neighborhoods and districts

Settlements at Uxbenká appear to have been organized socially, politically and economically into neighborhoods. Three larger

clusters of residential groups that include public architecture likely represented seats of districts, following Smith's (2011: 53) model, in which:

“...neighborhoods are relatively small spatial zones whose creation and maintenance result from social interaction, mutual support, and other bottom-up or generative social processes. They often co-exist with larger residential zones created by municipal or state authorities for administrative purposes. I call these latter units districts.”

The concept of neighborhoods has been understudied in the Maya region. Elsewhere, neighborhoods have been proposed for spatial organization within multi-unit buildings at Ur (Mesopotamia, Brusasco, 2004), ancient Athenian houses (Goldberg, 1999), and Pueblo Bonito at Chaco Canyon in the southwestern US (Bustard, 2003). Generally, studies in the Maya lowlands have not used neighborhoods and districts as units of analysis to illustrate settlement histories, or to link those locations to critical resources in their local environment (but see Smith, 2011; Folan et al., 2014; Arnauld et al., 2012; Hoggarth, 2012). We use spatial statistics and local topographic features to identify clusters of settlement groups that we propose are meaningful in these terms. Smith (2010) notes that neighborhoods should be defined by some elements of their material culture which differ from other adjacent neighborhoods. At Uxbenká we have observed differences in patterns of ceramic production and frequencies within domestic contexts (Jordan and Prufer, in press), suggesting variation in domestic economies across the landscape. Our combined spatial, chronological, and archaeological data allow us to infer the longest occupied and largest of these groups, particularly those with special function public architecture that were local seats of power controlled by groups likely descended from some of the earliest colonists on the landscape.

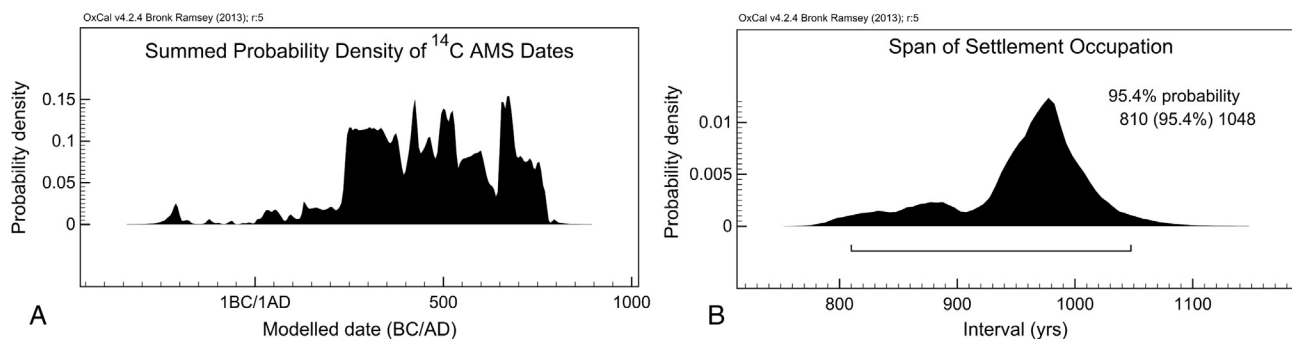


Fig. 4. (A) Summed probability densities of all settlement dates from Uxbenká. These dates bracket the settlement occupation between 300 BC and AD 750, though we discuss possible gaps in the end dates in the text. The span of occupation (B) suggests continuous occupation at Uxbenká lasted between 810 and 1048 years at 2σ .

We identify Uxbenká neighborhoods based on a Nearest Neighbor Analysis (NNA) and Kernel Density analyses performed on settlement data in ArcGIS 10.2. The perimeter of each settlement group was optimally digitized using a 5 m contour that allowed us to systematically define the extent of the hilltop area used in daily activities for each settlement group around all mapped buildings. NNA results of the settlement system produced a Z-score of -3.24 ($p < 0.001$) indicating a >99% likelihood that the overall distribution of settlements across the landscape is not random. The Kernel Density map was produced using the mean observed distance between groups, calculated in NNA, as the search radius for the distance between households (using Spatial Analyst Toolkit in ArcGIS). The resulting map reflects the mean observed distance between settlement groups and allows us to visually define neighborhoods based on spatial proximity and the presence of waterways, which act as natural boundaries between social groups (Fig. 5; see Prufer and Thompson, 2014). We excluded Groups B, D, and G of the site core from these analyses as extant architecture exhibits no direct evidence of residential function, even after extensive excavations (Prufer et al., 2011; Prufer and Thompson, 2016).

Based on these analyses Uxbenká settlements were grouped into neighborhoods and districts (Fig. 5). The latter designation

was made only if a neighborhood group also included monumental architecture and elaboration of elite households. As discussed above districts are considered centers of gravity for nearby neighborhoods, and presumably have additional economic, religious and political functions as residential zones with administrative duties. At Uxbenká we identify three areas as likely district centers based on these criteria: (a) all contain larger than usual residential architecture and date to early phases in the history of the polity; and (b) all also have highly elaborated tombs in multiple structures, suggestive of strong descent group ties to their neighborhood (Prufer and Thompson, 2014). While most of these tombs are looted, at two of these groups there is evidence of sequential interments. These features, combined with proximity to a likely trade route, are indicators of social differentiation with nearby residential groups, and increased frequencies of elaborated prestigious artifacts suggest a relationship between district seats and core elites.

District centers also have other distinctive features. District 1's (D1) center is the residential Group L, located in direct proximity and connection to the Stela Plaza (Group A). It sits on a modified toe ridge and has at least two complex tombs with elaborate grave goods, one of which contained the remains of between 11 and 13 individuals (Thompson et al., 2013). D1 dates to as early as AD 100 and is likely linked to the ruling political families at Uxbenká. D2's

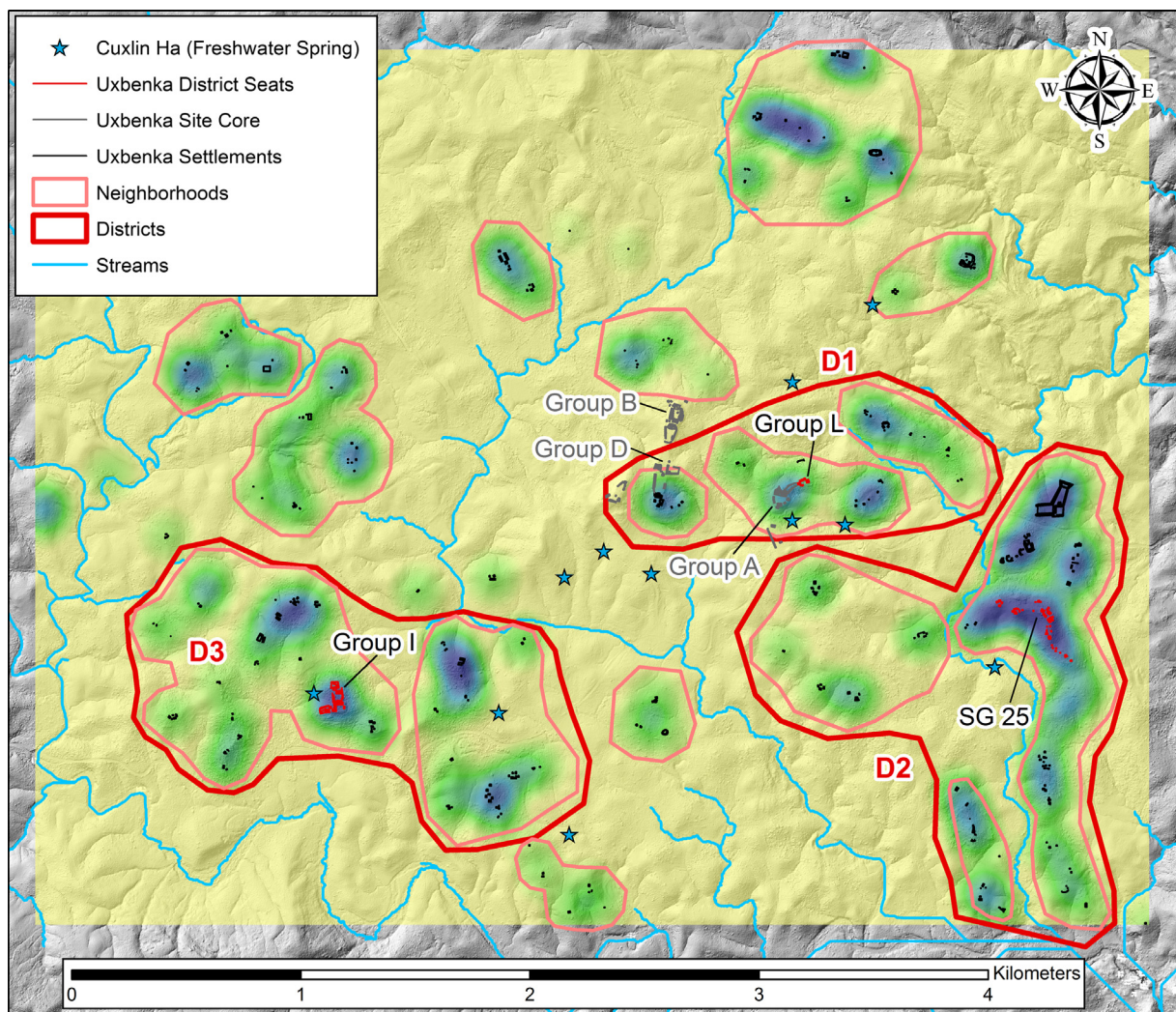


Fig. 5. Neighborhoods and districts map for Uxbenká. Locations of the three districts are indicated by heavy red lines, while light red lines indicate individual neighborhoods, as described in the text. The kernel density output of neighborhoods is represented in green (lower magnitude) and blue (higher magnitude). Districts (D1 - 3) and district seats (Groups I and L, and SG 25) discussed in the text are labelled. Perennial streams and freshwater springs (cuxlin ha) are also noted.

center is SG 25, which also dates to as early as AD 100 and consists of both residential and monumental architecture. It has two large looted tombs one of which is in a 4 m high shrine or temple. This group is linked to two other ridges with massive landscape modification and megalithic walls that may be defensive features. D3's center is Group I, a residential group that also houses monumental and public architecture including a temple and a ball court. Its earliest structure faces onto a plaza containing at least three documented tombs, at least one of which was reentered. This group is located 2 km west of the site core and dates to the as early as AD 200.

2.4. Demographic assessments and population growth

Previous efforts at Uxbenká calculated population density from estimated maize yields at a given planting density and fallow length. This approach assumes that population dynamics in ancient Maya society were strongly dependent upon the ecological constraints of maize agriculture. Our recent research (Prufer et al., 2015) suggests that current land use practices indicate a 3–5 year fallow period within 3 km of the modern village. Recent survey results and analyses of LiDAR shows little evidence of likely maize-producing settlements extending more than 3 km from the site core. Using these constraints, two years of data derived from modern (2009–2010) experimental corn plots in farm fields at Santa Cruz, (Culleton, 2012) population maximum for Uxbenká would be between 2390 (low planting density) and 4190 (high planting density), though these estimates do not accommodate other forms of agricultural production such as agroforestry (i.e. cacao or other economic tree-crops) which would have decreased the availability of land for maize agriculture.

Here we complement our maize yield results with architectural estimates of population following methods published by Rice and Culbert (1990). Basically, with various refinements, we convert household structure counts by time period to population estimates assuming 5.5 individuals per household. This method offers a conservative approach to population estimates; it assumes that the area around the site core has been more thoroughly investigated than the outlying area beyond 2 km from the site core. The resulting estimate should be biased toward larger numbers of early groups, whereas the later occupied groups, which dominate at a distance, may be slightly underestimated. During the earliest initial but clear settlement of the site (ca. 200 BC) we assume a very low population density ($n = 40$) consistent with the paucity of evidence of households at this time. In the Late Preclassic we anchor the population estimate ($n = 515$) to AD 250, localized around the site core. The Early Classic population ($n = 2257$) by AD 600 is expanding with the establishment of districts up to 2 km from the core, but primarily along an east-west trade route; the Late Classic population ($n = 3427$) indicates growth to the north of the core and is increasingly dispersed by AD 800. Since the rate and pace of abandonment cannot be estimated with any confidence, it is not included in these calculations, but there is no evidence for continued occupation of the site after AD 900–950.

Though the absolute population estimate at any time is not necessarily accurate, this approach produces a conservative model of population growth, modeling a minimum growth rates ($R^2 = 0.9314$, Fig. 6). Since no sites are founded during the Terminal Classic, the model assumes the same population as is predicted during the Late Classic.

2.5. Trade and communication routes influencing Uxbenká

In 1978 Norman Hammond proposed that two ancient trade routes linked the Caribbean Sea via southern Belize the Guatemala Highlands and the central Petén, one of which ran through the Rio Blanco Valley near to Uxbenká (Hammond, 1978). In the 1960s

and early 1970s ethnographers also noted that the trip from San Antonio, located 8 km east of Uxbenká, to Pueblo Viejo, 10 km to the west, was made by a footpath that connected five villages to the Guatemalan border (Rambo, 1962; Wilk, 1991). This route was converted to a logging track in the 1970s and a dirt road in the 1980s. Although disturbed by recent (2014) road construction, our earlier (2011) LiDAR data reveal remnants of the original footpath in places where it deviated 10–20 m from the roadway (Supplemental Section S-2). This discovery has allowed us to use Least Cost Analysis (LCA; ArcGIS 10.2) to reconstruct the pathway, based on our LiDAR derived DEM. We consider all rivers around Uxbenká to be passable and we know from experience that there are no lakes, steep cliffs, or other physically impassable features. We chose as an eastern starting point the confluence of two rivers in San Antonio village, a likely stop on the route near to a series of small ruins visible in the LiDAR. As a western ending point we chose a central location in the village of Pueblo Viejo, at the west edge of our LiDAR dataset. Our DEM-derived LCA path tends to follow the older, unpaved road and remnants of the older footpath (Fig. 7); both the unpaved road and footpath diverge slightly from the modern road in some areas, suggesting that the road itself is not influencing the LCA, but rather that the road was placed on the path of least cost for foot traffic (Thompson and Prufer, 2015). We propose below that there are linkages between this proposed trade route, the spatial locations of the principal Uxbenká districts, and their occupation histories.

2.6. Settlement decision making, location, and chronology

Here we assess (a) why settlements are located in a particular location within the overall settlement system of a polity and (b) how the choices made to settle in a location affected the duration of occupation in a location, the relative success of its occupants over time, and larger patterns of socio-economic development. To do this we describe a suite of variables that might have been considered by ancient colonists settling a landscape, focusing on three that can be measured effectively given what we know about (a) the geospatial organization and extent of the Uxbenká settlement; (b) chronological data on the initial founding and duration of occupation of settlement groups, and the scale of investment in settlement architecture; and (c) distance from each settlement group to two important resources: (i) permanent potable water and (ii) the pathway we have identified as a likely east-west trade route. Other socio-environmental variables may well have been significant, but they are more difficult to measure in the past, or, as in the case of agricultural substrate and maize yields, may not have differed much over the area we are examining (see Fig. 8 and Supplemental Section S-3).

We assess the relationship between settlement footprint, the combined area of all structures within each settlement groups (in m^2), and the overall spatial footprint of all individual settlement groups, the latter representing the area of land modification to accommodate structures and plazas and other level spaces (Prufer et al., 2015; Prufer and Thompson, 2016), against the earliest estimated occupation of each settlement group to determine if the size of settlements, as a reflection of labor investment, correlates with time of initial settlement.

Information on perennial water source data have been drawn from two sources: (a) GIS derived hydrology models (see Thompson and Prufer, 2015), ground-truthed through dry season fieldwork to identify perennial streams and creeks, and; (b) fresh-water springs (*cuxlin ha*) identified with the assistance of Mopan Maya farmers during fieldwork. Some of these *cuxlin ha* have clear indicators of pre-Columbian use, such as retaining walls for pooling water or sluices and pools excavated to bedrock. Local farmers and archaeologists use these springs for drinking water during the dry season.

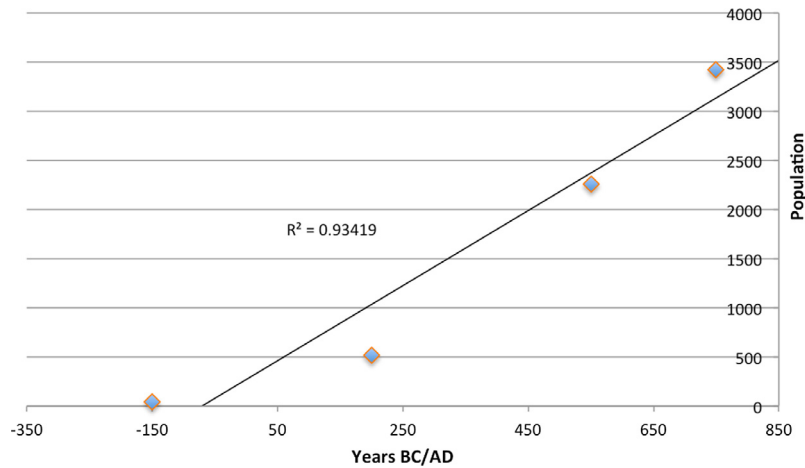


Fig. 6. Population growth model for Uxbenká. This conservative model draws on the earliest date known for each settlement group and the number of structures in a group. While it may not necessarily be accurate for any point in time, it does reflect the likely rate of growth across the polity.

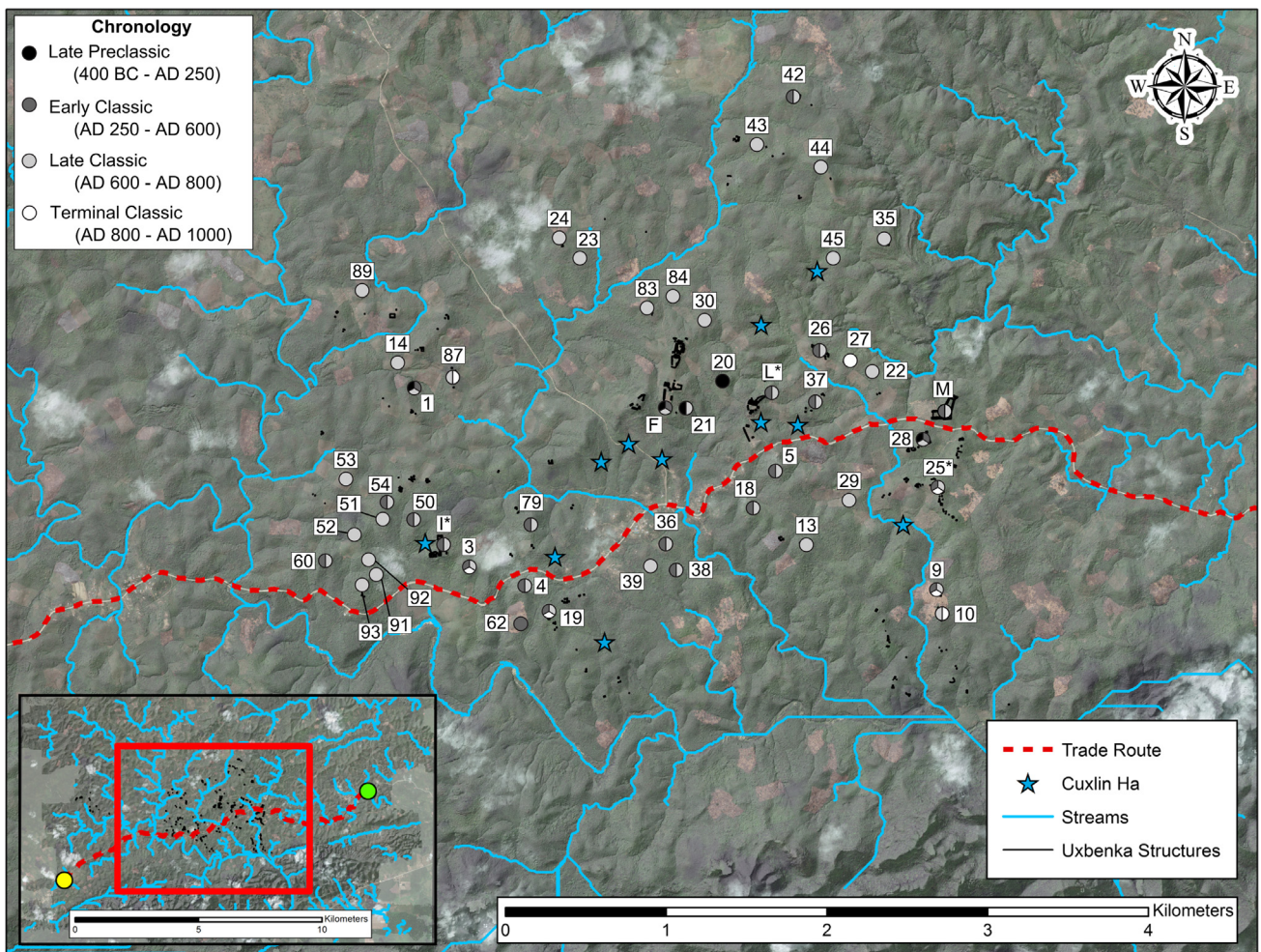


Fig. 7. The geospatial overview of the chronological development of the settlement system of Uxbenká in relationship to social and ecological variables discussed in the text. The least cost path of the probable trade route overlain on a LiDAR and GeoEye Satellite image (Prufer et al., 2015). Settlement groups are indicated by letter or number, and assigned time periods shown in circles.

2.7. Statistical analyses

While our radiocarbon dates constrain the ages of many settlement groups, a broader picture of occupation is gained by concur-

rent use of ceramic data which identifies Late Classic occupations underrepresented in the AMS ¹⁴C record and provides some sense of chronological history for unexcavated groups. We have binned radiocarbon dates into four time periods (Late Preclassic 300 BC

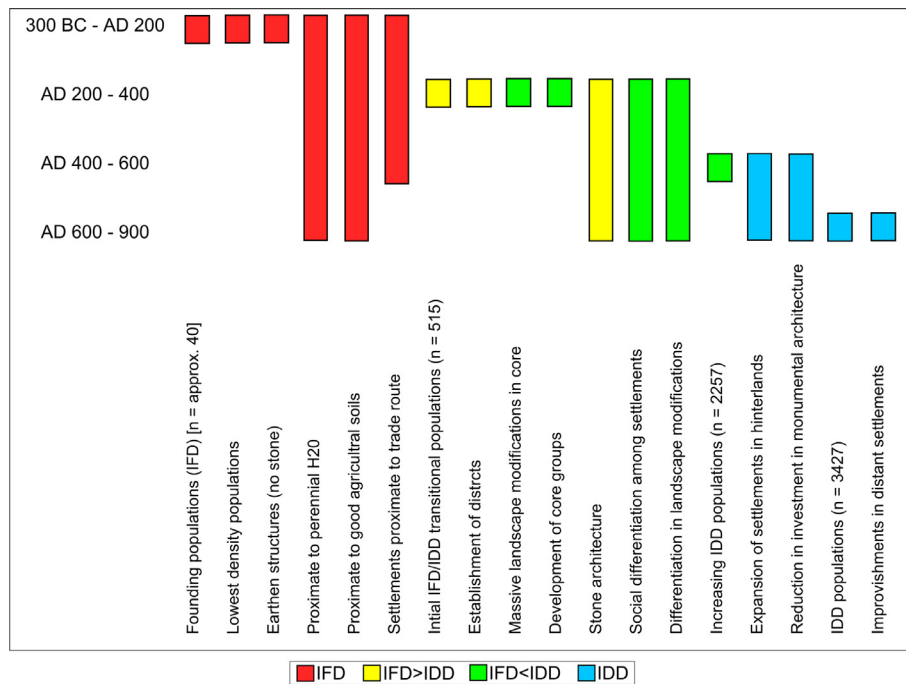


Fig. 8. Schematic of changes associated with the shift from an IFD population model to an IDD over the history of the Uxbenká polity.

– AD 250; Early Classic AD 251 – AD 600; Late Classic AD 601 – AD 800; and Terminal Classic AD 801 – AD 1000) to produce an expanded dataset of 48 dated residential groups. In each case, the earlier indicator of occupation (radiocarbon date or dates inferred from presence of ceramic types) was taken as the initial settlement of the group.

For each settlement group variable – group center point distance to nearest water source, distance to the trade route, log transformed total architectural footprint, and number of structures – sample medians for each time period were compared using the non-parametric Kruskal-Wallis (KW) rank sum test (further details in Supplemental Section S-4). Where appropriate, Bonferroni comparisons based on the Wilcoxon-Mann-Whitney two-sample procedure were then performed comparing the pairs of sample means. Statistical analysis was conducted in R (R Core Team, 2014).

3. Occupation date and distance from water to settlement group

There is a slight trend across our binned time periods toward an increased average distance from water source to a settlement group. From the Late Preclassic (254 m) when populations are low, the mean distance remains stable during the Early Classic (252 m) then increases in the Late Classic (291 m) when populations are at their highest. However, there are no significant differences between the three time periods (KW p -value = 0.5843, Fig. 9). Water is abundant on the Uxbenká landscape, with the consequence that access to dry season sources was not a high salience factor in settlement decisions; all households likely had fairly convenient access to year round water.

4. Occupation date and distance from trade route to settlement group

Mean distance to the nearest point on the trade route drops somewhat from 534 m in the Late Preclassic to 401 m in the Early Classic. This difference is driven largely by the small sample size of Late Preclassic settlements and by SG 1, an outlier which is located

1212 m from the trade route and produces a right skewed distribution for the Late Preclassic period (Fig. 9). During the Late Classic, distance to the trade route rises to 932 m, suggesting that settlement groups founded later in time were located further from what we interpret as a key economic artery and correlate of higher population density and residences of high status groups. Differences in sample medians are significant (KW p -value = 0.003) and Bonferroni comparisons indicate that the sample mean distance to the trade route during the Late Classic period is significantly different from the Early Classic (p -value = 0.0006). Differences between the Late Preclassic and the Early Classic and between the Late Preclassic and Late Classic were not found to be significant (p -values = 0.3083 and 0.2152, respectively).

5. Occupation date and area of residential group footprint

Due to the small size of much of the settlement architecture, and difficulties deriving accurate z -height and volumetric data from these small buildings from LiDAR (see Prufer et al., 2015), we have opted instead to utilize both architectural and modified landscape footprints for the following analyses. Data for the (a) total area of all structures with each settlement group (hereafter *structure area*, Fig. 10) and (b) for the modified landscape associated with each settlement group (hereafter *settlement area*, Fig. 10) were right skewed and hence were log transformed prior to analysis. Log transformed settlement area decreases from 7.8 in the Late Preclassic, to 7.5 in the Early Classic, and 7.0 in the Late Classic, but the differences between groups are not significant (KW p -value = 0.2015). The number of structures contained in each sample group is consistent during all time periods with the exception of SG 28, which has over 20 structures and dates to the Late Preclassic and Early and Late Classic. The influence of this group brings the mean number of structures per group to 7.8 for the Late Preclassic and 7.5 for the Early Classic. The Late Classic mean value of 4.5 structures per group is representative of the broader pattern over time and across the landscape. Differences between the number of structures per group in each time period are not significant

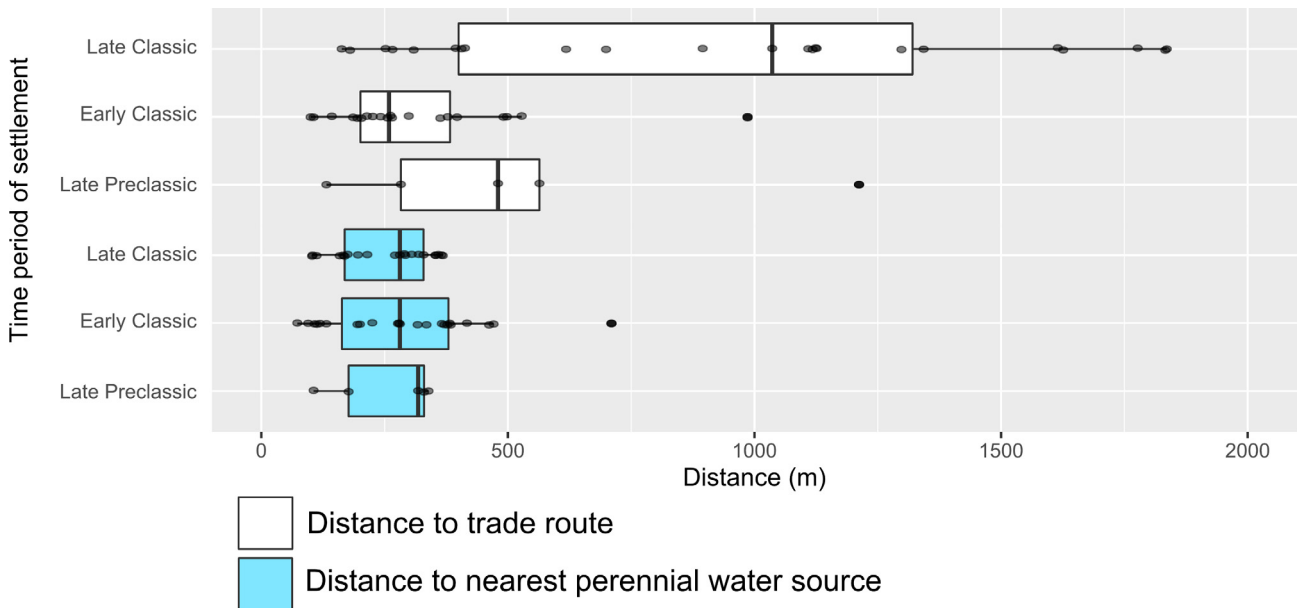


Fig. 9. Distance to nearest water source and shortest distance to trade route, in meters, by time period. The median value is indicated by vertical bars. Outliers for distance to trade route are most pronounced in the Late Classic.

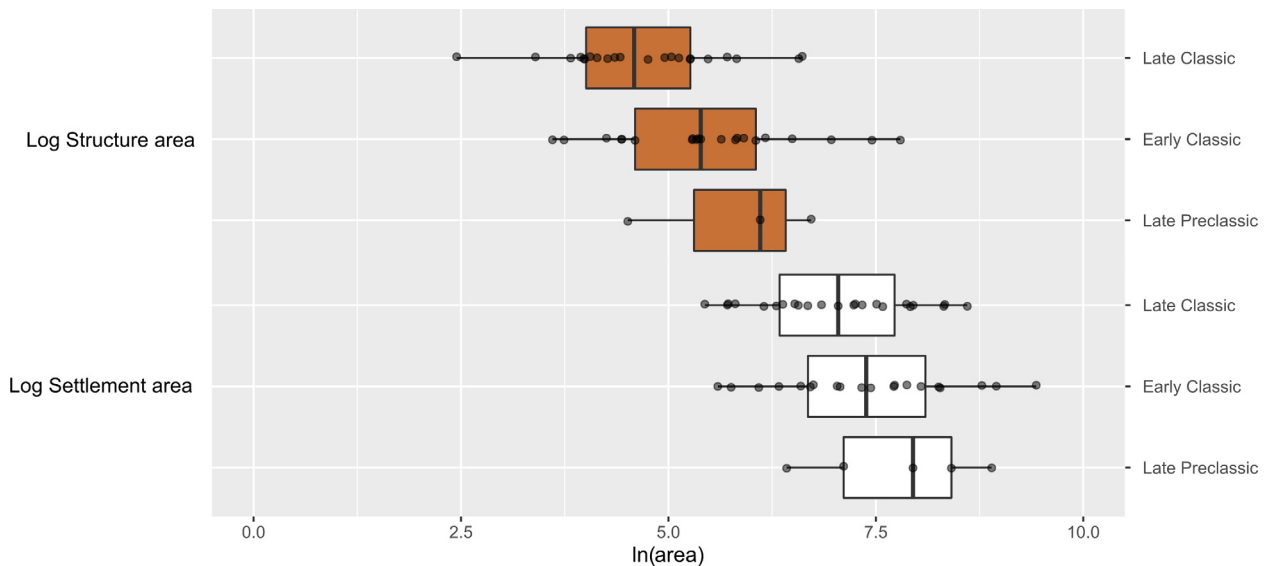


Fig. 10. Log transformed settlement area (total area of modified landscape within a given settlement group) and structure area (sum of area of structures in each group). The median value is indicated by vertical bars.

(KW p-value = 0.5491), suggestive of confidence in this method as a proxy measure for population growth and stability.

Analysis of the structure area within each settlement group provides a mean of 456 m² per settlement group during the Late Preclassic. This figure remains relatively constant through the Early Classic (455 m²) then falls to 177 m² for the Late Classic. Differences exist between overall time periods (KW p-value = 0.02335), although differences between settlements occupied in the Late Preclassic and those settled in the Early Classic were found to be insignificant when Bonferroni comparisons were conducted (p-value = 0.5613). Structure area was, however, found to be significantly larger for Early Classic settlements when compared to Late Classic settlements (p-value = 0.0126). This would suggest that settlement groups founded earlier in the history of the site are larger (particularly for the Early Classic period). They are significantly

smaller for those founded in the Late Classic, implying later occupants may have been relatively more impoverished at a time when population size overall peaked.

6. Discussion

6.1. Evidence for settlement and socio-political developments at Uxbenká

We believe that the development of the settlement system at Uxbenká agrees in key details with tenets of the IFD/IDD models for predicting the consequences of population growth on a heterogenous, space-limited landscape (Puleston and Tuljapurkar, 2008). Uxbenká's initial settlement was scattered across several

hilltops relatively close to each other, suggesting that colonizers first established house groups near to perennial springs (though other water resources abound), on good farmland, and near to the trade route. The earliest documented settlements are located near to what became the Classic Period core (SG 20 and Group F) though the oldest, SG 28, is located 1.3 km to the east. Populations were small and what little we know about those early settlers suggests they lived in perishable structures on low dirt platforms; we see no signs of social stratification (Prufer et al., 2011). These settlements date to between 300 BC and AD 200. We see no evidence suggesting that decisions about location were politically constrained, consistent with the IFD. The impact of the LCA route at this time is not known, but the growth of complex polities in the Petén and the appearance of coastal trade communities by AD 200 suggest that commerce and communication were becoming important. It is also probable that this route formed the key artery for intracommunity economic and social movement among households.

Beginning in AD 200 there is a clear trend toward building with stone and the first signs of social stratification evidenced by investments in public works, large-scale landscape modifications (Prufer and Thompson, 2016) and public architecture (Culleton et al., 2012) as population increased from perhaps as low as 40 to over 500 individuals. All three central settlement groups that ultimately became district seats were occupied (SG 25, Group F, and Group I). Trade has become locally important, reflected in non-local obsidian, groundstone, jade, and marine shell in higher frequencies in higher status residential contexts located near to the proposed trade route (Thompson et al., 2013). Obsidian is ubiquitous in almost all residential contexts from AD 200 onward.

From AD 200–400 Uxbenká's population increases fivefold over the Late Preclassic and the polity undertakes its largest investments in capital projects of the entire 1150-year occupation. These architectural activities focus on the site core, a series of hilltops and ridges spread across 2 km² and also at what became likely district seats. The primary residential group for the site core was likely Group L, one of the oldest and longest established district seats and the location of at least two large tombs accessed by stairways, at least one of which was used repeatedly. This period coincides with enormous investment in landscape modification, architectural construction, and plaster production (Prufer and Thompson, 2016), indicating that dominant political elites were able to mobilize significant labor from the local population.

In the outlying areas we also see the beginnings of a proliferation of smaller, more difficult to date groups on hilltops with modest to little landscape modification. They are located primarily as infill between the already established elite residential compounds Group I, Group L, and SG 25. Based on chronological and spatial data, we can assume a growing population corresponds with increasing appropriation of labor by political elites in the site core, as well as significant labor investment in large settlement groups that are likely beginning to serve a more authoritative role as district seats. The lack of other settlements in the broader region and the general centralization of settlements near the trade route (\bar{x} = 396 m) suggest that concessions by dominant members of the community were sufficient to mitigate out migration. The environmental attractiveness of the local habitat –including the suitability elevating features of abundant perennial water sources and highly fertile soils– may have reduced the need for elites to make concessions when negotiating with commoners their obligations to provide support. In a development we discuss more fully below, political investments by these “old wealth” elites are actually enhancing the socio-environmental suitability of their habitats near the core.

Until approximately AD 400, Uxbenká was the only political center of any prominence in the foothills of southern Belize. Its

nearest neighbor was Ex Xux, a minor center in the Bladen drainage in the interior of the Maya Mountains (Prufer, 2005), some 45 km to the north. However, after AD 400 there is rapid growth of neighboring political centers. Nimli Punit, located 12 km to the northwest (ca. AD 400, Irish and Braswell, 2015), is followed less than a century later by the founding of Pusilhá, located 18.5 km to the southwest, and a host of smaller sites (Braswell and Prufer, 2009). Uxbenká emigrants may have founded these new polities, but currently there is little evidence for ceramic or architectural similarities between Uxbenká and Pusilhá. The smaller centers are largely unstudied, leaving this at present as conjecture. Less conjectural, growth of these nearby polities eventually would have closed off the option of emigration from Uxbenká by residents seeking to escape exploitation.

After AD 400 there is an initial shift of Uxbenká settlement to the north of the core, away from the trade route. By AD 600–800 the average distance from the core to new settlements has tripled. This trend parallels an overall reduction in the number and size of structures per newly established settlement group. The footprint of all structures per group peaks in the Early Classic at 473 m² then drops by 62–177 m² after AD 600. The architectural footprint and complexity of newly forming residential compounds diminish and there is a trend away from larger basal platforms back toward simpler one to two course walls built over bedrock or filled with compacted soil. The paucity of secure AMS ¹⁴C dates for these Late Classic structures is a reflection of the smaller building size as well as difficulties in recovering charcoal from secure contexts. Still, the dates indicate a persistent residential population until AD 800 and likely later.

These later and more outlying households retain the advantages of proximity to perennial water supplies and arable land. These groups display an overall lack of imported non-local or hypertropic goods and these burials display an absence of formal grave furnishing or indicators of status enhancement. Even though they bear the marks of fewer resources, less investment in architecture and in landscape modifications, and overall lower status, they did have access to the necessities for food production. However, they are removed from direct access to the trade route and at considerable distance from the public areas of the site core and the special function spaces in district seats. They also are more removed from the security and protection afforded those living in proximity to the core.

This core-to-periphery gradient highlights the disparities that we would expect with a shift to more despotic (IDD) resource and settlement dynamics in later settlements. Despite relative impoverishment at the periphery, the major district seats of the site appear to be relatively unaffected during the Late Classic: the dynastic tomb at Group L is reentered at least once in the Late Classic; in Group I a large ballcourt was built during a major architectural reorganization; and at SG 25 abundant Late Classic polychrome ceramics from multiple deposits and a jade plaque suggest continued economic activity centered on wealth (Thompson et al., 2013). Able to defend their privileges, political and economic elites retained their higher status and disproportionate measures of resource dependent well-being.

However, we do see changes in large capital projects. Earlier efforts to expand the area of leveled hilltops and ridgelines to accommodate seven major residential/civic ceremonial complexes represented the largest investment of labor in the built environment in Uxbenká's history. After AD 400 investment in site core landscape modification declined (Prufer and Thompson, 2016), but structural work persisted. In Group A (the Early Classic central area of political control) investment in remodeling of architecture continued until AD 600, then ceased (Culleton et al., 2012); in Groups B and D architectural construction lasted through the Late Classic Period (Aquino et al., 2013). Maintenance of all core areas in the form of

re-plastering continued unabated until after AD 800 and in Group A carved stone monuments were dedicated until AD 781.

These changes signal the entrenchment of differential resource control, despotic behavior of elites, within Uxbenká's population. Elites altered their strategies to mobilize labor and resources, likely reducing concessions made to non-elites between AD 400 and 800. This is reflected in population growth associated with expanding numbers of settlement structures, expansion of settlements in the periphery of the polity, away from the economically important trade route, and in the smaller and less numerous and elaborate structures found in the neighborhoods being established there. By contrast, the central civic-ceremonial core was not infilled with residential buildings, but retained its largely agricultural and elite/ceremonial character, likely producing either food or other economically important crops.

Early in the shift from IFD to IDD, it appears that elevated core habitat suitability – abundant arable lands, a compact and smaller producer population, and the political and religious amenities of residence near centers of authority – reduced the need for elites to make concessions (Bell and Winterhalder, 2014). These factors would have been augmented by the favorable agro-ecological environment on the Uxbenká periphery and closure of frontiers beyond that might otherwise have invited outmigration. Elite demands associated with rapid landscape modification and construction was tolerated despite the burden. Nonetheless, continued growth in population would, at some point, have started straining the ability of peripheral settlements to both feed themselves and meet those core demands. We envision that in the Late Classic continued population expansion challenged the ability of the core despotic leadership to maintain a sustainable balance between their socio-economic needs and an increasingly marginalized population of producers.

By the Terminal Classic (after AD 800) the site was in disrepair and the population at the periphery was relatively impoverished. Site core dates in Group B place the last remodeling activities between AD 750 and 880 (Aquino et al., 2013; Culleton et al., 2012). It appears that core elites were unable to maintain control over the population at Uxbenká, though the center continued as a complex polity until the abandonment. We see two possibilities: (a) With the arable landscape of Uxbenká saturated, population growth unabated and elite demands undiminished, elites were unable to successfully manage rapid declines in the welfare of the productive population. This possibility assumes that options for out-migration to surrounding and newly established polities were closed; (b) Those newly established, surrounding polities were both attractive and open to migrants. An increasingly impoverished Uxbenká population living at the hinterland margins of the site would have had economic incentive to migrate or shift allegiances away from elite demands untempered by concessions. In either case, Uxbenká elites apparently did not adapt sufficiently or quickly enough, perhaps as a result of centuries of “path dependency” (Chase and Chase, 2014).

Interestingly, this late time period roughly corresponds with the initial settlement and development around AD 750 of Lubaantun, located 12.5 km to the northeast of Uxbenká (Irish and Braswell, 2015). The appearance of a new and growing polity, with lower densities, higher suitability and lower elite demands on commoners, located just a few hours walk from Uxbenká, may have provoked – if emigration was blocked – a frustrating comparison, or if emigration was not blocked, emigration. It is important to note that Lubaantun is 4 km southwest of the Late Classic political center of Xnaheb and 9 km southwest of Nimli Punit. Unfortunately, the florescence of Lubaantun was brief and it was in decline within two generations, the political core and hinterlands completely abandoned by AD 900.

6.2. Ideal free to ideal despotic (settlement) distributions

This analysis is not the first to suggest that framing the origins of human social stratification within the IFD and IDD models will provoke insights on this important evolutionary development (Bell and Winterhalder, 2014; Kennett et al., 2009; Kennett and Winterhalder, 2008; Shennan, 2007, 2009; Summers, 2005). Unique, however, is the detail of documentation available in the Uxbenká case and, what largely has been missing from previous discussions, our ability – enabled by that detail – to state an explicit mechanism for the transformation. Up to now applications of this approach have relied on simply assuming, or on ad hoc rationales for, the emergence from an IFD of an IDD featuring resource defense capacities and unequally experienced environmental suitabilities. We have lacked endogenous mechanisms able to generate the first and then continuing, perhaps increasing, disparities in ability to garner and defend a disproportionate share of resources. More simply, we have had to posit without explaining our nascent despots.

Uxbenká provides an explanation. We assume two habitats resembling the Uxbenká core and periphery. The core is occupied first, perhaps randomly, maybe due to some environmental advantage not measured in our analysis, or because of proximity to an economically advantageous trade route that elevates its resource availability hence its suitability. As expected in the standard IFD model, it fills with residents who eventually experience negative density dependence, prompting some of the new growth to spill over into the peripheral habitat. Although individuals initially will experience equalized suitabilities over these two habitats, consistent with the basic IFD premise, because we humans are a socially organized and collaborative species, the first-settled, core habitat nonetheless retains advantages. Three relevant points emerge:

- (a) Horticultural and agricultural societies known to anthropologists typically have some form of lineal kinship organization, often segmentary and often attributing higher status to the lineage recognized as being the oldest and most central. These concepts of kin-relatedness have been fundamental to studies of the Maya from the perspectives of archaeology (McAnany, 1998) and epigraphy (Munson and Macri, 2009). In our settlement scenario, the *initial* occupants of the core habitat become after a few generations the *prior* inhabitants and oldest lineage, gaining priority by their seniority. With seniority comes socio-political authority. As the population grows, new lineages bud off the original, but inherit less and less of this elevated status. Given social differentiation organized along lineage principles, emigrants to the peripheral habitat are likely to be those with the least claims to high status by descent. Linear kinship structure means that individuals in each habitat will look first to their neighbors, who are their closest kin.
- (b) Likewise, while it is the case that the IFD initially will equalize *individual* suitabilities over core and periphery, density will be greater in the core, a result of its earlier settlement and elevated suitability. In an obligate social species like ourselves, relatedness and greater density in themselves confer natural advantages and here they co-occur in the first-occupied habitat. Defense comes first to mind as an advantage, but likely of equal importance are economies of scale in economic production and political organization, formally recognized by the *Allee* effect. These twin advantages of early settlements reinforce each other: kinship fostering social cohesion, particularly as against the peripheral habitat, and density fostering differential resource holding, perhaps resource generating, capacity.

- (c) The core habitat settlement will garner and be able to ensure to itself further benefits if it uses its early lineage and economic advantages to localize within its borders the physical embodiments of religious and political capital. Habitat suitability thus gains socio-political dimensions. By initiating and then monopolizing the development of sacred lore and sites, monuments and public exhibition, core elites can enhance their authority and further enlarge resource disparities between core and periphery. Whether or not active resource extraction from peripheral settlements is initiated as a political or a religious obligation, this mingling of environmental, economic and sacred advantage illustrates the manner in which being first becomes being foremost.

Why don't individuals simply migrate from periphery to core to take advantage of the elevated opportunities there? We propose that *initially* this results from the stickiness of kin allegiances in both settlements, manifest as reluctance to leave close kin within your own habitat and, similarly, reluctance to accept more distant kin from outside your habitat. This kind of allegiance is the most general implication of the reproductive skew models mentioned earlier. Elevated relatedness and limitations on "external" options promote kin solidarity, keeping in mind that we are talking about social kinship, which can be manipulated by elites to their advantage.

We believe that these factors, apparent in the Uxbenká case, are sufficient to promote an IFD-IDD transition. Other alternative models can also be tested (e.g. [Feinman, 2013](#)). [Bell and Winterhalder \(2014\)](#) show that if *Allee* effects are sufficiently strong, then a founding population that mistakenly occupies a lower ranking habitat will, nonetheless, find it advantageous to remain there for a considerable period. Elites in a high ranking location may fumble the natural advantages available to them. Low ranking habitats by suitability may, nonetheless, be of such extent that their low-density population eventually outnumbers that of a higher ranking neighboring habitat and settlement. Or, a low-ranking habitat may have greater potential for *Allee* effects, hence promise of subverting the edge gained by an earlier start to population growth and development in a higher ranking neighbor. In short, the features of the IFD/IDD that guide our proposed model for Uxbenká may work out the same or quite differently in other cases.

7. Conclusion

The ideal free distribution has proven to be one of the more flexible behavioral ecology models, having been applied productively to problems of migration, settlement and social development on spatial scales ranging from drainages on small islands ([Kennett et al., 2009](#); [Winterhalder et al., 2010](#); [Jazwa et al., 2016](#)), to the state of California ([Coddington and Jones, 2013](#)) and to central Europe ([Shennan, 2007](#)), to the island regions of Sunda and Sahul ([Allen and O'Connell, 2008](#); [O'Connell and Allen, 2012](#)) and the Pacific region more generally ([Kennett et al., 2006](#); [Kennett and Winterhalder, 2008](#)). It suits analysis of prehistoric hunter-gatherers as well as ethnographic pastoralists ([Moritz et al., 2014](#)) and the horticultural or agricultural societies more commonly analyzed. It can accommodate predictions based on factors that are endogenous and density-dependent ([Bell and Winterhalder, 2014](#)) or exogenous and density-independent (e.g., changes in the environment; [Jazwa et al., 2013](#); [McClure et al., 2009](#)). Here we add to this versatility by analyzing the long prehistory of Uxbenká, a Maya polity and a rainfall dependent swidden agricultural community, in light of mechanisms that have the potential to catalyze the development of an ideal despotic (IDD) out of an ideal free (IFD) settlement distribution.

If the earliest habitats settled in a region are the most auspicious for human development because of high suitability, they will over the course of subsequent periods of population growth, infill and expansion into lower and lower ranked locales, retain two important advantages: (a) settlement time depth and continuity confer, in the context of lineal social organization, social priority and its advantages; and (b) they will lead other settlements in the growth and ultimate density of population, thus of defensive and productive capacity. The former generates inherent social advantage; the latter natural advantages in terms of economic productivity, potential division of labor, and resource defense. Our proclivity to kin organization and local economic cooperation catalyzes the development of an IDD out of an IFD. While the IFD is driven by equilibration of per capita suitability, it does not imply that groups distributed among ranked habitats have equal opportunity to generate and defend their resources or to develop the socio-economic, religious and, ultimately, political advantages that ensure the persistence perhaps expansion of these advantages.

This paper represents the first concerted effort to apply the predictions of the IFD/IDD transition to a complex archaeological society. Data used here were gathered over a 10 year period of intensive survey and excavations at Uxbenká. The project was designed in particular to focus on comparative site core and settlement organization, direct dating of the architectural development of the polity, geospatial modeling of the landscape and the built environment, and experimental studies of agroecology. We provide a model for how settlements can expand and evolve into neighborhoods and districts in the context of the development of despotic, kin-selected leadership strategies. The model links long-term growth and decline of a population and its socio-economic organization to the availability and control of cultural and natural resources. Our results suggest the despotic rulers, as defined in the paper, can have remarkable impacts on how settlements and populations are distributed across a landscape and through time.

The data presented here reinforce the notion that longitudinal interdisciplinary research can allow us to test evolutionary models of societal development, emergence and maintenance of status hierarchies, and the role of human decision making in the success and failure of sociopolitical systems in their ecological setting. The IFD/IDD is essentially a simple and flexible model of population ecology. It is simple in its relatively few core tenets positing that at low population density people will have freedom in settlement choices and will distribute themselves across a landscape accordingly, while as populations grow over time overall freedom of settlement choices are constrained in concert with emergent qualities of social inequality. It is flexible in that key suitability variables that influence both the IFD and the IDD can be both environmentally and culturally specific, and that over time these variables are conditioned by economic, political, and social decision-making. We view this paper as a first step toward integrating this model from Human Behavioral Ecology into the archaeology of complex societies.

Acknowledgements

We thank the Belize Institute of Archaeology for permission to conduct research at Uxbenká. This research was supported by the Alphawood Foundation, United States (Prufer) and the National Science Foundation, United States BCS-0620445 and HSD-0827305 (Prufer), HSD-0827275 (Kennett), and HSD-0827277 (Winterhalder). We are grateful the contributions of numerous individuals who conducted fieldwork related to this study including V. Aquino, C. Cortez, C. Daughtrey, E. Kalosky, C. Mustain, A. Nazaroff, W. Trask, as well as J. Southon (Keck Carbon Cycle AMS Facility, UC Irvine), one anonymous reviewer, and the people and

leadership of the Mopan Maya community of Santa Cruz upon whose lands Uxbenká is located.

Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at <http://dx.doi.org/10.1016/j.jaa.2016.11.003>.

References

- Allee, W.C., Park, O., Emerson, A.E., Park, T., Schmidt, K.P., 1949. Principles of Animal Ecology. WB Saunders Co., Ltd.
- Allen, J., O'Connell, J.F., 2008. Getting from Sunda to Sahul. In: Clark, G., Leach, B.F., O'Connor, S. (Eds.), *Islands of Inquiry: Colonisation Seafaring and the Archaeology of Maritime Landscapes*. ANU E-Press, Canberra, pp. 31–46. Terra Australis 29.
- Aquino, V.V., Prufer, K.M., Meredith, C., Culleton, B.J., Kennett, D.J., 2013. Constraining the age of Abandonment of Uxbenká site core using archaeological stratigraphy and AMS ¹⁴C Dates. *Res. Rep. Belizean Archaeol.* 10, 269–279.
- Arnould, M.C., Manzanilla, L.R., Smith, M.E. (Eds.), 2012. *The Neighborhoods as a Social and Spatial Unit in Mesoamerican Cities*. University of Arizona Press, Tucson, AZ.
- Ashmore, W., 1981. *Lowland Maya Settlement Patterns*. School of American Research, Santa Fe.
- Awe, J.J., Hoggarth, J., Helmke, C., 2014. Prehistoric settlement patterns in the upper Belize river valley and their implications for models of low-density Urbanism. In: Helmke, C., Sachse, F. (Eds.), *A Celebration of the Life and Work of Pierre Robert Colas*. Acta Mesoamerica, pp. 263–286.
- Bahrani, Z., 2010. *Conjuring mesopotamia: imaginative geography and a world past*. In: Preucel, R., Mrozovsky, S. (Eds.), *Contemporary Archaeology in Theory: The New Pragmatism*. Willey-Blackwell, pp. 159–174.
- Baines, K., 2015. *Embodying Ecological Heritage in a Maya Community: Health, Happiness, and Identity*. Lexington Books.
- Bell, A.V., Winterhalder, B., 2014. The population ecology of despotism: concessions and migration between central and peripheral habitats. *Human Nat.* 25, 121–135. <http://dx.doi.org/10.1007/s12110-014-9190-7>.
- Borgerhoff-Mulder, M., Bowles, S., Hertz, T., Bell, A., Beise, J., Clark, G., Fazzio, I., Gurven, M., Hill, K., Hooper, P.L., Irons, W., 2009. Intergenerational wealth transmission and the dynamics of inequality in small-scale societies. *Science* 326 (5953), 682–688.
- Braswell, G., Prufer, K.M., 2009. Political organization and interaction in Belize. *Res. Rep. Belizean Archaeol.* 6, 43–55.
- Bronk Ramsey, C., 2009. Bayesian analysis of radiocarbon dates. *Radiocarbon* 51 (1), 337–360.
- Brusasco, P., 2004. Theory and practice in the study of Mesopotamian domestic sphere. *Antiquity* 78 (299), 142–157.
- Bustard, W., 2003. Pueblo Bonito – when a house is not a home. In: Neitzel, J. (Ed.), *Pueblo Bonito: Center of the Chacoan World*. Smithsonian Books, Washington DC, pp. 80–92.
- Buston, P.M., Zink, A.G., 2009. Reproductive skew and the evolution of conflict resolution: a synthesis of transactional and tug-of-war models. *Behav. Ecol.* 26 (3), 672–683.
- Cant, M.A., English, S., 2006. Stable group size in cooperative breeders: the role of inheritance and reproductive skew. *Behav. Ecol.* 17 (4), 560–568.
- Chase, D.Z., Chase, Arlen F., 2014. Path dependency in the rise and denouement of a Classic Maya City: the case of Caracol, Belize. *Archeol. Papers Am. Anthropol. Assoc.* 24, 142–154.
- Clutton-Brock, T.H., 1998. Reproductive skew, concessions and limited control. *TREE* 13 (7), 288–292.
- Codding, B.F., Jones, T.L., 2013. Environmental productivity predicts migration, demographic, and linguistic patterns in prehistoric California. *Proc. Natl. Acad. Sci.* 110 (36), 14569–14573.
- Culleton, B., 2012. *Human ecology, agricultural intensification and landscape transformation at the ancient Maya polity of Uxbenká, southern Belize* PhD Dissertation. Department of Anthropology, University of Oregon.
- Culleton, B., Prufer, K., Kennett, D.J., 2012. A Bayesian AMS ¹⁴C Chronology of the Classic Maya Urban Center of Uxbenká, Belize. *J. Archaeol. Sci.* 39, 1572–1586.
- D'Altroy, T.N., Earle, T.K., 1985. Staple finance, wealth finance, and storage in the Inka political economy. *Curr. Anthropol.* 26 (2), 187–206.
- Dunham, P.S., Prufer, K.M., 1998. En la cumbre del clásico: descubrimientos recientes en la montaña maya en el sur de Belice. In: LaPorte, J.P., Escobedo, H.L. (Eds.), *XI Simposio de Investigaciones Arqueológicas en Guatemala*. Ministerio de Cultura y Deportes. Instituto de Antropología e Historia y Association Tikal, Guatemala City, pp. 165–170.
- Ebert, C.E., Hoggarth, J.A., Awe, J.J., 2016. Classic period maya water management and ecological adaption in the Belize River Valley. *Res. Rep. Belizean Archaeol.* 13, 109–119.
- Feinman, G.M., 2013. The emergence of social complexity. In: Carballo, D. (Ed.), *Cooperation and Collective Action: Archaeological Perspective*. University Press of Colorado, pp. 35–56.
- Folan, W.J., Kintz, E.R., Fletcher, L.A., 2014. *Coba: A Classic Maya Metropolis*. Academic Press, Elsevier.
- Fretwell, S.D., Lucas Jr., H.L., 1969. On territorial behavior and other factors influencing habitat distribution in birds. I. Theoretical development. *ActaBiotheoretica* XIX, 16–36.
- Gillespie, S.D., 2002. Body and Soul among the Maya: Keeping the Spirits in Place. *Archeol. Papers Am. Anthropol. Assoc.* 11 (1), 67–78.
- Goldberg, M.Y., 1999. Spatial and behavioral negotiations in Classical Athenian city houses. In: Allison, P.M. (Ed.), *The Archaeology of Household Activities*. Routledge, New York, pp. 142–161.
- Hammond, N., 1975. *Lubaantun: A Classic Maya Realm* (Peabody Museum Monographs, Number 2). Harvard University, Cambridge, MA.
- Hammond, N., 1978. Cacao and cobaneros: an overland trade route between the Maya highlands and lowlands. *Mesoamerican Commun. Routes Cult. Contacts Papers* 40, 19–26.
- Hoggarth, J., 2012. *Social Reorganization and Household Adaptation in the Aftermath of Collapse at Baking Pot, Belize* PhD Dissertation. Department of Anthropology, University of Pittsburg.
- Irish, M., Braswell, G., 2015. Towards an archaeological chronology of Southern Belize. *Res. Rep. Belizean Archaeol.* 12, 271–280.
- Isendahl, C., Smith, M.E., 2013. Sustainable agrarian urbanism: the low-density cities of the Mayas and Aztecs. *Cities* 31, 132–143.
- Jazwa, C.J., Kennett, D.J., Winterhalder, B., 2013. The ideal free distribution and settlement history at old Ranch Canyon, Santa Rosa Island, California. In: Jazwa, C.S., Perry, J.E. (Eds.), *California's Channel Islands: The Archaeology of Human-Environment Interactions*. University of Utah Press, Salt Lake City, pp. 75–96.
- Jazwa, C.S., Duffy, C.J., Leonard, L., Kennett, D.J., 2016. Hydrological modeling and prehistoric settlement on Santa Rosa Island, California, USA. *Geoarchaeology* 31 (2), 101–120.
- Johnstone, R.A., 2000. Models of reproductive skew: a review and synthesis. *Ethology* 106 (1), 5–26.
- Jordan, J.M., Prufer, K.M., 2014. Contextualizing Uxbenká: ceramic analyses from site core and household contexts. *Res. Rep. Belizean Archaeol.* 11, 317–326.
- Jordan, J.M., Prufer, K.M., 2017. Identifying domestic ceramic production in the maya lowlands: a case study from Uxbenká, Belize. *Latin American Antiquity* (in press).
- Kalosky, E.K., Prufer, K.M., 2012. Recent results of settlement survey and Hinterland Household Excavations at the Classic Period Site of Uxbenká, Toledo District, Belize. *Res. Rep. Belizean Archaeol.* 9, 255–266.
- Keller, G., Stinnesbeck, W., Adatte, T., Holland, B., Stueben, D., Harting, M., De Leon, C., dela Cruz, J., 2003. Spherule deposits in Cretaceous-Tertiary boundary sediments in Belize and Guatemala. *J. Geol. Soc.* 160 (5), 783–795.
- Kennett, D.J., 2005. *The Island Chumash: Behavioral Ecology of a Maritime Society*. University of California Press, Berkeley.
- Kennett, D.J., Anderson, A., Winterhalder, B., 2006. The ideal free distribution, food production, and the colonization of Oceania. In: Kennett, D.J., Winterhalder, B. (Eds.), *Behavioral Ecology and the Transition to Agriculture*. University of California Press, Berkeley, pp. 265–288.
- Kennett, D.J., Winterhalder, B., 2008. Demographic expansion, despotism, and the colonisation of East and South Polynesia. In: Clark, G., Leach, F., O'Connor, S. (Eds.), *Islands of Inquiry: Colonisation, Seafaring and the Archaeology of Maritime Landscapes* (Terra Australis 29). Australia National University Press, Canberra, pp. 87–96.
- Kennett, D.J., Winterhalder, B., Bartuff, J., Erlandson, J.M., 2009. An ecological model for the emergence of institutionalized social hierarchies on California's Northern Channel Islands. In: Shennan, S. (Ed.), *Pattern and Process in Cultural Evolution*. University of California Press, Berkeley, pp. 297–314.
- Kushnick, G., Gray, R.D., Jordan, F.M., 2014. The sequential evolution of land tenure norms. *Evol. Hum. Behav.* 35 (4), 309–318.
- McAnany, P.A., 1995. *Living With the Ancestors: Kinship and Kingship in Ancient Maya Society*. University of Texas Press, Austin, Texas.
- Malley, S., 2012. *From Archaeology to Spectacle in Victorian Britain: The Case of Assyria, 1845–1854*. Routledge, London.
- McAnany, P.A., 1998. Ancestors and the Classic Maya built environment. In: Houston, Stephen D. (Ed.), *Function and Meaning in Classic Maya Architecture*. Dumbarton Oaks Research Library and Collection, Washington D.C., pp. 271–298.
- McClure, S.B., Jochim, M.A., Barton, C.M., 2006. Human behavioral ecology, domestic animals, and land use during the transitions to agriculture in Valencia, eastern Spain. In: Kennett, D.J., Winterhalder, B. (Eds.), *Human Behavioral Ecology and the Transitions to Agriculture*. University of California Press, Berkeley, pp. 197–216.
- McClure, S.B., Barton, C.M., Jochim, M.A., 2009. Human behavioral ecology and climate change during the transition to agriculture in Valencia, eastern Spain. *J. Anthropol. Res.* 65 (2), 253–269.
- Moritz, M., Hamilton, I.M., Chen, Y.J., Scholte, P., 2014. Mobile pastoralists in the Logone Floodplain distribute themselves in an Ideal Free Distribution. *Curr. Anthropol.* 55 (1), 115–122.
- Moyes, H., Prufer, K.M., 2013. The geopolitics of emerging Maya rulers: a case study of Kayuko Naj Tunich, a foundational shrine at Uxbenká, southern Belize. *J. Anthropol. Res.* 69 (2), 225–248.
- Moyes, H., Robinson, M., Prufer, K.M., 2016. The Kayuko mound group: a festival site in southern Belize. *Antiquity* 90 (349), 143–156.
- Munson, J.L., Macri, M.J., 2009. Sociopolitical network interactions: a case study of the Classic Maya. *J. Anthropol. Archaeol.* 28 (4), 424–438.

- O'Connell, J.F., Allen, J., 2012. The restaurant at the end of the universe: modelling the colonisation of Sahul. *Aust. Archaeol.* 74 (1), 5–31.
- Prufer, K.M., 2005. The early classic in Southern Belize: a regional view from Uxbenká and Ek Xux. *Res. Rep. Belizean Archaeol.* 2, 169–178.
- Prufer, K.M., Kindon, A., Moyes, H., Culleton, B.J., Kennett, D., 2011. Uxbenká: the development of a frontier community in the eastern periphery of the Maya Lowlands. *Latin Am. Antiquity* 22 (2), 199–223.
- Prufer, K.M., Thompson, A.E., 2014. Settlements as neighborhoods and districts at Uxbenká: the social landscape of maya community. *Res. Rep. Belizean Archaeol.* 11, 281–289.
- Prufer, K.M., Thompson, A.E., 2016. LiDAR based analyses of anthropogenic landscape alterations as a component of the built environment. *Adv. Archaeol. Practice* 4 (3), 393–409.
- Prufer, K.M., Thompson, A.E., Kennett, D.J., 2015. Evaluating airborne LiDAR for detecting settlements and modified landscapes in disturbed tropical environments at Uxbenká, Belize. *J. Archaeol. Sci.* 57, 1–13.
- Puleston, C.O., Tuljapurkar, S., 2008. Population and prehistory II: Space-limited human populations in constant environments. *Theor. Popul. Biol.* 74 (2), 147–160.
- R Core Team, 2014. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria, p. 2013.
- Rambo, A.T., 1962. The Kekchi Indians of British Honduras: an ethnographic study. *Katunob* 3, 40–48.
- Reimer, P.J., Bard, E., Bayliss, A., Beck, J.W., Blackwell, P.G., Ramsey, C.B., Buck, C.E., Cheng, H., Edwards, R.L., Friedrich, M., Grootes, P.M., 2013. INTCAL13 AND MARINE13 Radiocarbon Age Calibration Curves 0–50,000 YEARS CAL BP. *Radiocarbon* 55 (4), 1869–1887.
- Rice, D.S., Culbert, P., 1990. Historical contexts for population reconstruction. In: Culbert, P.T., Rice, D. (Eds.), *Precolumbian Population History in the Maya Lowlands*. University of New Mexico Press, Albuquerque, New Mexico, pp. 1–37.
- Robin, C., 2003. New directions in classic maya household archaeology. *J. Archaeol. Res.* 11 (4), 307–356.
- Robinson, M.E., McKillop, H.I., 2013. Ancient Maya wood selection and forest exploitation: a view from the Paynes Creek salt works, Belize. *J. Archaeol. Sci.* 40 (10), 3584–3595.
- Shennan, S., 2007. The spread of farming into central Europe and its consequences. In: Kohler, T.A., van der Leeuw, S.E. (Eds.), *The Model-Based Archaeology of Socionatural Systems*. School for Advanced Research Press, Santa Fe, pp. 141–155.
- Shennan, S., 2009. Evolutionary demography and the population history of the European Early Neolithic. *Hum. Biol.* 81 (2–3), 339–355.
- Smith, M., 2010. The archaeological study of neighborhoods and districts in ancient cities. *J. Anthropol. Archaeol.* 29, 137–154.
- Smith, M., 2011. Classic maya settlement clusters as urban neighborhoods: a comparative perspective on low-density urbanism. *Journal de la Société des Américanistes* 97 (1), 51–73.
- Summers, K., 2005. The evolutionary ecology of despotism. *Evol. Hum. Behav.* 26, 106–135.
- Sutherland, W.J., 1996. *From Individual Behaviour to Population Ecology*. Oxford University Press, Oxford.
- Thompson, A.E., Ebert, C.E., Prufer, K.M., 2013. Shifting dynamics and Use of Space at Uxbenká. *Res. Rep. Belizean Archaeol.* 10, 255–270.
- Thompson, A.E., Prufer, K.M., 2015. Airborne LiDAR for detecting ancient settlements, and landscape modifications at Uxbenká, Belize. *Res. Rep. Belizean Archaeol.* 12, 251–259.
- Vogt, E., 1970. Human souls and animal spirits in Zinacantan. In: Pouillon, J., Maranda, P. (Eds.), *Echanges et communications: Melanges offerts a Claude Lévi-Strauss a l'occasion de son 60eme anniversaire*, vol. 2. Mouton, The Hague, pp. 1148–1167.
- Welsh, W., 1988. *An analysis of classic lowland maya burials*. BAR International Series 409 Oxford: British Archaeological Reports.
- Wilk, R.R., 1991. *Household Ecology: Economic Change and Domestic Life Among the Kekchi Maya in Belize*. University of Arizona Press.
- Wiley, G.R., 1968. *Settlement archaeology: an appraisal*. *Settlement Archaeol.*, 208–226.
- Winterhalder, B., Kennett, D.J., Grote, M.N., Bartuff, J., 2010. Ideal Free Settlement on California's Northern Channel Islands. *J. Anthropol. Archaeol.* 29, 469–490.
- Wittfogel, K.A., 1957. *Oriental Despotism A Comparative Study of Total Power*. Oxford University Press, Yale University Press, London, New Haven.