Journal of Archaeological Method and Theory
https://doi.org/10.1007/s10816-020-09505-3

Household Inequality, Community Formation, and Land Tenure in Classic Period Lowland Maya Society

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Accepted: 16 December 2020/Published online: 08 January 2021

Abstract
Access to social capital and valued resources modulates household decision-making as people seek to occupy the best-quality patches of land available. Prior occupancy, inheritance, and land tenure norms can constrain opportunities resulting in inequality between households. We examined processes of settlement development and structural inequality at two Classic Period (250–900 CE) Maya centers, Ix Kuku'il and Uxbenká, in Southern Belize. From the lens of human behavioral ecology (HBE), we evaluate the predictions of two population density models, the ideal free distribution (IFD) and the ideal despotic distribution (IDD), on household decision-making. To do so, we correlate the initial foundation date of households with nine measurable suitability variables as proxies for social and environmental resources. We conclude that at Uxbenká and Ix Kuku'il, social resources, such as the ability to mobilize labor, cooperation, and access to a transportation corridor, likely influenced where people chose to live. Environmental resources, including good farmland and access to perennial water sources, were widely distributed across the landscape and accessible to everyone. This study highlights the importance of social relationships on household decision-making, which is often difficult to detect in the archaeological record. The development and manifestation of institutionalized inequality are processes relevant to all societies past and present.

Keywords Human behavioral ecology · Ideal despotic distribution · Inequality · Land tenure · Settlements · Households · Maya

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Introduction

Humans make household-level decisions through a range of considerations from individual and inclusive fitness to conforming to rules of group living, often based on norms of social organization or economic hierarchies. Kinship, both consanguineal and affinal relationships, have long been recognized as factors influencing residency (Joyce and Gillespie 2000) with concepts of kin identity linked through time to land tenure (McAnany 2013; Shenk *et al.* 2010). In low-density agrarian hierarchical societies, like the Classic Period (250–900 CE) Maya, one of the most important decisions a person could make is where to reside. At a basic level, settlement choices can determine how much energy one must expend to meet basic needs such as travel time to agricultural fields and sources of fresh water, or to participate in collective social events. Settlement choices can also shape cooperative networks, effectively guiding economic interactions and opportunities.

Human behavioral ecology (HBE) is a useful framework to test hypotheses of settlement selection including how and why humans choose to live in a given location. Within HBE, the ideal free distribution (IFD) and the ideal despotic distribution (IDD) are density-dependent population models that can be used to analyze decision-making within a population. The IFD assesses the distribution of freely moving populations based on resource distributions (Fretwell 1969; Sutherland 1996) and the IDD incorporates inequality and differential access into the distribution of human populations (Bell and Winterhalder 2014). IFD and IDD models have been applied to a range of human societies including ancient hunter-gathers (Davis *et al.* 2020; Jazwa *et al.* 2013, 2019; Kennett *et al.* 2006), horticultural/agricultural societies (Giovas and Fitzpatrick 2014; Lane 2017; Prufer *et al.* 2017), and historic communities (Codding *et al.* 2019; Yaworsky and Codding 2018). Using this framework and building on our previous research (Prufer *et al.* 2017) as a foundation, we expand our study to test for variations in resource accessibility to compare settlement decision-making at two Classic Period Maya polities located at the eastern periphery of the southern Maya lowlands.

We ask, *do earlier settled households have preferential access to resources, compared with later settled households, and, if so, what resources?* Resources include wealth, the ability to deploy labor, and access to water, high-quality agricultural land, and market goods, as well as access to transportation corridors. Suitability variables, or measurable proxies for resources (see “Resources”), may influence settlement selection, or where people (households) choose to live. The locations where people chose to live in the past may reflect the availability of land, proximity to kin and corporate groups, the importance of social interactions, and access to locally available resources. Suitability variables can be selected based on the specific sociopolitical, economic, geographic, and temporal contexts, accounting for local variations in resources and behaviors when evaluating reasons for settlement decision-making.

While evolutionary models such as the IFD and IDD often focus on individuals and their decision-making, here, we consider the household the smallest unit of decision-making (Joyce and Gillespie 2000; Levi-Strauss 1982). Households (Table 1) are corporate groups where decisions are made regarding property and intergenerational inheritance of wealth (Borgerhoff *et al.* 2009). Land rights and tenure are often legitimized via norms of descent (McAnany 2013). To some degree, these household-level decisions can be reflected in settlement patterns on the landscape based on the distributions of households of different status and their relative age and length of occupancy (Prufer *et al.* 2017). Even within restrictive, despotic systems, subordinates may be able to maintain some degree of autonomy for household decision-making, particularly as it applies to corporate-level cooperation.

This study uses pedestrian survey and excavation data from two Classic Maya polities in southern Belize, Ix Kuku'il (IKK), and Uxbenká (UXB), to test the relationship between household foundation date and nine suitability variables. Uxbenká and Ix Kuku'il are situated on similar geographic and geological landscapes in the southern foothills of the Maya Mountains (Fig. 1) and are of comparable settlement system size and occupation periods. In aggregate, these communities contain 302 households (plazuelas)[1], of which 103 have temporal data. Plazuelas are clusters of residential structure platforms situated around a central plaza (Ashmore and Willey 1981:8), often on discrete hilltops or knolls of hills. We equate the plazuela to a kin-based household (Table 1). We do not include public civic/ceremonial architecture of non-residential plazas in this study.

We compare household decision-making using 80 AMS ^{14}C dates and nine suitability variables. We present (a) a high-precision settlement chronology for Ix Kuku'il and Uxbenká; (b) expand on the settlement chronology for Uxbenká with 10 new AMS ^{14}C dates, newly dated plazuelas based on ceramic typologies, and refining previously published AMS ^{14}C dates with the IntCal20 calibration curve; (c) identify social and ecological resources available within these communities; (d) test for differential access to resources based on occupational priority; and (e) situate our results within an evolutionary and behavioral ecology framework. Our aim is to present how detailed, multi-proxy chronologies from settlement contexts and spatial and statistical analyses can inform household decision-making and the development and persistence of social inequality in the past.

Because the length of occupancy of households as a proxy for land tenure and the timing of initial occupation of individual settlements is central to our argument, we limit our discussion to 103 plazuelas with reliable chronologies: 35 from Ix Kuku'il and 68 from Uxbenká. Following the expectations of the IFD, we predict that the earliest settled plazuelas, or those founded during the Late Preclassic and Early Classic (Table 2) and that are occupied the longest, will show evidence of differential access to at least one resource compared with shorter occupied settlements that were founded later in the history of the polities. This type of occupational priority was documented in the Maya region (LeCount *et al.* 2019) and we hypothesize that longer occupied households show evidence of greater wealth due to differential access to and control over resources.

Significance of the Study

Archaeological evidence of how and when social inequalities emerge, persist, and eventually diminish varies greatly, but understanding how these processes occur is universal to the human experience (Kintigh *et al.* 2014a, 2014b) and through cross-

[1] Throughout this paper, what has been referred to as a "Settlement Group" in previous publications (Jordan and Prufer 2017, 2020; Prufer et al. 2015, 2017; Thompson et al. 2018) will be called "Plazuela" with letters indicating the sub-plazuela. For example, "Settlement Group 25 Plazuela E" is now "P 25E." Plazuelas with an "X" in front of them were documented during survey at Ix Kuku'il, although a *K*-means cluster analysis has reassigned several of those plazuelas to the Uxbenká settlement system (Fig. 3; SI Table 1).

Table 1 Units of analysis used in this study

Unit of analysis	Description	Function	Activity	Leadership or smaller unit of analysis	Visible?
Household/plazuela	Kin group equivalent to the spatial layout of a household. One or more buildings situated around a central plaza, often on a discrete hilltop. Plazuelas include buildings and the activity areas such as spaces between buildings	Social. Corporate/reproductive	Household scale agricultural and craft production	Head of household	Yes
Neighborhood	Spatial cluster of households likely formed of kin groups	Face to face daily interaction	Local social mixing and cooperative labor groups	Neighborhood Seat; ranking neighborhood household	Modeled
District	Cluster of neighborhoods with an economic, political, or ceremonial public center	Social mixing, public ceremony, some corvee labor, some redistribution of concessions	Economic extraction and redistribution, local authority. Clearly defined hierarchy	Dominant household or district seat; ranking district household or extended households	Modeled
Polity	Geographic and unitary political unit	Polity leadership, foreign diplomacy, boundary control, top-down redistribution	Management of core public works, public security, macro-economic decisions	Despot; apical kin groups, despotic leaders	Yes
Descriptive only					
Settlement system	All places people lived, or geographic extent of where people lived within a polity. Defined by spatial borders such as decrease in density or bounding geographic topographic features	Extent of polity households. Descriptive only	Integrated economic, political, social, and diplomatic	–	Yes

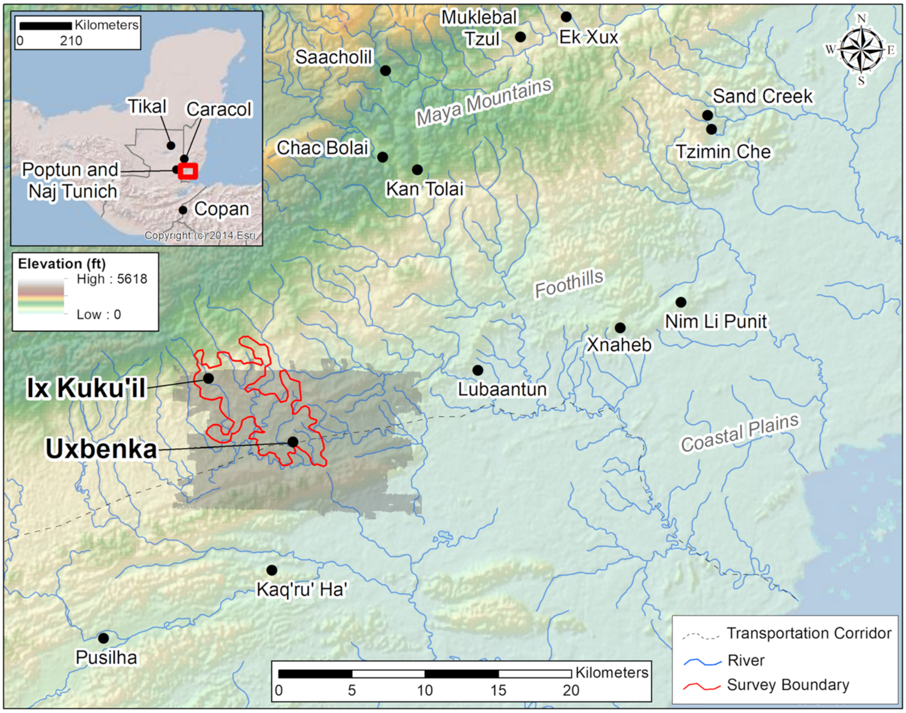


Fig. 1 Map of the major Classic Maya centers in southern Belize in relation to the three geographic regions, topography, and hydrology. The UAP lidar data (shaded area) and pedestrian survey zone (red outline) are highlighted. The location of southern Belize within the Maya region (inset)

cultural comparative studies we can gain a more holistic understanding of these processes (Feinman and Neitzel 2020). This study provides a framework for how similar assessments can be conducted in other spatiotemporal contexts. Archaeologists elsewhere can apply our approach, the IFD and IDD, to understanding how social and environmental resources impact settlement decision-making over time (Weitzel and Codding 2020). Quantifiable proxies for suitability variables and robust chronologic information for settlement data are needed. Ultimately, comparative analyses from multiple spatiotemporal contexts are needed to deepen our understanding of processes of urbanization and inequality and to consider how forms of political governance,

Table 2 Regional chronologic periods for southern Belize

Period	Abbreviation	Dates
Late Preclassic	LPC	300 BCE–250 CE
Early Classic I	EC1	250–400 CE
Early Classic II	EC2	400–600 CE
Late Classic	LC	600–800 CE
Terminal Classic	TC	800–1000 CE
Postclassic	PC	1000–1519 CE

ecological context, and kinship impact human behaviors (Feinman and Neitzel 2020; Kintigh *et al.* 2014a).

Inequality is present in all forms of human societies. Key to understanding social inequality in complex agrarian societies is the relationship between land tenure, intergeneration transference of wealth, and cooperation and kin selection and how those variables influence settlement decision-making. We use HBE frameworks, well-dated household contexts, and suitability variables to evaluate how inequality emerges and develops. We found power dynamics, cooperation, and kinship and lineal descent were key in settlement selection and household decision-making and the emergence, development, and maintenance of inequality. Our results can elucidate how unequal access to goods within a community results in systemic inequality and can potentially help guide modern policies to reduce unjust inequalities in our own communities.

Theoretical Frameworks

Evolutionary anthropology models emphasize the roles of selection and fitness to explain human behaviors (Bird and Codding 2016; Clark 2000; Winterhalder and Smith 2000) and in the context of decision-making in the past (Boone 1992; Smith and Winterhalder 2003; Winterhalder 2002). The IFD model was originally developed in animal ecology but proves useful in discussions of the underlying causes of variations in human settlement patterns (Codding and Bird 2015; Giovas and Fitzpatrick 2014; Jazwa *et al.* 2013). It is a flexible model in that it allows for the incorporation of relevant suitability variables that can be used to predict how humans respond to shifts in suitability as it relates to population density over time (Weitzel and Codding 2020).

The general IFD predicts that initial settlers in an open landscape will first occupy the highest ranked locations (H1, Fig. 2a) based on access to preferred resources and unconstrained by social hierarchies or peer competitors (Jazwa *et al.* 2016). While those settlers may initially improve the quality of their patch in the landscape through such activities as cooperative defense, investment in intensification, or other improvements (the *Allee* effect; Allee *et al.* 1949), over time, increasing population density amplifies competition and diminishes the effective suitability of the highest ranked, or highest quality, habitat, which is reduced to that comparable with a second rank habitat. Continued population growth will then spill over into the second-ranked habitat (H2, Fig. 2a), and then into the hypothetical third ranked habitat and beyond. Patch quality, or ranking, is thus density dependent. For humans in agrarian communities, the effect of adding new households (and thus increasing population) on a landscape eventually reduces patch quality until equilibrium is reached as suitability across all occupied locations is at a reduced quality. Freely moving corporate units (*i.e.*, households) will cease to settle in that area, with increased growth requiring emigration to different land patches, resulting in the establishment of new colonies across the landscape (Kennett 2005; Winterhalder *et al.* 2010).

Differential access to and control over resources is a key driver of inequality (Boone 1992; Shennan 2011; Smith *et al.* 2010). The IDD adds an axis of inequality whereby only some individuals are able to freely distribute themselves on the landscape.

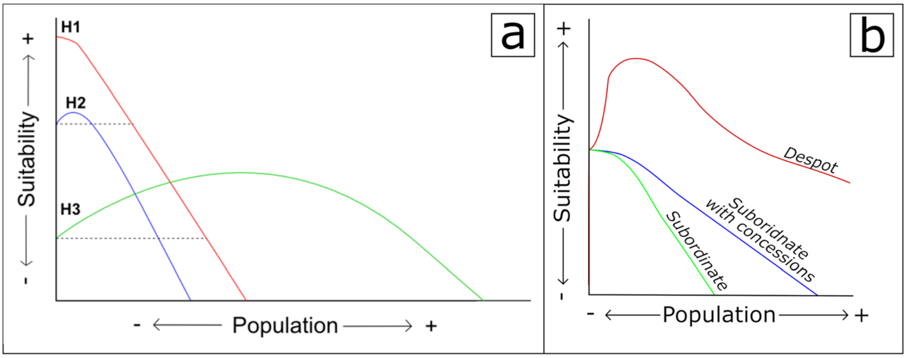


Fig. 2 Ideal free distribution (IFD) with the *Allee* Effect where habitat suitability initially increased with human adaptations to the environment (**a**). Eventually, as population density increases, the suitability of H1 decreases to the point where new colonizers will settle on H2, as indicated by the dotted line (Adapted from Sutherland 1996). Ideal Despotic Distribution (IDD) with despots and subordinates (**b**). Despots have access to more resources than subordinates, regardless of population density. Subordinates that receive concessions from despots reside in patches with higher suitability than those that do not receive concessions under an IDD (Adapted from Bell and Winterhalder 2014).

Individuals who are able to occupy higher value patches and defend them are able to accumulate a disproportionate share of resources (Bell and Winterhalder 2014). They may then be able to convey those resources to their (actual or fictive) descendants.

In agrarian societies, over time, some households accrue resources, most often through control of land. Dominant-controlled land can be allocated to subordinate households through usufruct rights for production. In return, subordinates much give back some portion of production, thus maximizing the dominants' returns through concessions. Systems of land tenure based on inheritance facilitate intergenerational landholding rights concentrated in dominant households, which then control a disproportionate share of wealth and labor (Cronk 1991; Shenk *et al.* 2010; Smith *et al.* 2010). These systems may arise from decision-making by founding households on an open landscape selecting high-quality patches of land. Intergenerational transmission of material, relational, and embodied wealth increases and perpetuates inequality (Borgerhoff *et al.* 2009, 2010; Bowles *et al.* 2010; Gurven *et al.* 2010; Mattison *et al.* 2016; Shenk *et al.* 2010). This is especially true as it pertains to land tenure (Field 2005; Shennan 2011).

One tenet of the IDD is that as a habitat becomes more densely occupied through endogenous population growth, control over local resources (*i.e.*, farmland and landesque capital, water, economic networks, and preferred locations for social interactions or defense) is increasingly held by smaller, often kin-related subsets of the population (Summers 2005). These households ultimately control and transmit the highest value patches of land through processes of kin-based, intergenerational transmissions of wealth. This process results in a density-dependent emigration of subsets of the population who lack resources (Bell and Winterhalder 2014).

Dominants, which we define as wealthy corporate households as a unit of analysis (Table 1), maintain their high status through coercion (Mattison *et al.* 2016). They defend wealth through exclusionary networks (Blanton *et al.* 1996; Boone 1992; Codding *et al.* 2019). As agrarian population density increases, inequality becomes institutionalized and subordinate households are increasingly marginalized.

Subordinates may reside as usufruct residents and agricultural producers on lands controlled by wealthy corporate households, or they may be relegated to peripheral patches of land with fewer valued resources and less direct access to benefits including community-wide services and public goods such availability of water, markets, temples, and access to roads (Blanton and Fargher 2008; Prufer *et al.* 2017).

A primary deterrent to emigration is concessions offered by dominant political and economic households or institutions (Bell and Winterhalder 2014). Emigration also carries its own risks and deterrents such as separation from kin networks. In a crowded geopolitical landscape of competing polities, emigration may also be deterred as conditions in neighboring, and potentially competing, communities may not be more economically beneficial. In a more open landscape with a lower population density, the benefits of emigration are higher, thus dominants may offer higher concessions to offset the risk of emigration. Conversely, in a crowded landscape with higher population density, concessions to subordinates can be lower and subordinates have fewer options to offset increasingly oppressive conditions. This tension of dominants desiring to minimize concessions and subordinate demands can introduce risk and fragility into a system, making it vulnerable to being destabilized by a wide range of internal and external forces such as social unrest, climate variability, and loss of economic networks. This process conforms to the IFD/IDD predictions whereby when population density is higher, overall suitability is lowered and subordinates likely experience lower quality of life, less access to resources, more human suffering, and will be less willing to conform to institutional inequalities.

When households preferentially use kin-selection exclusively to transmit control over resources, it involves inclusive and exclusive modes of cooperation (Clech *et al.* 2019). Everyone cooperates, but dominants always do so with an eye towards defending their larger share of resources, and subordinates do so for a variety of reasons from minimizing energetic costs to avoiding tensions with dominants or even resisting unequal structures. Different forms of cooperation can occur simultaneously (Carballo *et al.* 2014). Voluntaristic cooperation among subordinates is encouraged by dominants and rewarded through concessions. Coercive modes of cooperation are exercised to defend resources. Collective action predicts people will engage in both cooperation and competition to advance both individual and group interests (Carballo *et al.* 2014) which can result in perpetuating inequality linked to political and economic norms (Blanton and Fargher 2008; Feinman and Carballo 2018). Greater inequality among subsistence populations is linked to resource concentration, sedentism, surplus of food and goods, ability to store the said surplus, and higher population density (Gurven *et al.* 2010). Here, we argue for the Classic Maya that exclusionary/networked dominants continuously reinforce and legitimize their standing through kin-based networks (Feinman 2017). Lineages of networked dominants are discussed in hieroglyphic texts from across the Maya Lowlands (Jackson 2013; Martin 2020; Munson and Macri 2009), asserting the importance of kin in Classic Maya society. Intergenerational transmission of wealth and differential access to resources was stark among the Classic Maya in terms of concentration of wealth and the ability to mobilize labor. There, the presence of dominant households in the archaeological record is reflected in larger household architecture, larger plazas, investment in landscape modifications, sequential use of tombs, and status-enhancing goods.

Situating Uxbenká and Ix Kuku'il

Regional Setting

Uxbenká and Ix Kuku'il are located in southern Belize, which is geographically divided into three regions: the coastal plains, the foothills, and the southern Maya Mountains (Fig. 1). At its peak, more than 30 Classic Maya polities coexisted in southern Belize, most of which are in upland or montane environments. Uxbenká is the earliest established center in the region and construction of masonry architecture began during the Late Preclassic (Prufer *et al.* 2011). Population expansion occurred after 400 CE with the foundation of most regional capitals (Prager *et al.* 2014; Thompson and Prufer 2019). Expansion ended with the start of political disintegration in the late 700 CE which lasted nearly two centuries (Ebert *et al.* 2014) with only ephemeral evidence for Postclassic occupations (Prufer and Kennett 2020). While peripheral to the Maya heartland, polities in southern Belize were powerful geopolitical actors recording detailed dynastic histories (Wanyerka 2009). Over 15 capitals were surrounded by large populations (Thompson and Prufer 2019) acting as nodes in expansive economic networks (Golitko *et al.* 2012).

The southern Belize polities are divided between those in the foothills, including Uxbenká and Ix Kuku'il, and those in the interior of the Maya Mountains (Dunham and Prufer 1998), with a couple southern and coastal outliers (Fig. 1). The foothill polities are located on the Toledo Uplands which is composed of a 25-km-long formation consisting of interbedded shales, sandstones, and mudstone bedrock (Wright *et al.* 1959). When exposed to the elements, this unique bedrock petrogenesis is rapid, resulting in highly productive nutrient-rich soils (King *et al.* 1986; Wright *et al.* 1959). Soil quality and potential erosion of soils are influenced by the local topography and slope of the terrain (Cortez 2016; Culleton 2012). The Toledo Uplands contain freshwater springs (*cuxlin ha'* in Mopan Maya) and abundant perennial streams resulting in year-round water availability across the landscape.

Uxbenká

Uxbenká is a Classic Maya polity with a monumental epicenter (Culleton *et al.* 2012; Prufer *et al.* 2011) surrounded by 136 settlement groups—or patio clusters (Ashmore 1981:51–53)—that can further be divided into 180 plazuelas. These plazuelas are dispersed across 21 km^2 (Thompson 2019) and were documented during a pedestrian survey. The plazuelas spatially cluster into 20 neighborhoods and three districts (Fig. 3; see Prufer *et al.* 2017; Prufer and Thompson 2014; Thompson *et al.* 2018).

Uxbenká Chronology

We use AMS ^{14}C dates and ceramic analyses to define the developmental trajectory of the Uxbenká settlement (Fig. 4a; Fig. 5; Table 3). We develop a simple Bayesian phase model for the residential plazuelas at Uxbenká (see Prufer *et al.* 2017) with dates calibrated using the IntCal20 radiocarbon curve (Reimer *et al.* 2020). Uxbenká's modeled start boundary is between 115 BCE–60 CE (95.4%) (Fig. 6a) and approximately 7% of dated plazuelas were founded prior to 250 CE (Table 4). The earliest

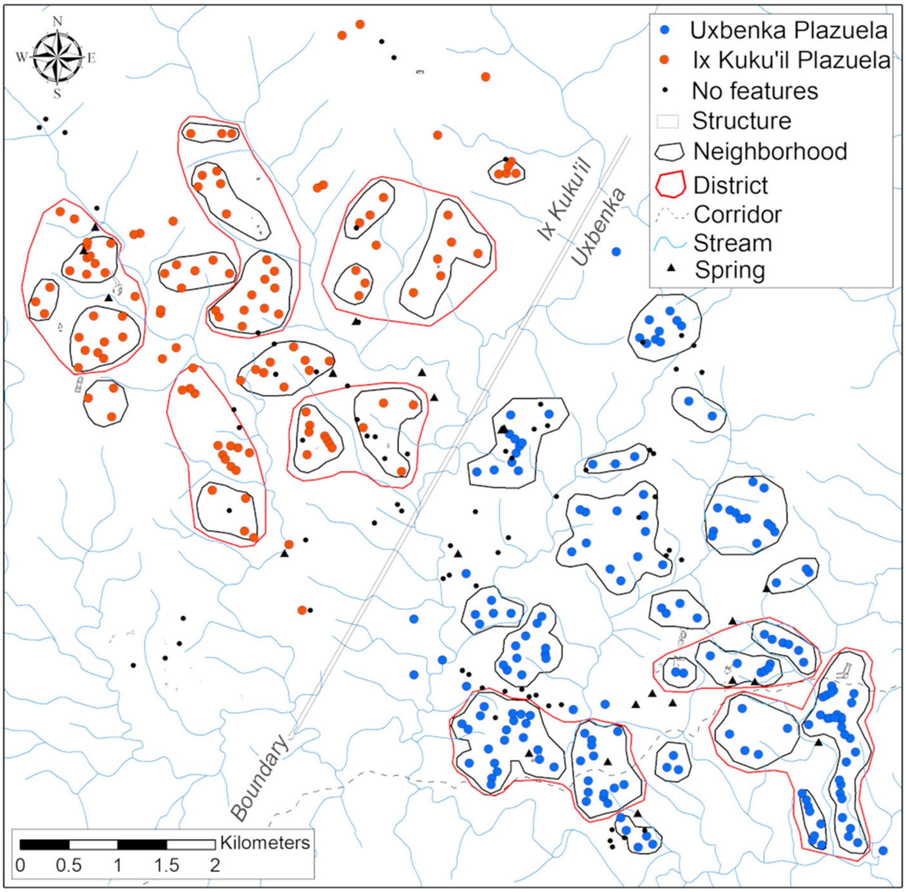


Fig. 3 Settlement map of plazuelas, neighborhoods, and districts at Uxbenká (blue) and Ix Kuku'il (orange) in relation to the boundary between the polities, sources of water, a transportation corridor, and hilltops with no archaeological features (black circles)

households were dirt platforms likely arranged as farming hamlets that were centered on kin-based relationships (Prufer *et al.* 2011). Before 400 CE, during the Early Classic I (Table 2), emergent dominants organized what was probably *corvée* labor to create massive platforms by flattening hill- and ridgetops (Culleton *et al.* 2012; Prufer and Thompson 2016). Atop these massive landscape modifications, monumental architecture was commissioned, and dominant lineages erected carved monuments declaring their familial rights to rulership (Munson and Macri 2009).

During the Early Classic, the occupants of Uxbenká constructed households near a transportation corridor (Fig. 4b; Prufer *et al.* 2017) with ample access to perennial water and quality farming land; they demonstrated their legitimacy at a large mountain top shrine and in caves overlooking the polity (Moyes and Prufer 2013; Moyes *et al.* 2016). The earliest established households likely maintained land tenure over generations and were the wealthiest households located at the three district centers. At Uxbenká, the wealthiest households have large tombs with multiple individuals, which were established early during the polity's development (Thompson *et al.* 2013).

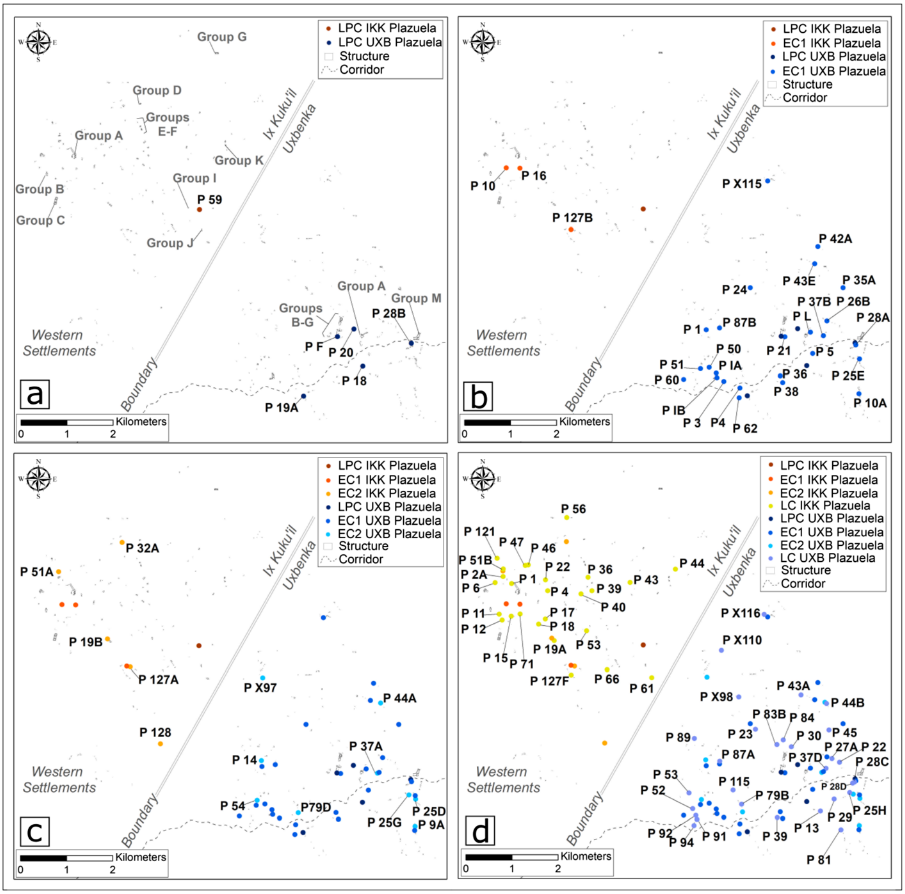
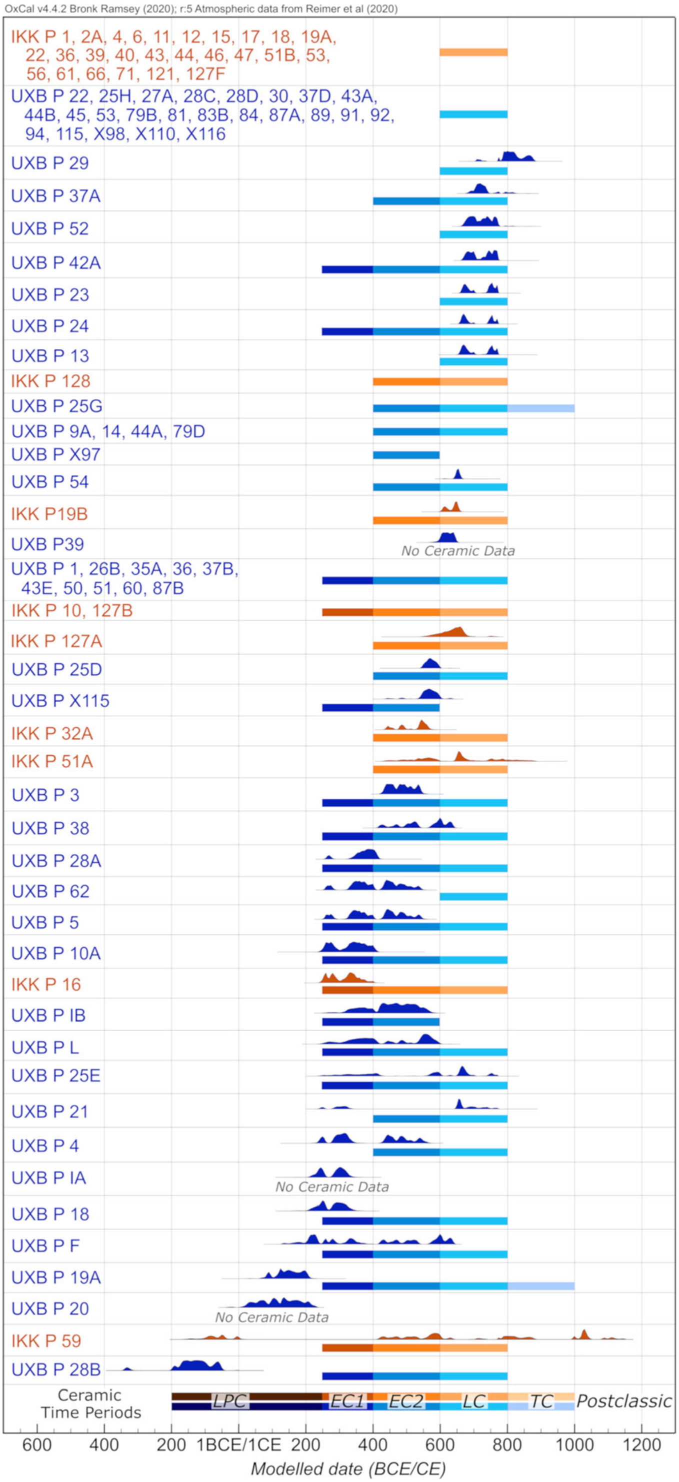


Fig. 4 Settlement map of Uxbenká and Ix Kuku'il during the Late Preclassic (**a**), Early Classic I (**b**), Early Classic II (**c**), and Late Classic (**d**). Plazuelas founded during each time period are labeled. Administrative groups are labeled in the Late Preclassic map

After 400 CE, during the Early Classic II, the settlement population of Uxbenká continued to grow and expand farther from the monumental epicenter (Group A, Groups B–G in Fig 4a). By the end of the Early Classic, more than half (57%) of all dated plazuelas had been founded (Fig 4c; Fig. 5; Fig. 6; Table 4; Supplemental Table 1). Powerful segments of the population residing in district centers continued to construct public architecture up to 1.5 km from the monumental epicenter, modifying hilltops and investing in ballcourts, small temples, and elaborate tombs. Other households within these districts, however, contain mostly small households with few wealth items and almost no formal masonry architecture. Those households were no doubt the ones who carried rocks, manufactured plaster, modified the landscape, and produced food as a condition of community membership (Prufer *et al.* 2017).

This trend continued throughout the Late Classic with the foundation of 43% of the dated plazuelas (Fig. 4d; Table 4). The late 700 CE marked a cessation in population growth (Fig. 7; Prufer and Kennett 2020; Prufer *et al.* 2017), and the monumental epicenter was largely abandoned by 830 CE (Aquino *et al.* 2013; Culleton *et al.* 2012).


OxCal v4.4.2 Bronk Ramsey (2020); r:5 Atmospheric data from Reimer et al (2020)
IKK P 1, 2A, 4, 6, 11, 12, 15, 17, 18, 19A, 22, 36, 39, 40, 43, 44, 46, 47, 51B, 53, 56, 61, 66, 71, 121, 127F
UXB P 22, 25H, 27A, 28C, 28D, 30, 37D, 43A, 44B, 45, 53, 79B, 81, 83B, 84, 87A, 89, 91, 92, 94, 115, X98, X110, X116
UXB P 29
UXB P 37A
UXB P 52
UXB P 42A
UXB P 23
UXB P 24
UXB P 13
IKK P 128
UXB P 25G
UXB P 9A, 14, 44A, 79D
UXB P X97
UXB P 54
IKK P19B
UXB P39
No Ceramic Data
UXB P 1, 26B, 35A, 36, 37B, 43E, 50, 51, 60, 87B
IKK P 10, 127B
IKK P 127A
UXB P 25D
UXB P X115
IKK P 32A
IKK P 51A
UXB P 3
UXB P 38
UXB P 28A
UXB P 62
UXB P 5
UXB P 10A
IKK P 16
UXB P IB
UXB P L
UXB P 25E
UXB P 21
UXB P 4
UXB P IA
No Ceramic Data
UXB P 18
UXB P F
UXB P 19A
UXB P 20
No Ceramic Data
IKK P 59
UXB P 28B
Ceramic Time Periods
LPC
EC1
EC2
LC
TC
Postclassic
600
400
200
1BCE/1CE
200
400
600
800
1000
1200
Modelled date (BCE/CE)

◀ **Fig. 5** Chronology of settlement expansion for Ix Kuku'il (orange) and Uxbenká (blue) based on AMS ^{14}C dates and ceramic seriations. All AMS ^{14}C dates were calibrated in OxCal v4.4.2 using the IntCal20 atmospheric calibration (Bronk Ramsey 2020; Reimer *et al.* 2020)

After occupying the landscape for more than eight centuries (Fig. 6c), Uxbenká's population ceased construction of new households between 715 and 835 CE (95.4%; Fig. 6b) based on the end boundary. However, small populations persisted well into the Terminal Classic and beyond based on AMS ^{14}C dates and ceramics from the monumental epicenter (Aquino *et al.* 2013; Prufer and Kennett 2020).

Ix Kuku'il

Ix Kuku'il is a smaller polity with a similar occupational history as Uxbenká (Thompson and Prufer 2019). The monumental epicenters of Uxbenká and Ix Kuku'il are less than 7 km apart, and undoubtedly, people at both polities interacted (Thompson and Prufer 2016). Pedestrian survey at Ix Kuku'il covered 21 km^2 and documented 97 settlement groups divided into 122 plazuelas (Table 3). The 122 plazuelas are clustered into 16 neighborhoods and 5 districts (Fig. 3), indicative of the dispersed nature of public architecture at Ix Kuku'il.

Ix Kuku'il Chronology

At Ix Kuku'il, small populations were present before 400 CE (Fig. 4 a and b), but there is currently no evidence prior to this time for the kind of labor mobilization for landscape modification that we see at Uxbenká. Early occupants were present on the landscape between 280 BCE and 15 CE (95% probability; Fig. 6d) based on a lower boundary modeled with Bayesian statistics of 16 AMS ^{14}C dates from residential contexts at Ix Kuku'il. The earliest households at Ix Kuku'il, which date to the Late Preclassic and the first part of the Early Classic, were likely constructed on dirt platforms and later modified into masonry platforms using locally available sandstones consistent with the evidence from Uxbenká (Prufer *et al.* 2011).

Shortly after 400 CE, population expansion occurred that was likely associated with Ix Kuku'il's rise as a minor center independent of Uxbenká (Fig. 4c; Fig. 5; Fig. 7). By 450 CE, a growing population was present at Ix Kuku'il (Fig. 5; Fig. 7). Multiple kin-based households, dispersed across the landscape rather than being clustered in a single area, were occupied during the Early Classic (Fig. 4 b and c). By the end of the Early Classic, 26% of dated plazuelas had been established (Table 4).

Settlements continued to expand during the Late Classic (Fig. 4d). A 50-year period from 700 to 750 CE contained few construction episodes (Fig. 5), but household construction persisted until 900 CE (Fig. 7). Populations grew throughout the Late Classic (Fig. 5) with the establishment of 74% of dated plazuelas (Table 4). All datable households have a Late Classic occupation based on ceramics (Supplemental Table 2), indicating that over centuries, the same homesteads continued to be occupied. Ix Kuku'il's resident population persisted well into the Terminal Classic and Early Postclassic (Fig. 7), with a modeled end boundary for the Ix Kuku'il settlement sequence between 995 and 1260 CE (95% probability; Fig. 6e). The decline of Ix

Table 3 Descriptive summary of households from Uxbenká and Ix Kuku'il

Site	Settlement groups	Dated settlement groups	Plazuelas	Dated plazuelas	% of plazuelas dated	Not dated plazuelas	Plazuelas dated with ceramics	Plazuelas dated with AMS ^{14}C	Total AMS ^{14}C dates	Total household structures	Environmental suitability variables analyzed	Social suitability variables analyzed
Uxbenká (Prufer *et al.* 2017)	94	48	n/a	n/a	n/a	n/a	n/a	n/a	54	408	Distance to water (m)	Settlement group area (m^2) number of structures in a settlement group, distance to transportation corridor (m)
Uxbenká (This study)	136	54	180	68	38	112	65	28	64	478	Distance to water (m), erosion, slope of the terrain (degrees), bedrock, soil classification	Plazuela area (m^2), number of structures in plazuela, total area (m^2) of structures in plazuela, distance to transportation corridor (m)
Ix Kuku'il (this study)	97	27	122	35	29	87	35	6	16	319	Distance to water (m), erosion, slope of the terrain (degrees), bedrock, soil classification	Plazuela area (m^2), number of structures in plazuela, total area (m^2) of structures in plazuela
Total (this study)	233	81	302	103	–	199	100	34	80	797		

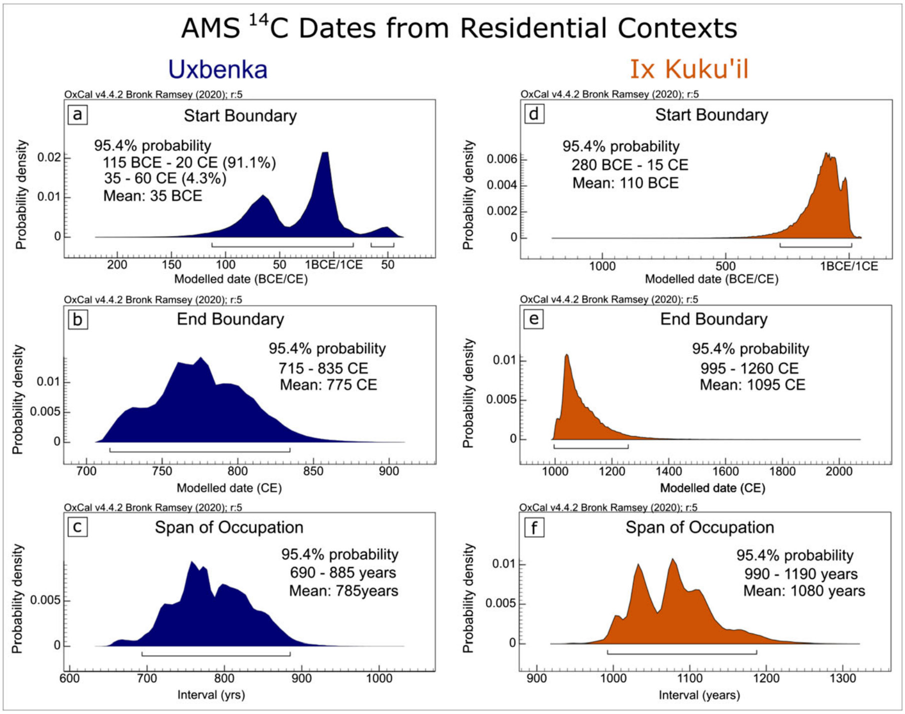


Fig. 6 Radiocarbon modeled start (**a**, **d**) and end (**b**, **e**) boundaries and the span (**c**, **f**) of household occupation based on AMS ^{14}C dates for Uxbenká (blue, left) and Ix Kuku'il (orange, right). All AMS ^{14}C dates were calibrated in OxCal v4.4.2 using the IntCal20 atmospheric calibration (Bronk Ramsey 2020; Reimer *et al.* 2020)

Kuku'il coincides with a drought that occurred in southern Belize between 1020 and 1100 CE (Kennett *et al.* 2012).

The construction of hinterland settlements at Ix Kuku'il spans approximately 1100 years (Fig. 6f) while Uxbenká's span of settlement construction is approximately 800 years (Fig 6c), although a summed probability distribution of all 179 AMS ^{14}C dates from Uxbenká's settlements, monumental epicenter, and agricultural lands spans more than 1200 years (Prufer and Kennett 2020). Although few excavations have occurred in the monumental epicenter of Ix Kuku'il, based on modeled terminal monument dates in southern Belize (Ebert *et al.* 2014), we assume Ix Kuku'il also experienced some degree of sociopolitical disintegration in the late 700s or early 800s CE. However, Ix

Table 4 Number and percent of dated households founded during each temporal period at Uxbenká and Ix Kuku'il

Date	Uxbenká		Ix Kuku'il	
	N	%	*N*	%
LPC	5	7	1	3
EC	34	50	8	23
LC	29	43	26	74
Total	68	100	35	100

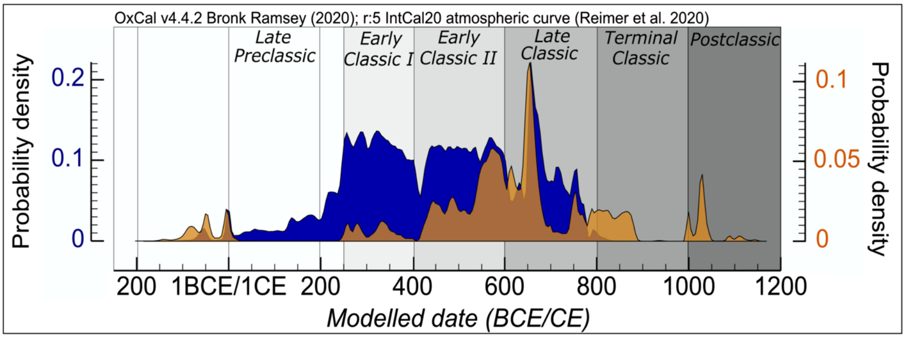


Fig. 7 Sum of settlement dates using AMS ^{14}C for Uxbenká (blue) and Ix Kuku'il (orange). All AMS ^{14}C dates were calibrated in OxCal v4.4.2 using the IntCal20 atmospheric calibration (Bronk Ramsey 2020; Reimer *et al.* 2020)

Kuku'il's occupational history follows patterns noted across the Maya lowlands, where rural farming populations persisted well after the disintegration of the Classic Period Maya sociopolitical system (Arnauld *et al.* 2017a; Lamoureux-St-Hilaire *et al.* 2015).

Dominants and Land Tenure at Uxbenká and Ix Kuku'il

Uxbenká and Ix Kuku'il have similar developmental histories but differ in the structure of their settlement systems; the overall structure of the settlement systems indicates that Uxbenká's settlements were hierarchically structured, while those at Ix Kuku'il were less formally structured (Thompson *et al.* 2018). However, both settlement systems have significant variations in household sizes and complexity including large households with administrative functions as district centers. Uxbenká's neighborhoods and districts are defined based on discrete geospatial statistics, while Ix Kuku'il's neighborhoods and districts are not defined by geospatial statistics, but on observations of the distribution of the largest and earliest households and comparisons with similar trends at Uxbenká.

Uxbenká and Ix Kuku'il vary in size and complexity of monumental architecture as indicators of political power. The stelae plaza (Group A) at Uxbenká contains 23 carved monuments dating from 376 CE to 780 CE. The ruling lineage claimed exclusionary relationships with Tikal, a powerful central Peten polity, as recorded on Uxbenká's Stela 11 (Wanyerka 2009). The central focus of the stela plaza is a large triadic structure situated on the northern side of Group A. Three ball courts are present at Uxbenká: (1) in a restricted plaza in Group B; (2) in a public plaza near a market in Group D; and (3) in the western district center, Group I.

At Ix Kuku'il, Group A has a single, uncarved stela and a 10 m tall inline eastern triadic shrine (Thompson and Prufer 2016). However, most public architecture at Ix Kuku'il is dispersed across the landscape. Districts at Ix Kuku'il were defined based on the presence of non-residential architecture including hilltop shrines, temples, and a ball court. P 19B (Plazuela 19B), P 51A, P 32A, and Group F were founded during the Early Classic and developed into some of the largest households (Fig. 4; Supplemental Table 2). Two other inline triadic shrines, a form associated with high-status households asserting power through ancestral ties (Awe *et al.* 2016; Chase and Chase 1995), are located in the hinterlands of Ix Kuku'il, far from the epicenter Group A. A low, eastern triadic building is located in the southern hinterlands at P 61. And a 3.5 m tall triadic building is on the north side of the P 90. The hinterland triadic shrines may represent territorial markers or local concessions by local dominants who often acted as mediators between ruling despots and subordinates (Walden *et al.* 2019).

Both Uxbenká and Ix Kuku'il exhibit multiple nodes of power dispersed across the landscape. Ix Kuku'il contains the second largest stela in the region and has long-distance imported goods including jade and obsidian. However, Uxbenká may have been more integrated with distant geopolitical centers in the central Peten (Golitko *et al.* 2012) based on evidence of a long dynastic history recorded across multiple stelae (Wanyerka 2009). Furthermore, Uxbenká exhibits greater political integration and complexity than Ix Kuku'il, based on monumental epicenter layouts and proximity to the regional transportation corridor.

Methods

All spatial analyses were completed in ArcMap v10.7. Radiocarbon dates were calibrated in OxCal v4.4.2 (Bronk Ramsey 2020) using the IntCal20 calibration curve (Reimer *et al.* 2020). All descriptive and statistical analyses were completed in R.

Survey Strategy

In the high-relief foothill region of southern Belize, "practically every hilltop sports some kind of settlement remains, right down to the simple household plazuela group" (Dunham 1990:169). This holds true at Uxbenká and Ix Kuku'il where nearly all ancient Maya households are on hilltops and ridges (Kalosky and Prufer 2012; Thompson 2020). Our pedestrian settlement survey focused on all hilltops and ridgelines, noting locations with and without archaeological features. Pedestrian survey data were georectified and snapped to the light detection and ranging (lidar) surface models. The boundary between Uxbenká and Ix Kuku'il was developed using a *K*-mean cluster analysis of all surveyed plazuelas. These results are further supported by the increased density of hilltops without archaeological features along a river valley (Fig. 3).

Excavation Strategy

Plazuelas were selected for excavation based on size, including large and small plazuelas to gain a representative sample of the population, and accessibility. Within a plazuela, excavation units were selected based on the size and preservation of the building. Larger buildings tend to have more construction sequences, providing greater insight into the occupational history of the household (*e.g.*, Ebert *et al.* 2016). However, larger buildings are also more likely to be targeted by looters. We often excavated either in the largest building or the best-preserved building in the plazuela. When possible, we also excavated in smaller buildings within the plazuela to understand the range of occupation within a single plazuela. All carbon samples were taken from excavation contexts including platform construction fill and *in situ* primary contexts such as caches and burial features.

Chronology Building

We assigned each plazuela to one or more time periods based on ceramic types and AMS ^{14}C dates (Supplemental Tables 1, 2, and 3). The Ix Kuku'il and Uxbenká ceramics fall into the same type-variety categories developed at Uxbenká (Jordan 2014), and ceramic phases correlate with time periods of approximately 200 years (Table 2). Low visibility and poor preservation made recovery of ceramics with temporally diagnostic traits difficult. In total, approximately 38% and 29% of plazuelas at Uxbenká and Ix Kuku'il, respectively, were assigned to temporal periods based on ceramic and AMS ^{14}C dates (Table 3).

In total, 103 plazuelas—68 from Uxbenká and 35 from Ix Kuku'il—were used in the statistical analysis. The Uxbenká settlement chronology is based on 64 AMS ^{14}C dates from excavations in 28 plazuelas (Table 3; Supplemental Table 3). A total of 65 plazuelas were dated with ceramics, 25 of which overlap with plazuelas that were dated with AMS ^{14}C (Supplemental Table 1). The Ix Kuku'il settlement chronology is based on 16 AMS ^{14}C dates derived from excavations at six plazuelas and ceramic data from all 35 plazuelas (Fig. 5; Table 3; Supplemental Table 2). All AMS ^{14}C dates were calibrated at a 2σ (95.4%) and rounded to the nearest 5 years (Stuiver and Polach 1977:362).

Simple Bayesian phase models were produced in OxCal v4.4.2 using a Markov chain Monte Carlo (MCMC) simulation (Bronk Ramsey 2020). The start and end boundaries represent the likelihood that the date falls within the modeled range based on calibrated input AMS ^{14}C dates. The summed probability distribution reflects the summation of all dates input for the event. The span represents the calculated span of time based on all input dates of the phase.

Resources

Not all resources are directly measurable so we used proxies to assess differences in wealth and access: Proxies for household wealth and mobilization of labor are the number of structures in a plazuela, total area of structures in a plazuela, and total area of the plazuela. Access to water is the distance to the nearest perennial water source. Proxies for access to high-quality agricultural lands include the slope of the terrain, categorical erosion of the terrain, soil classification, and type of bedrock. Access to market goods is measured by the distance to the transportation corridor.

Social Resources

Social resources include wealth and the mobilization of labor and proximity to a transportation corridor. These resources are assessed through four measurable suitability variables—plazuela area, number of structures, area of structures, and distance to the transportation corridor (see below and Table 3; Supplement S-1). The number of structures is based on platforms documented during the pedestrian survey; the structures were not recorded for two of the dated Uxbenká plazuelas (Table 5). The area of individual structures and each plazuela was calculated using the Calculate Geometry function in ArcMap. At Uxbenká, distance to the transportation corridor was measured

Table 5 Number of dated plazuelas used in statistical analyses for each suitability variable

Dated plazuelas with variable		
Variable	Uxbenká	Ix Kuku'il
Structures	66	35
Total structure area in plazuela	66	35
Plazuela area	68	35
Distance to water	68	35
Zonal slope	68	30
Erosion	68	35
Soils	68	35
Bedrock	68	35
Distance to corridor	68	0

using the Generate Near Table function from the center point of each plazuela to the corridor (see Prufer *et al.* 2017; Thompson and Prufer 2015).

Least Cost Path for Transportation Corridor Archaeologists use geoscience information systems (GIS) and least cost paths (LCP) to model pathways or transportation routes (Lugo and Alatriste-Contreras 2019; White 2015; White and Surface-Evans 2012). Today, modern merchants (called *cobaneros*) follow our transportation corridor to move goods from the Alta Verapaz of Guatemala through southern Belize (Hammond 1978). We ran LCP using a slope model (in degrees) of a 1-m lidar-derived digital elevation model (DEM). This path is calculated using topography and represents the path of least resistance to move across the landscape. Using an LCP analysis, we previously modeled the east-west transportation corridor connecting the Caribbean to the eastern Pasion region, passing through Uxbenká; this corridor was a key variable in settlement selection (Prufer *et al.* 2017). This corridor is situated south of the Uxbenká monumental epicenter, passing near the earliest settled households and local dominants in the district seats (see Figs. 3 and 4). The same corridor is used in this analysis.

To create a comparable analysis, we modeled three potential transportation corridors using LCPs that would connect through Ix Kuku'il to larger, nearby polities and places of importance to the Classic Maya including Caracol, Uxbenká, Lubaantun, Poptun, and Naj Tunich cave (see Fig. 1). However, none of the modeled LCPs passed through the Ix Kuku'il polity (Supplemental Fig. 1; Supplement S-1). However, the proximity of Ix Kuku'il to the Maya Mountains made diverse montane resources available to residents (Dunham and Prufer 1998).

Environmental Resources

Environmental resources include access to year-round water sources and high-quality agricultural land. The environmental resources are assessed through five measurable suitability variables—bedrock type, soil classification, categorical erosion values, slope of the terrain in degrees, and distance to water. Suitability variable data for bedrock (mudstone or mixed mudstone and limestone), soil classification (four soil types), and erosion (categorized into less erosion, some erosion, and more erosion) were collected for each plazuela in GIS using digitized maps of established soil and land surveys (King *et al.* 1986; Wright *et al.* 1959; Supplement S-2; Supplemental Figs. 2-5; Supplemental Table 4). Slope was measured for all plazuelas within the lidar zone using a 50 m buffer around each plazuela, a slope model (degrees) of the 1-m lidar DEM, and the Zonal Statistics function within the Spatial Analyst toolbox. Five of the dated plazuelas at Ix Kuku'il are north of the lidar data acquisition and therefore do not have slope data (Table 5; Supplemental Fig. 6). Distance to water sources (springs and streams) was measured with the Generate Near Table function in the Analysis Tools toolbox (Supplement S-2).

Statistical Assessments

Chronological data provide insights into the growth, expansion, and decline of Uxbenká and Ix Kuku'il, and combined with our proxy data, we tested for preferential selection of resource accessibility between earlier and later plazuelas. The estimated foundation date of each plazuela was derived from ceramic data and AMS ^{14}C dates. Due to the low sample size of Early Classic I and Early Classic II plazuelas at Ix Kuku'il, and the fact that no plazuelas were founded during the Terminal Classic, we conflated the foundation dates into three categorial periods for statistical analyses: Late Preclassic (LPC), Early Classic (EC), and Late Classic (LC; Table 2). Likewise, at Ix Kuku'il, only one plazuela (P 59) dates to the Late Preclassic and, therefore, was lumped in with the Early Classic for statistical analyses (Supplemental Table 5). Radiocarbon dates that straddled two time periods were designated into the time period associated with the mean of the 2-sigma probability distribution of the calibrated date (see Supplemental Table 3). For example, the earliest date at Uxbenká P 21 spans from 235–335 cal CE (95.4%) with a mean of the 2-sigma probability distribution of 290 cal CE (Supplemental Table 3) and, therefore, was designed to the Early Classic.

Kruskal-Wallis and Wilcoxon Tests for Non-parametric Continuous Data

To evaluate the IFD and IDD models and the relationship of plazuela foundation and preferential access to resources at Uxbenká and Ix Kuku'il, we ran a non-parametric Kruskal-Wallis (KW) rank sum test and a Wilcoxon ranked sum (WRS) two-sample test in R (Supplement S-3 and S-4). We analyzed six suitability variables for each group: number of structures, total area of structures, plazuela area, distance to water, (zonal) degree of slope, and distance to corridor (Uxbenká only). To further assess the variation in time between the Late Preclassic, Early Classic, and Late Classic at Uxbenká, we used a Wilcoxon two-sample test with Benjamini and Hochberg (BH) correction. This correction controls the false discovery rate and the expected proportion of false discoveries among rejected hypotheses. The false discovery rate is a less strict condition than the family-wise error rate and more powerful. These ranked tests are ideal for data with a range of distributions (VanPool and Leonard 2011). The KW accounts for limited outliers by analyzing the sample medians.

Chi-square for Categorical Data

Three of the suitability variables—bedrock, soil classification, and erosion—are nominal or categorical data, which cannot be analyzed using a KW test. The frequency tables for these variables contained cells with low values due to the low variability in the environment. Therefore, we analyzed the frequency of these resources using a Pearson's chi-square (X^2) test as well as a Fisher's exact test with a Yate's continuity correlation to account for the low cell values (VanPool and Leonard 2011; Supplement S-5 and S-6).

Results

Two suitability variables were statically significant ($p < 0.05$) between earlier and later households at Uxbenká (total structure area and plazuela area) and Ix Kuku'il (number of structures and total structure area) (Table 6). Earlier households developed into the largest households likely due to land tenure, access to resources, and the ability to harness labor to generate wealth. None of the environmental suitability variables were statistically significant (Table 6 and Table 7; Supplemental Table 6). The summary statistics for each suitability variable (number of samples per time period, means, and medians) are reported in SI Table 5. Box-and-whisker plots show the trends in suitability variables over time at Uxbenká and Ix Kuku'il (Figs. 8 and 9).

Number of Structures

By the time of abandonment, earlier founded households had more structures than later founded households. This trend is statistically significant at Ix Kuku'il ($p = 0.0005$) using a Kruskal-Wallis test (KW); this trend is not statistically significant at Uxbenká (KW, $p = 0.0855$), regardless of time using a Wilcoxon rank sum (WRS) pairwise comparison (Supplemental Table 6). At Ix Kuku'il, Early Classic founded plazuelas contain 5 structures, while Late Classic founded plazuelas contain 3 structures (median values; Fig. 9; Supplemental Table 5).

Table 6 Kruskal-Wallis results. Italicized values are statistically significant ($p < 0.05$)

Kruskal-Wallis p values for all time periods		
Variable	Uxbenká	Ix Kuku'il
Number of structures	0.0855	*0.0005*
Total area of structures	*0.02811*	*0.0074*
Plazuela area	*0.0356*	0.1360
Distance to water	0.8091	0.2420
Zonal slope	0.5955	0.5576
Distance to corridor	0.2112	–

Table 7 Chi-square and Fisher's exact test results. None of the variables are statistically significant

Pearson's chi-square Fisher's exact test *p* values for all time periods

Variable	Uxbenká				Ix Kuku'il			
	X^2	*df*	X^2 *p*	Fisher's exact test *p*	X^2	*df*	X^2 *p*	Fisher's exact test *p*
Soil classification	1.8348	6	0.9342	0.9597	3.7048	2	0.1569	0.1936
Bedrock	0.10076	2	0.9509	0.93	0.31784	2	0.5729	0.2571
Erosion	5.3192	4	0.2561	0.1596	0.97222	2	0.615	0.6028

Total Structure Area (m²) in Plazuelas

The structures built in earlier households are larger than structures built in later households. This trend is statistically significant at both Ix Kuku'il (KW, $p = 0.0074$) and Uxbenká (KW, $p = 0.02811$). At Ix Kuku'il the average structure area within Early Classic plazuelas is 334 m^2, whereas the mean Late Classic structure area is 169 m^2. At Uxbenká, this trend is not statistically significant between the Late Preclassic and Early Classic (WRS, $p = 0.846$) or the Late Preclassic and Late Classic (WRS, $p = 0.32$) but it

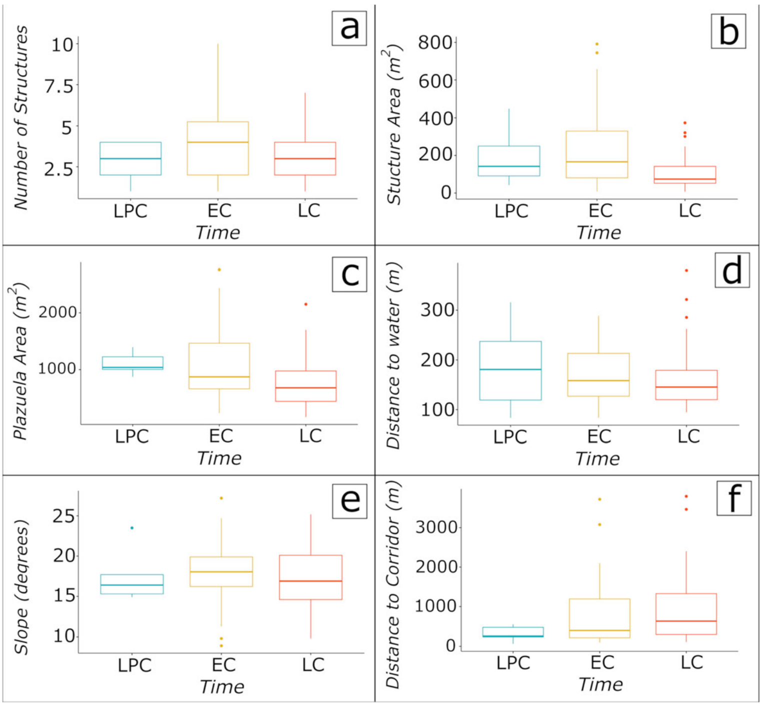


Fig. 8 Box-and-whisker plots with errors showing the trends in suitability variables over time at Uxbenká. Dots represent outliers. Number of structures (**a**); structure area (**b**); plazuela area (**c**); access to water (**d**); lidar-derived slope (**e**); and distance to the transportation corridor (**f**)

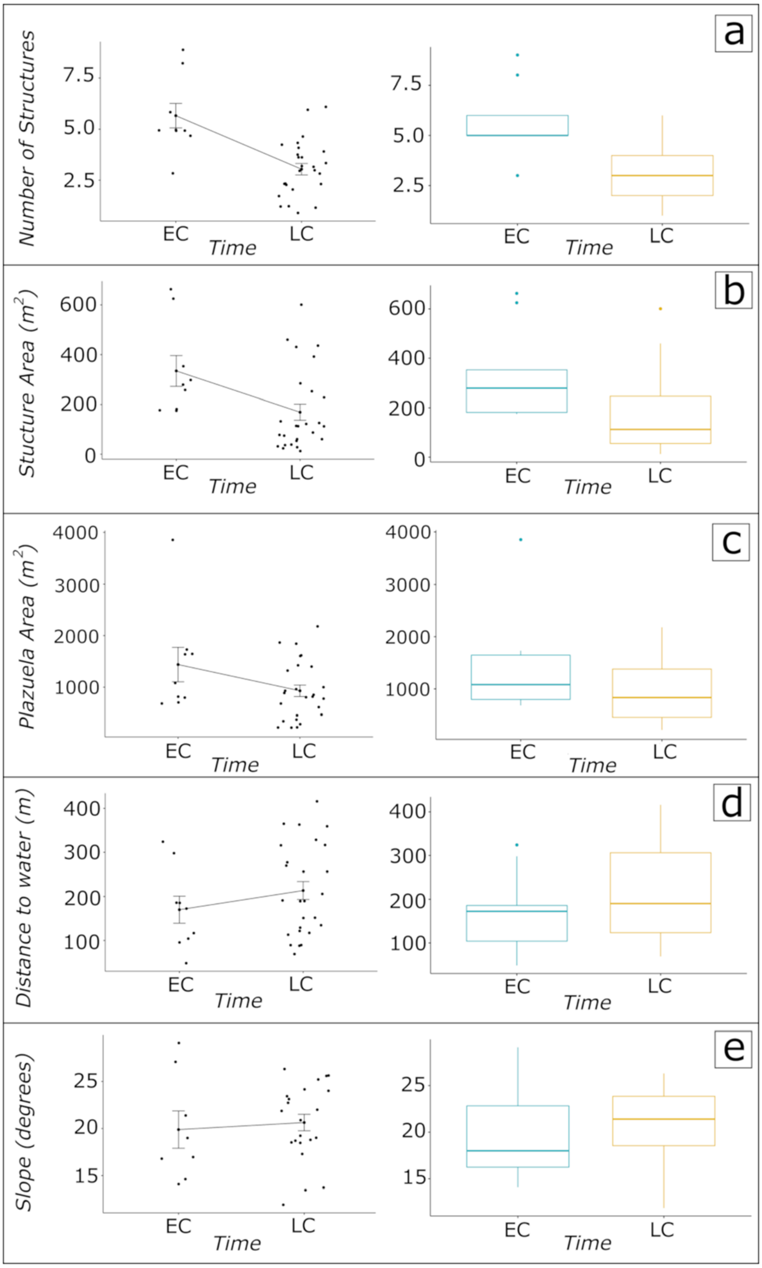


Fig. 9 Data points and means (left) and Box-and-whisker plots with errors and outliers (right) showing the trends in suitability variables over time at Ix Kuku'il. Number of structures (**a**); structure area (**b**); plazuela area (**c**); access to water (**d**); and lidar derived slope (**e**)

is statistically significant between the Early Classic and Late Classic (WRS, $p = 0.027$). The average Late Preclassic structure area is 195 m^2 and the average Early Classic and Late Classic structure areas are 236 m^2 and 110 m^2, respectively.

Plazuela Area (m^2)

Earlier households are larger than later households (Figs. 8 and 9). This trend is present at Ix Kuku'il, with Early Classic plazuelas averaging 1439 m^2 and Late Classic plazuelas averaging 930 m^2, but it is not statistically significant (KW, p = 0.136). This trend is statistically significant across all dated plazuelas at Uxbenká (KW, p = 0.0356). Differences in the plazuela size are statistically significant between the Late Preclassic and Late Classic (WRS, p = 0.05) and Early Classic and Late Classic (WRS, p = 0.05). Late Preclassic plazuelas are an average area of 1108 m^2, Early Classic plazuela area averages 1070 m^2, and Late Classic plazuelas are an average of 768 m^2.

Distance to Water (m)

Distance to water does not vary significantly between earlier and later households. At Ix Kuku'il, Early Classic households are closer to water (mean: 170 m) than Late Classic households (mean: 214 m), but this trend is not statistically significant (KW, p = 0.242). At Uxbenká, households founded during the Late Classic are slightly closer to water (mean: 165 m) than Early Classic (mean: 168 m) and Late Preclassic (mean: 187 m) households. This trend is not statistically significant among all time periods (KW, p = 0.8091) nor between them.

Zonal Slope (Degrees)

There is little variability in the slope of the terrain regardless of household foundation date. The slope of the terrain is not statistically significant at Ix Kuku'il (KW, p = 0.5576) or Uxbenká (KW, p = 0.5955). The slope at Ix Kuku'il is slightly steeper (EC, 19.9°; LC, 20.6°) than the slope at Uxbenká (LPC, 17.6°; EC, 18.0°; LC, 17.3°).

Distance to Corridor (m)

Earlier households at Uxbenká are closer to the corridor than later households, but this trend is not statistically significant (KW, p = 0.2112). Late Preclassic households are closest to the corridor with an average distance of 319 m. Early Classic households average 808 m from the corridor, and Late Classic households are the farthest away, with an average distance of 989 m from the corridor. Notably, this suitability variable was statistically significant in our previous study (Prufer *et al.* 2017). However, several outliers in the updated dataset lower the median values that were used in the KW test (medians: LPC, 261 m; EC, 402 m; LC, 640 m).

Soils, Bedrock, and Erosion

The earlier settlers at Uxbenká and Ix Kuku'il did not preferentially select settlement location based on soil classification, bedrock, or erosion of the soils. None of the results are statistically significant (Table 7). However, this is likely due to the lack of variability in the environment (Fig. 10). For example, almost all of Ix Kuku'il households are on mudstone (Fig. 10a) and in areas more susceptible to erosion (erosion value: 4 in Fig. 10c). Uxbenká's landscape reflects greater variability, but the

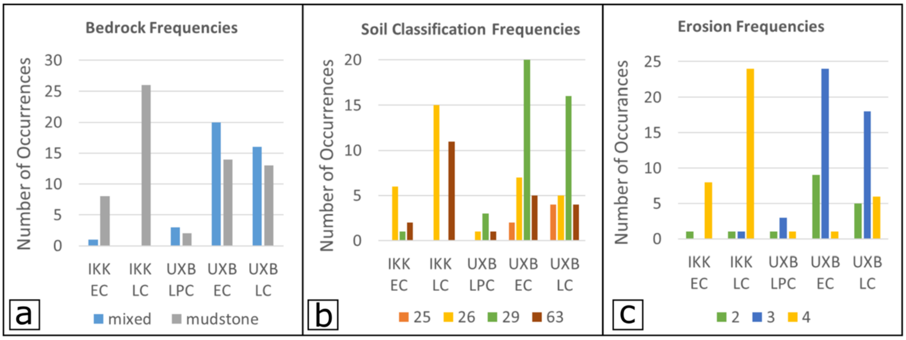


Fig. 10 Frequency bar charts by time period (LCP, EC, LC) for bedrock (**a**), soil classifications (**b**), and erosion (**c**) at Uxbenká and Ix Kuku'il

ubiquitous high-quality land did not result in one soil or bedrock type being preferentially selected for during the foundation of new households.

Discussion

Uxbenká and Ix Kuku'il were likely founded due to the resource-rich local environment of the Toledo Uplands. As a result of land tenure, the earliest founded households were able to assert control over land, and mobilize more labor to farm that land, likely through usufruct impermanent rights. Later founded households are those on the periphery and may have had access to more farmlands, but were more marginal in terms of access to social resources. This is evident in a paucity of any status-enhancing goods or investment in the built environment (*i.e.*, large architecture and plazuela expansions) in most peripheral households. Labor mobilization was an important social resource, which was assessed with measurable suitability variables (the number of structures, total area of structures, and plazuela area); these suitability variables are statistically significant at a 95% confidence interval ($p < 0.05$) at both Uxbenká and Ix Kuku'il. Likewise, earlier households at Uxbenká lived closer to the transportation corridor than later households, although this trend is not statistically significant.

A land tenure system based on exclusionary economic practices by dominants that favored kin-based inheritance and corvee labor to ensure production was likely in place at both Uxbenká and Ix Kuku'il for the Classic Period and is reflected in investments in the built environment, including hilltop modifications and the maintenance of springs. These findings highlight the importance of social networks, including kinship, as they relate to inherited inequality and the transmission of material wealth in settlement selection and household decision-making. Intangible resources such as kinship and social networks are difficult to detect archaeologically, especially within household archaeology, but proxies such as household size, proximity, and longevity of occupation allow archaeologists to quantifiably evaluate these resources. Here, we highlight the importance of the processes for understanding the emergence and persistence of inequality. These processes elucidate intergenerational inequality, which are relevant to modern and ancient societies alike.

Social Relationships as Constraints on Household Decision-making

The social relationships such as cooperative alliances, kin selection, and ability to mobilize labor were important in the decision of where people chose to live. Social bonds form relational wealth, which can involve gift exchange, social networks, and relationships established through shared knowledge (Borgerhoff *et al.* 2010; Bowles *et al.* 2010). Relational wealth is a form of intergenerational wealth transmission that manifests in the accumulation of material wealth (Shenk *et al.* 2010; Smith *et al.* 2010), such as larger households, prestige goods including jade, and elaborate mortuary furniture, which are common among the dominant families across Uxbenká and Ix Kuku'il.

Access to the transportation corridor, while not statistically significant, was preferentially selected for by Uxbenká's earliest households based on average distances for the three time periods (Fig 8f). This corridor may have been used for centuries prior to the founding of Uxbenká, as the LCP reflects the path of least resistance east-west across the landscape. Its presence likely influenced the initial foundation of the Uxbenká and facilitated local commerce and exclusionary trade networks, benefiting those who were most proximate to the route and their descendants. The earliest households at Uxbenká (P 28B, P 18, P 19A, P 20, and Group F; Fig. 4a; Fig. 5) date to the Late Preclassic and are all within 600 m of the corridor (Fig. 8f; Supplemental Table 7). Early settlers likely selected household locations close to this social resource. Due to their advantageous location and ability to monopolize the movement of goods across the region, some of these households increased in wealth and power, emerging as dominants, and eventually controlled access to the corridor, forcing subordinates onto marginal lands further from the corridor (Prufer *et al.* 2017).

While we did not identify a potential transportation corridor at Ix Kuku'il using an LCP analysis (see Supplement S-1), Ix Kuku'il households likely relied on a variety of resources from the Maya Mountains and foothills as part of their managed mosaic. Ix Kuku'il households most certainly interacted with their nearest neighbor, Uxbenká, based on shared ceramic types and architectural similarities. Uxbenká was likely an economic hub and stopping point along an important transportation corridor connecting the southeastern Petén with the Caribbean Sea (Hammond 1978; Prufer *et al.* 2017). The proximity between Ix Kuku'il and Uxbenká would have provided Ix Kuku'il households with access to imported goods via merchants or markets. Today, people living in the Mopan Maya villages near Uxbenká and Ix Kuku'il walk to adjacent communities to visit extended family, exchange goods via barter economy, and catch the bus to visit the larger, regional administrative and market town, Punta Gorda.

Distributed Environmental Resources

Mobile foragers lived on this landscape for thousands of years prior to fully developed agriculture. They would have had an intimate knowledge of the rich and diverse resources including abundant freshwater and high-quality farmland (Kennett *et al.* 2020; Prufer *et al.* 2019) which was likely appealing to the earliest farmers who constructed permanent stone buildings during the Late Preclassic. Statistically, all occupants on the Uxbenká and Ix Kuku'il landscape had equal access to high-quality land. However, we argue that access to environmental resources, such as water and high-quality agricultural lands, was possibly controlled by dominants at Uxbenká and later Ix Kuku'il. Subordinates resided on the land by usufruct rights in exchange for part of their production of goods. Part of the production of goods may have included cacao, which grows well in southern Belize (Baron 2018; Stanley 2016). Historically, cacao groves were owned by dominants (Garrison *et al.* 2019) and in southern Belize, dominant-owned cacao groves may have provided the basis for revenue and trade along the transportation corridor.

The greatest distance from a household to water at Uxbenká is less than 400 m and 415 m at Ix Kuku'il. Water is both a critical resource for humans, but also a focal point for social interactions. Households likely visited their local water resource on a daily basis and also interacted with neighbors. For example, within our study area, washing in the river strengthens social bonds among modern Maya women (Baines 2015). Springs are often used in rituals by Maya communities (Tedlock 1992), and among highland Zincanteco Maya communities freshwater springs are shared ritual and household resources for lineage groups (Vogt 2004). In archaeological contexts, wells were a nexus for social interaction within neighborhoods (Hutson 2016). Therefore, while not statistically significant in terms of settlement selection due to their widespread availability, we believe accessibility to rivers and springs in the past may have acted as a mechanism for social cohesion and solidarity among neighbors and kin groups. The abundance of water on the Uxbenká and Ix Kuku'il landscape would have been attractive to early and later settlers alike.

Between the earlier and later settled households, the steepness of hillslopes was similar at Uxbenká and Ix Kuku'il. Hilltop defensibility, breezy settlement locations, and general viewshed were important for all households based on the similarity in household hillslopes. Hillslopes across the landscape do vary. At Uxbenká, households are on hills with slopes varying from 9 to 27°. Hillslopes are slightly steeper at Ix Kuku'il because it is located farther north, deeper in the foothills of the Maya Mountains. Hillslopes at Ix Kuku'il vary from 12 to 29°.

Bedrock lithology, soil classification, or hillslope susceptibility to erosion did not impact household location at either Ix Kuku'il or Uxbenká, likely because of the homogeneity of the high-quality soils and bedrock on the Toledo Uplands. At Uxbenká, households were constructed equally on mudstones (composed of sandstone, siltstones, and mudstones of similar lithologies) and mixed limestone and shale bedrocks (Fig. 10). During pedestrian surveys, we rarely identified limestone architectural construction blocks. We argue that household construction was often on mudstone bedrock because it provided easily accessible building materials proximate to the most fertile soils favored for higher agricultural yields.

In southern Belize, the landscape and quality of soils played a major role in the placement of ancient Maya communities. Most of the political centers are situated in fertile valleys and along the foothills of the Maya Mountains. Six ancient Maya centers are on the Toledo Uplands even though the Uplands constitute only 6% of the southern Belize landscape (Dunham 1990:169). Modern comparative studies indicate that agricultural (specifically maize) yields on the landscape surrounding Uxbenká were high (Pacheco-Cobos *et al.* 2015), with an average yield of 1830 kg/ha. Comparatively, maize yields in Mexico varied from 1228 kg/ha to 1787 kg/ha (Cortez 2016:40) and from 250 kg/ha to 1700 kg/ha in the northern Yucatan (Pacheco-Cobos *et al.* 2015). Among the occupants of Uxbenká and Ix Kuku'il, high-quality soils are ubiquitous across the landscape, and emerging dominants would have ceded the use of some of the lands as concessions to subordinates in exchange for labor in agriculture and for public works. Other concessions were likely the offer of collective security, access to imported goods traded along the corridor, and participation in collective events.

Shifts from the IFD to the IDD: Land Tenure and Inherited Inequality

Land tenure and inherited inequality were key considerations in determining the location and degree of inequality at Uxbenká and Ix Kuku'il. The population history of southern Belize differs from other Late Preclassic and Early Classic transitions elsewhere in the Maya region (*e.g.*, La Joyanca; Arnauld *et al.* 2017b). At Uxbenká, small populations were present during the Late Preclassic. Massive landscape modifications occurred between 175 and 400 CE (Culleton *et al.* 2012; Prufer and Thompson 2016), evidenced by the emergence of networked elites and a focus on dynastic leadership rather than corporate leadership strategies (Prufer *et al.* 2011; Moyes and Prufer 2013). Monuments carved well before 400 CE indicate that networked dynastic leadership was present at Uxbenká at least a century prior to any other polity in the region. This also corresponds with the construction of public architecture in local districts, signaling a shift from the IFD to the IDD as dominants harnessed labor for these constructions in the Uxbenká epicenter and district seats (Prufer *et al.* 2017) and likely the production of agricultural goods (*i.e.*, cacao) being traded through exclusionary networks. These same processes occurred at Ix Kuku'il but several centuries later than at Uxbenká with the initial foundation of Ix Kuku'il adhering to the predictions of the IFD and shifting to the IDD after 400 CE.

Ix Kuku'il's development follows the regional trends of southern Belize, with little evidence of Preclassic occupations, small but growing populations during the Early Classic, and a massive population expansion during the Late Classic (Thompson and Prufer 2019). At Ix Kuku'il, the earliest households were spread out across the landscape adhering to the tenets of the IFD. After 400 CE, population expansion occurred across Ix Kuku'il. The growth of Ix Kuku'il after 400 CE coincides with the cessation of massive hilltop modifications in the Uxbenká epicenter. Two of the Ix Kuku'il district centers, P 32A and P 51A, were founded during the Early Classic II, during the transition to increased autocratic power. Over time, the earlier households developed into the largest households, acting as centers of social interaction with local dominants residing within the dispersed district centers. The dominants likely embodied more power and authority through inherited wealth and benefitted from land tenure and the ability to exploit labor of subordinate members of the polity. This likely resulted in a number of local dominant households that also functioned as district heads (see Fig. 3). By the Late Classic, these dominant households were dispersed across the landscape, providing concessions of public and administrative services and spaces to hinterland communities, while simultaneously creating a panopticon effect of surveillance (Bentham and Božovič 1995). We link these demographic events to a shift from the IFD to the IDD at Ix Kuku'il as the population grew during the second half of the Early Classic and into the Late Classic.

In our case study, the shift from the IFD to the IDD is linked to land tenure and inherited inequality. Dominant kin groups accrue wealth through labor mobilization and land improvements. Over centuries, these settlers improved the land (ala, the *Allee* affect) with hilltop modifications, creating public but defensible spaces, gaining knowledge of the land, and maintaining local springs. These improvements increase patch quality and provide resources for dominants to reduce out-migration away from the corporate (kin) group to other land or communities through concessions and provisioning of public goods and services (*sensu* Blanton and Fargher 2008). Ultimately, this results in continued growth near the earliest established households.

There is little evidence for agricultural land improvements such as terracing (Chase and Weishampel 2016; Macrae and Iannone 2011; Murtha 2002), raised beds, or plots for farming that are seen at other ancient Maya centers (Beach *et al.* 2019). This is likely due to the quality of the soil and rapid pedogenesis. However, there is evidence for water management at Uxbenká and Ix Kuku'il, which also improved habitat suitability. Large, now sediment-infilled, check dams are present at Uxbenká (Culleton 2012) and several check dams and long walls perpendicular to streams are present at Ix Kuku'il. A stone-lined well is located at the base of Uxbenká group A. Other regional investments in water features include a tunneled entryway to a well-maintained spring located in a ceremonial context under the main plaza of Muklebal Tzul (Prufer and Kindon 2005). These features for controlling water may have been constructed as public works projects to manage water flow in flood conditions (*i.e.*, check dams) or for dry season water procurement through wells and *cuxlin ha'*. Since these features are located outside of the epicenter, they may have been commissioned by individual districts.

Today, *cuxlin ha*' are cleaned and maintained by kin and neighborhood groups. They are primarily used by the corporate group, but passersby may use the springs as well, transforming the private spring into a public good. Maintenance includes expanding the spring for better water flow, keeping debris out of the spring, constructing small walls around the spring, and placing rocks in the adjacent stream for washing clothing and dishes. The proximity of all households to water and the maintenance of springs align with resource preferences and the *Allee* effect, with land improvements directly associated with land tenure.

At Uxbenká and Ix Kuku'il, public buildings including ball courts, small temples, and eastern triadic shrines are dispersed across the landscape. Public spaces are also located in districts and near the earliest households and the labor needed for the construction of public spaces was mobilized by emerging dominant households. The district seats at Uxbenká, P 25E, P IA, and P L are connected to public spaces and are among the earliest dated households (Fig. 4; Fig 5; Prufer *et al.* 2017). Similar trends are present at Ix Kuku'il based on our limited excavations. Early households include P 16 and P 51A near Group A, and P 32A and P 19B, both of which have small temples.

Labor mobilization to construct public spaces was controlled by dominants in both the monumental epicenter and the districts. While the epicenter was likely under the control of an apical dynastic lineage, districts were likely controlled by other ranking lineages. Over centuries as households expanded, some kin groups fissioned off onto nearby hilltops, resulting in the dispersed settlement patterns at Uxbenká and Ix Kuku'il (Thompson *et al.* 2018). There were likely also immigrants moving into the area (Trask *et al.* 2012), particularly early in the polity's history when more land would have been available. Ranking lineages continued to maintain tenure over land and production, using labor extracted from nearby households. The subordinate households adhered to these demands, receiving concessions of usufruct land rights, security, and access to public spaces and goods. While kin-selection is not always advantageous (see Bliege Bird and Bird 1997), the proximity of lineal groups directly influences kin selection and wealth accumulation (Cronk 1991).

Subordinates living in hierarchically complex polities also maintained residences and had families. Above we suggested that these are corporate groups interspersed within districts, frequently forming their own neighborhoods even though they may have been economically obligated to surrender a portion of the goods they produced in exchange for the concession of usufruct land access, security, and group membership. Today, lineal descent and residence patterns reflect kin-related groups that are spatially clustered (Boremanse 1998; Vogt 1965; Wilk 1997); similar patterns have been reconstructed for the Classic Period (Hage 2003). Kin-selection as an underlying structure for the transmission of land tenure existed in colonial Yucatan (Restall 1999) and inheritance from fathers to both sons and daughters has been documented in early Colonial (1521 - 1821 CE) Mexico (Witschey 2013). In some communities, it is not so much land as land access and tree crops that are inherited (Wilk 1997). Inheritance as a means for transmission of rights to land has also been hypothesized for ancient Maya society (LeCount *et al.* 2019; McAnany 2013). At Uxbenká and Ix Kuku'il, related subordinate families living in proximity to kin and neighbors likely formed cooperative networks to assist each other in tasks such as farming and house building. The modern practice of reciprocal labor, or *usk'inak'in* ("a day for a day") in Mopan Mayan, is common among neighbors and kin groups (Baines 2015:60; Downey 2009; Wilk 1997) with the primary exchange being reciprocal labor and group meals. However, kin selection can also result in one offspring being favored over others for the intergenerational transmission of wealth (Clech *et al.* 2019), leading to conflict. With limited resources, such as land, disaffected offspring may opt to fission off forming their own household units on patches of land further away from their kin, leading to the formation of new communities. These processes may help explain the expansion of the settlement systems across the landscape and development of Ix Kuku'il as an independent polity.

To summarize, the high agricultural productivity and availability of water in the Toledo Uplands meant that even those living in peripheral areas would have access to arable land through usufruct rights. At Uxbenká, key land parcels near the transportation corridor controlled by district seats increased household wealth; they also controlled the labor necessary to make those lands productive. At Ix Kuku'il, harnessing labor as a social resource was important in household decision-making. Early settlers, who developed into local dominants through inherited inequality and land tenure, provided concessions to later households encouraging them to reside nearby, adhering to the tenets of the IDD. However, because kin selection and lineal descent groups are commonly practiced among ancient and modern Maya communities, aspects of the IFD remain at play as expanding households had flexibility in where they chose to settle. Not only were social resources important for settlement selection, but our findings highlight the continuum and scales of power present in complex societies (Blanton *et al.* 1996) and the flexibility and potential nested nature of the IFD and IDD model wherein a household may maintain some degree of agency (IFD) even within a restricted system (IDD).

Conclusions

The development of inequality through differential access to resources and the intergenerational transmission of wealth occurs within all human societies (Mattison *et al.* 2016). This study assesses the development of inequality in low-density urban communities through the lens of HBE and the IFD and IDD. We found that the earliest settlers of two Classic Maya centers likely founded households on the quality farmland near to water and an established transportation corridor connecting them to the sea and to the Peten. This follows the tenets of the IFD. As communities grew and populations expanded before 400 CE, autocratic power and authority vested in the earliest settlers resulted in patterns aligned with the IDD. We also propose that the IFD and IDD should be considered as a continuum with households exhibiting relative degrees of wealth and power across time and space.

Social relationships deeply constrained household decision-making and settlement selection in the past. Specifically, social resources and relationships, including access to a transportation corridor, land tenure, kin selection, cooperation, and the transmission of wealth, impacted household location at both Uxbenká and Ix Kuku'il. Dominant households dispersed across the landscape in district seats, likely the kin of subordinate households, influenced settlement choice, encouraging lower status kin to reside closer to them and within their political sphere, perhaps using social relations and networks as a controlled resource.

We evaluated the influence of resources on settlement decision-making over time and found that none of the five environmental suitability variables (distance to water, bedrock, soils, erosion, and slope of the terrain) impacted settlement decision-making at Uxbenká or Ix Kuku'il with statistical significance. These results are likely due to the highly productive soils of the Toledo Uplands, and a plethora of freshwater sources, including streams and freshwater springs, resulting in widespread access to good farmland and water for all households likely through usufruct rights. However, other studies in areas of patchy or uneven distributions of resources found the variations in the environment were key to settlement selection (Jazwa *et al.* 2016; Lane 2017), highlighting the heterogeneity in human behaviors and the importance of local environments and resources on human behaviors.

Archaeologists can apply these models to their study given that they have comparable datasets, which would include numerous data points with known occupation dates, and measurable suitability variables. Here, our data points were plazuelas and we used nine suitability variables. The determination of suitability variables, representative of social and environmental resources, is flexible among different social, temporal, and environmental conditions in both the IFD and IDD models. Other studies evaluated measurable environmental variables including water, land and soil quality, slope of the terrain, elevation, temperature, and faunal abundance in a variety of spatiotemporal contexts (Bartruff *et al.* 2012; Jazwa *et al.* 2013; Kennett *et al.* 2006; Moritz *et al.* 2014; Lane 2017; Smith and Winterhalder 2003; Winterhalder 2002; Winterhalder *et al.* 2010). However, few of the previous studies evaluated social resources through measurable suitability variables. As this study shows, social variables, such as kin selection, land tenure, the role of cooperation to negotiate access to resources, territoriality (Codding *et al.* 2019), investing in the built environment (Prufer *et al.* 2017), and the influence of despotic leaders or (kin) groups on other social formations (Bell and

Winterhalder 2014), are an integral aspect in household decision-making and settlement selection.

This case study of the IFD and IDD among the Classic Maya highlights household decision-making processes that we experience today. Under the IDD, people may be restricted in where they choose to live based on economic forces, legal restrictions, and land tenure norms. But within these constraints, there is generally some flexibility in where households can be situated. In general, households have an interest in living in places that facilitate economic opportunities, access to necessary resources, proximity to kin and other community members, and security. In this way, the processes of household decision-making in the past are applicable to modern contexts.

Key results of this study—the heterogeneity of settlement selection, the importance of social relationships including cooperation and kinship on household decision-making, and the development of inequality over the centuries—are applicable to the evolution of agrarian hierarchical societies in the past and today. Across the Maya lowlands, inherited inequality is well-documented within the monumental epicenters. But how subordinates responded to inequality and the impacts of inequality on land tenure and settlement location has been less studied. Our findings are unique in evaluating how social relationships, which are often difficult to detect in archaeological contexts, constrained household decision-making in the past.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s10816-020-09505-3.

Acknowledgments We thank the Belize Institute of Archaeology (J. Morris, director) for permission to conduct research at Ix Kuku'il and Uxbenká. We are indebted to the many individuals who participated in fieldwork and analysis related to this study, a list to long to enumerate here. In particular, we thank J. Jordan, J. Thompson Jobe, B.J. Culleton, M. Williams, D. Enigk, C. Meredith, and P. Przystupa. We thank the co-directors of research at Uxbenká (led by K.M.P.) D.J. Kennett, B. Winterhalder, and R. Zarger. Three anonymous reviewers and L. Traxler, B. Houk, J. Boone helped make this paper stronger, although any errors remain the responsibility of the authors. This research would not have been possible without the support and collaboration of the people and leadership of the Mopan Maya communities of Santa Cruz (Uxbenká) and San Jose (Ix Kuku'il), and, respectively, the Uxbenká Kin Ajaw Association (UKAA) and the Green Creek Farmer's Cooperative.

Author Contributions A.E.T. and K.M.P designed and conducted the study; A.E.T. analyzed the spatial data; K.M.P. and A.E.T. conducted the statistical analysis; A.E.T. wrote the paper, with contributions from K.M.P.; A.E.T. and K.M.P. revised the paper for publication; A.E.T. produced all figures and tables.

Funding Data used in this study was funded by the National Science Foundation (BCS–DDIG-1649080, K.M. Prufer and A.E. Thompson; BCS-0620445, K.M. Prufer; HSD-0827305, K.M. Prufer), the Explorer's Club of New York Exploration Fund (A.E. Thompson), the UNM Roger's Research Award (A.E. Thompson), and the Alphawood Foundation (K.M. Prufer).

Data Availability All data used in this study are available in the main text and supplementary materials.

Compliance with Ethical Standards

Conflict of Interest The authors declare that there are no conflicts of interest.

Code Availability All code is available in the Supplemental Materials (S-3, S-4, and S-6).

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