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Comparing geostatistical analyses for the identification of neighborhoods, districts, and social communities in archaeological contexts: A case study from two ancient Maya centers in southern Belize

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ABSTRACT

Ancient communities are composed of social units at varying scales although these units and the geospatial methods used to define them are rarely discussed in the archaeological literature. Recent studies emphasize the presence of neighborhoods and districts in low density urban communities, increasing the need for more discussion on how these units are defined and measured. We use new and previous field and remote sensing settlement survey data of two Classic Period (AD 300–900) Maya centers located in southern Belize, Uxbenká and Ix Kuku'il, and compare several geostatistical and geospatial methods to identify the presence of neighborhoods and districts. We found that results vary based on the method and linkages they use, therefore the methods used in similar analyses will significantly impact the archaeological interpretations of settlement distributions. Using multiple methods for the identification of neighborhoods, districts, and social units within archaeological contexts enables more holistic interpretations of settlement distributions.

1. Introduction

Using geostatistical analyses to recognize social groups in the archaeological record has increased our understanding of how people organized themselves across the landscape. Identifying neighborhoods and districts, as well as smaller social units (i.e. kin-groups) within ancient communities represents a challenge to reconstructing social relationships (Hare and Masson, 2012) but remains significant to understanding and interpreting ancient social organization as communities were "usually divided into small and larger units directly under the control of certain individuals" (Kurjack, 1974: 6). Analyses of larger scale settlement patterns integrated with household archaeology allow archaeologists to form a more complete picture of the complex society evolution (Ashmore, 1981; Earle and Kolb, 2010; Tourtellot, 1983) and to comparatively examine the spatial and temporal relationships between communities (Bevan and Conolly, 2006; Bevan et al., 2013a; Canuto and Bell, 2013; Fash, 1983; Hassan, 1978; Hutson et al., 2016b). The study of interactions between residential groups and sociopolitical organization is an integral part of understanding modern urban landscapes and is relevant to ancient and modern societies alike.

In this study, we employ several geostatistical methods for the identification of clustered settlements that we interpret as social communities including neighborhoods and districts, using datasets from two well documented ancient Maya centers in southern Belize, Uxbenká and Ix Kuku'il. We use survey and geospatial data to analyze differences in settlement patterns and distributions of households across a landscape and link them to potential reasons for why such differences may occur within similar geographic and temporal settings. Specifically, we ask, 1) *How do different geostatistical analyses reflect scales of community interactions and distributions?* And, 2) *Are there differences in settlement distributions across the landscape at two contemporary Late Classic communities? If so, what causes the differences in settlement patterns?* Differences in settlement patterns reflect variations and changes in community development and organization across both space and time, which are influenced by both local environments, shifts in leadership strategies, and the time of site foundation; through the comparison of intraregional settlement patterns, we explore variations and diversity in semi-urban developments between two ancient Maya communities located only 6.7 km apart in similar geophysical landscapes in the southern foothills of the Maya Mountains (Fig. 1).

1.1. Settlement density and neighborhood analyses in Mesoamerica

The observance of socially and spatially defined neighborhoods and districts in archaeological contexts is relatively recent (Arnauld et al., 2012a; Hutson et al., 2016b; Smith and Novic, 2012; Smith, 2010,

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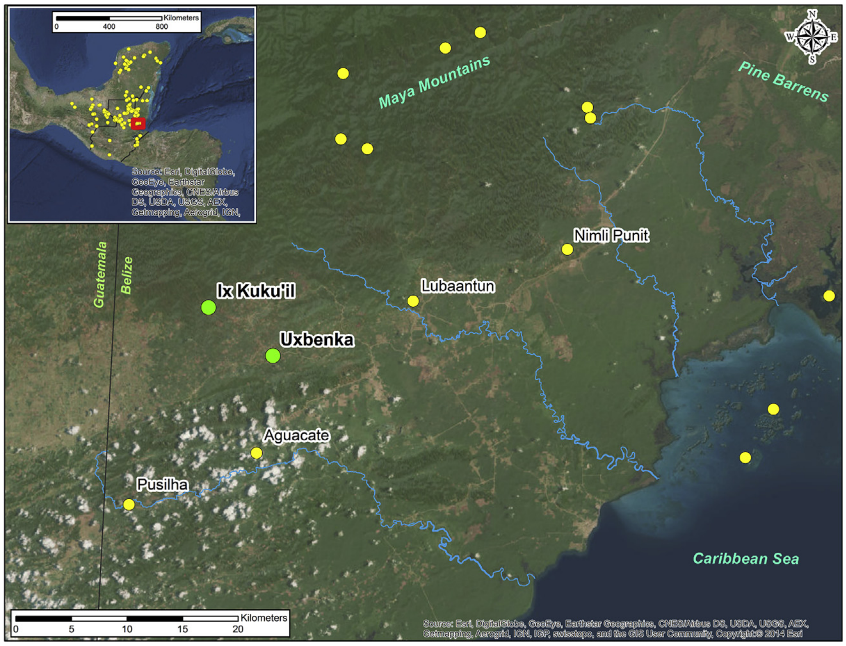

Fig. 1. Map of southern Belize showing regional ancient Maya centers. Sites mentioned in the text are labelled with an emphasis on Ix Kuku'il and Uxbenká.

2011), but is gaining popularity and driving settlement research to holistically discuss changes in ancient urban and peri-urban landscapes. Neighborhoods are defined as social groups that interact face-to-face on a daily basis and have distinct social and physical characteristics (Smith, 2010, 2011), or have "day-to-day socioeconomic relationships" (Arnauld et al., 2012b: 205). Densely-settled urban centers with multi-room buildings in Mesoamerica, such as Teotihuacán (Gomez-Chavez, 2012; Manzanilla, 2012; Millon et al., 1973; Widmer and Storey, 2012) and Tenochtitlan (Smith, 2010), as well as neighborhood studies across larger landscapes within low-density urban communities have been focal areas of recent studies (e.g., Rio Bec [Arnauld et al., 2012b], Copan Valley [Hendon, 2012], La Joyanca [Lemonnier, 2012], Mayapan [Hare and Masson, 2012], Uxbenká [Prufer et al., 2017a; Prufer and Thompson, 2014], Buena Vista del Cayo [Peuramaki-Brown, 2014], Baking Pot [Bevan et al., 2013a; Hoggarth, 2012], Blue Creek [Houk and Zaro, 2015], Chan Chich [Houk and Zaro, 2015], Chunchucmil [Hutson et al., 2016b], and Caracol [Chase, 2016]). However, with few exceptions such as recent research at Chunchucmil (Hutson et al., 2016b), these studies rarely describe which methods were used to identify or classify archaeological neighborhoods nor compare the distribution to contemporaneous settlements associated with other political centers located within the larger geophysical/geopolitical landscape or incorporate discussions of multi-scalar communities, such as districts which are composed of multiple neighborhoods.

Districts can include higher-status residences and typically incorporate significant investments in landscape alteration, and/or public political or religious architecture (Chase, 2016; Prufer et al., 2017a; Smith, 2010, 2011). Districts have political, economic, and religious functions and are sociopolitical centers of gravity for nearby neighborhoods. A few studies have compared material culture (Jordan and Prufer, 2017) including architectural variation (Fash, 1983; HutsoHutson et al., 2016b; Lemonnier, 2012) between neighborhoods and districts. Similarly, comparative geostatistical analytical methods in these regards are not often discussed.

In archaeological research, the spatial identification of neighborhoods and districts are used in discussions of social groupings; however, in general, neighborhood analysis is still relatively understudied with little in-depth analysis or interpretation (Smith, 2011: 52). Although neighborhoods have been identified at several ancient Maya centers (see above), the presence of distinct district centers has seldom been discussed in the Maya region, with the exception of Caracol (Chase, 2016), Chunchucmil (Hutson et al., 2016b) and Uxbenká (Prufer et al., 2017a) [though other scholars allude to these ideas]. Studies of settlements as social units in the Maya lowlands are increasingly common (Arnauld et al., 2012a; Ashmore, 1981; Ford and Fedick, 1992; Healy et al., 2007; Lohse and Valdez, 2004; Montmollin, 1995; Robin, 2003; Willey, 1965), however, they uncommonly incorporate geospatial and geostatistical analyses of neighborhoods and districts to illustrate settlement histories, or to link those locations to critical resources in their local environment. The dearth of geostatistical data on emerging neighborhoods may be, in part, due to the lack of robust chronological histories among settlement groups, full-coverage settlement survey in the region (see Prufer et al., 2017a), or the fact that temporal equivalency often does not directly correlate with spatial proximity (Hare and Masson, 2012; Hendon, 2012); however, advances in remote sensing technology, such as lidar, have the ability to rapidly change survey coverage and the identification of archaeological features across the landscape (Chase et al., 2011, 2012, 2014, 2016; Chase and Weishampel, 2016; Doneus et al., 2008; Ebert et al., 2016; Evans et al., 2013; Golden et al., 2016; Harmon et al., 2006; Hutson et al., 2016a; Lasaponara et al., 2011; Loughlin et al., 2016; Macrae and Iannone, 2016; Magnoni et al., 2016; Prufer et al., 2015; Reese-Taylor et al., 2016; Rosenswig et al., 2013; Štular et al., 2012; Thompson and Prufer, 2015; Yaeger et al., 2016).

In contrast, we test for the presence of clustering of ancient households using several different statistical analyses in our study. None of these analyses directly accounts for the chronology of the settlement groups, but rather focuses on their broader geospatial location across the larger geopolitical landscape during the same broader time period. All households at both Classic Period Maya centers, Uxbenká and Ix Kuku'il, have Late Classic (AD 600–800) components (Prufer et al., 2017a,b; Thompson and Prufer, 2016). Thus these analyses are focused on geospatial differences between centers based on the Late Classic landscape.

1.2. Regional background

Southern Belize is located in the southeastern Petén and is geographically circumscribed with swampy *bajos* to the south, the Caribbean Sea to the east, unfavorable pine forests to the northeast, and the Maya Mountains to the north and northwest (Fig. 1) (Jamison, 1993; Leventhal, 1990, 1992). The region was occupied thousands of years prior to the foundation of Maya centers based on data indicating continuous human presence since before the Archaic Period (8000–2000 BC) (Prufer et al., 2017b) including Middle Preclassic (1000–400 BC) agricultural features (Culleton et al., 2012). By the end of the Late Preclassic (400 BC – AD 250), small farming villages, including Uxbenká, were present (Prufer et al., 2011). During the Early Classic (AD 250–600), Pusilha, Nim Li Punit, Aguacate, and Ix Kuku'il (Fig. 1) were founded as regional populations grew (Irish and Braswell, 2015; Novotny, 2015; Thompson and Prufer, 2016). Population density peaked during the Late Classic (AD 600–800) and new centers, including Lubaantun and Xnaheb, were formed (Dunham, 1990; Dunham et al., 1989; Hammond, 1975; Irish and Braswell, 2015; Jamison, 1993, 2001). Political disintegration occurred during the Terminal Classic (AD 800–1000) (Aquino et al., 2013; Culleton et al., 2012), with little evidence of Postclassic occupation in the region (Braswell and Prufer, 2009; Houk, 2015; McKillop, 2004; Wanyerka, 2009).

1.2.1. Archaeological background of Uxbenká and Ix Kuku'il

Uxbenká and Ix Kuku'il are located in the southern foothills of the Maya Mountains. The core areas of each site are located 6.7 km apart, with hinterland households populating the homogenously hilly landscape between the political centers. The ancient Maya in this region favored building on hilltops, which provided natural defenses, a cool breeze, a flat area for household activities, and are less suitable for farming (Prufer et al., 2017a). Hillslopes are ideal for farming and valley bottoms flood frequently during the monsoon season, making them less ideal for residential areas.

Uxbenká is a medium-sized Classic Maya (AD 250–900) polity and extensive settlement survey and excavations (see Culleton et al., 2012; Kalosky and Prufer, 2012; Prufer et al., 2011; Prufer et al., 2015; Prufer and Thompson, 2016; Thompson et al., 2013) have resulted in a high-precision chronology, which combines ^{14}C AMS radiocarbon and ceramic dates (see Jordan and Prufer, 2014; Prufer et al., 2017a), for the occupation of Uxbenká over eleven centuries. The first masonry structures appeared during the Late Preclassic, and massive anthropogenic landscape modification occurred in the first part of the Early Classic (Prufer and Thompson, 2016) and were followed by a period of fluorescence during the Early and Late Classic periods (Prufer et al., 2017a). Uxbenká was abandoned by AD 830 (Aquino et al., 2013; Culleton et al., 2012). Settlement survey and household excavations have been a priority of the Uxbenká Archaeological Project (UAP) and are key to understanding the variations within and among domestic areas. Nine administrative areas or elite residential spaces (Groups) and more than 90 households (Settlement Groups or SGs) have been identified at Uxbenká and suggest multiple nodes of power existed within the political center, as the administrative areas are spread out across the landscape (Fig. 2a and b); test unit excavations have been conducted in more than 40% of the settlements and all of the administrative areas (Prufer et al., 2015, 2017a; Prufer and Thompson, 2014; Thompson and Prufer, 2015).

Like Uxbenká, Ix Kuku'il has undergone extensive settlement survey. These findings documented eight administrative plazas and more than 60 residential areas (Fig. 2c and d) with decentralized administrative areas and nodes of power across the landscape (Thompson and Prufer, 2016). Ceramic assemblages and ^{14}C radiocarbon dates indicate that Ix Kuku'il was founded around AD 400 during the Early Classic with population expansions into the Late and Terminal Classic; as is typical of the region, there is no evidence of Postclassic occupation at Ix Kuku'il. At Ix Kuku'il, 10% (n = 7) of the settlement groups and 37.5% (n = 3) administrative groups have undergone test unit excavations (Thompson and Prufer, 2016). The extensive survey data at both sites, in conjunction with chronological markers for 48 settlement groups at Uxbenká (Prufer et al., 2017a) and 29 households at Ix Kuku'il, enables a micro-regional comparison of settlement distributions between the two ancient communities.

Based on these chronologies, Uxbenká and Ix Kuku'il had centuries of contemporary occupation, although Uxbenká was founded several hundred years before Ix Kuku'il. The longevity of Uxbenká's occupation and political regime likely influenced the development of its settlement system, resulting in the manifestation of neighborhoods and districts founded by early despots and incipient elites during the Late Preclassic period (Prufer et al., 2017a). Comparatively, Ix Kuku'il's shorter chronological sequence appears to have resulted in a vastly different settlement system that lacked a hierarchically structured settlement system and geospatially defined neighborhoods and districts possibly due to the fact that regional elite authority was already well-established by the foundation of Ix Kuku'il during the Early Classic. Though our analysis focuses on the Late Classic landscape, this was influenced by Late Preclassic and Early Classic geopolitical strategies and settlement patterns. To test these hypotheses, geospatial statistics are used to compare the distributions of all settlements across the landscape, most of which are assumed to date to the Late Classic, as a testable indicator of differences in settlement patterns between two contemporary communities during the apex phases of occupation at these Classic Period Maya centers. These results encourage a discussion of the impact of methodology in our identification of ancient settlement clusters and intra-site social communities.

2. Methods

Remotely-sensed lidar (see Prufer et al., 2015; Thompson and Prufer, 2015) and on-the-ground survey data (see Kalosky and Prufer, 2012; Prufer et al., 2017a; Prufer and Thompson, 2014; Thompson and Prufer, 2016) form the basis for statistical tests conducted in two software programs, ArcGIS and R, to geospatially analyze and compare the ancient communities of Ix Kuku'il and Uxbenká. We employ several methods to test the geospatial relationships of household distributions at Ix Kuku'il and Uxbenká. These methods include: Nearest Neighbor Analysis (NNA), Kernel Density (KD) Analysis, Directional Distributions (DD), and Ripley's K Function in ArcGIS, and hierarchical and k-means clustering in R as well as cluster validation using the Nbclust package (Charrad et al., 2014).

All analyses used the center point (northing and easting) within each settlement group as the input for the geospatial location of each settlement group (See SI Table 1; it is a policy of the Belizean Institute of Archaeology to not divulge exact UTM locations of archaeological sites, however our grid presentation allows replication of the results.) Data points should be of similar function, time period, and be from similar landscapes (Bevan and Conolly, 2006). Data points in this paper have the same function (residential groups), are from the same time period (Late Classic), and are situated on similar, homogenously hilly, landscapes creating homogeneity among the inputs for the dataset (per Bevan and Conolly, 2006). Therefore, clustered households could represent smaller intra-site social units, such as neighborhoods and districts.

2.1. Nearest neighbor analyses in ArcGIS

The Nearest Neighbor Analysis (NNA) tool in ArcGIS 10.2 Spatial Statistics Tools toolbox calculates the mean observed Euclidean distance between user-selected areas, in this case, settlement groups represented as individual points, as well as the statistical probability of their distributions being clustered or dispersed. This information, calculated from the collected settlement survey data, indicates if households were clustered together or were randomly dispersed across the landscape. If there is a highly clustered NNA, small clusters of households are present, which we interpret as neighborhoods.

Next, a kernel density map was created from the NNA results using the observed mean distance between groups from the NNA; this visualization of the statistical NNA results enables visual identification of

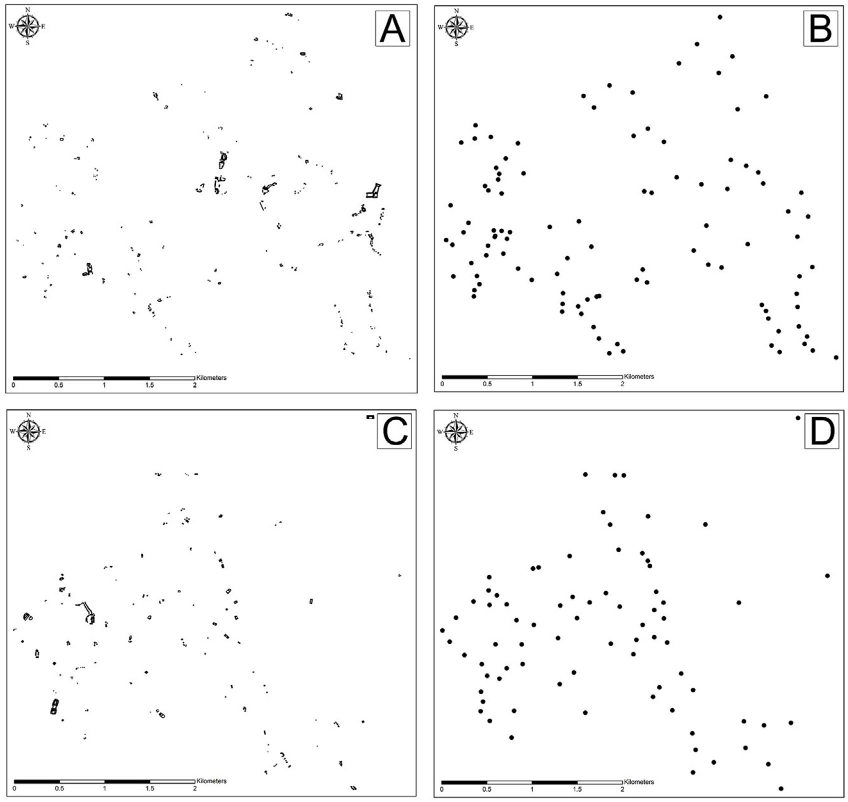

Fig. 2. Settlement maps of documented archaeological architecture for Uxbenká (2a and 2b) and Ix Kuku'il (2c and 2d). Settlement maps on the left (2a and 2c) show the mapped administrative and settlement architecture at each site. Maps on the right show the distribution of settlements based on the center point of each group.

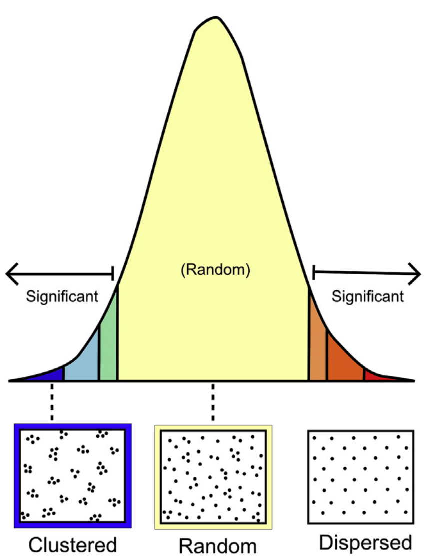

Fig. 3. ArcGIS Nearest Neighbor Analysis (NNA) reflecting the statistical difference between clustered (Uxbenká) vs. random (Ix Kuku'il) and randomly dispersed inputs, in this case settlement groups.

the likely locations of neighborhoods. Our inputs included the observed mean distance from the NNA for the search radius, and the automatically input cell size, square kilometers for the area units, densities for the output values, and planar for the method. The identification of neighborhoods is based on the distance between settlement groups and features that may deter individuals from having face-to-face interactions (Smith, 2010), such as rivers, bodies of water, and high or low relief features.

2.2. Directional Distribution analysis in ArcGIS

DD analysis was conducted on core groups, which contain both administrative and elite residential architecture and were likely district centers, per Smith (2010). The DD tool summarizes the directional trends, dispersion of input features, and central tendencies to create standard deviational ellipses among nearby groups. Using the DD in combination with the NNA and Kernel Density mapping, district centers can be identified. District centers had political, economic, and religious functions and acted as centers of gravity for nearby neighborhoods.

2.3. Ripley's K function

Ripley's K Function examines data point clusters using multiscalar analyses and describes trends over a given area of interest (Bevan and Conolly, 2006; Bevan et al., 2013b). Ripley's K Function is a second-order analysis that determines if the data points exhibit a statistically significant trend of clustering or dispersion at a range of distances using up to 999 permutations. Ripley's K Function also resolves issues with

Table 1
ArcGIS Nearest Neighbor Analysis (NNA) results for point-based inputs for all settlements at Ix Kuku'il and Uxbenká.

Site	Number of settlements	Dataset Type	Nearest Neighbor Ratio	z-score	p-value	Observed Mean Distance (m)	Results
Ix Kuku'il	68	Point	0.976042	−0.404795	0.685629	227.7331	Random
Uxbenka	105	Point	0.83458	−3.24275	0.001184	165.0021	Clustered

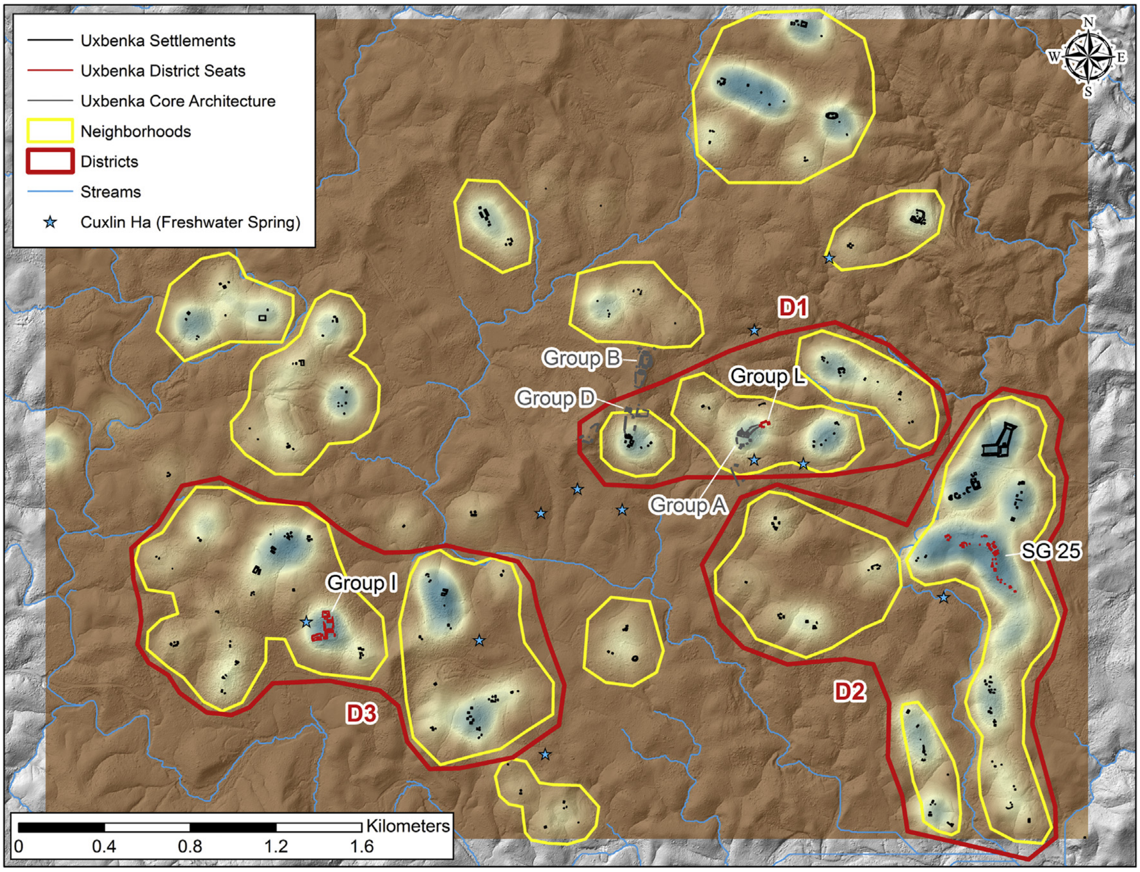

Fig. 4. A settlement map of Uxbenká showing 16 geospatially discrete neighborhoods and three district seats (modified from Prufer et al., 2017a: Fig. 5) based on ArcGIS NNA, KD, and DD analyses. Settlement Groups (SGs) and Groups discussed in the text are highlighted on the map.

boundaries that could influence the results (Bevan and Conolly, 2006). Using the datasets for Uxbenká and Ix Kuku'il, we set the parameters to 20 bands, 999 permutations, and the beginning distance of 0 m with 50 m increments. We did not include a boundary correction and used the minimum enclosing rectangle for the study area.

2.4. Cluster analysis in R statistical software

Statistical analyses in R (v3.3.2, R Core Team, 2015) focused on cluster validation to determine the number of clusters present at each site (see SI Code). Initially, cluster analysis and cluster validation were performed using the combined Uxbenká and Ix Kuku'il datasets to ensure that the sites could be considered geospatially distinct from one another given their close proximity. Subsequent analyses demonstrate differences in settlement patterning within both sites.

For each dataset, cluster validation was performed using the NbClust package (Charrad et al., 2014). The NbClust package calculates 29 indices to determine the optimal number of clusters for a given dissimilarity matrix. Dissimilarity matrices were calculated using Euclidean distance and the k-means method. Cluster number was restricted to a minimum of two and a maximum of twenty. In addition to these analyses, the gap statistic was calculated using the clusGap function as this provided more flexibility than NbClust when determining input parameters. The gap statistic was calculated using 500 Monte Carlo samples. The k-means aggregation method was chosen for all analyses. The optimal number of clusters was determined by examining the number of indices favoring a given number of clusters for each dataset. Based on the estimated number of clusters, determined through cluster validation, settlements were clustered using k-means clustering, complete-linkage clustering, and hierarchical clustering. Hierarchical agglomerative clustering was also performed on the combined dataset using the single-linkage, complete-linkage, and k-means methods.

3. Results

3.1. Nearest Neighbor Analysis in ArcGIS

The NNA results suggest that Uxbenká's households were geospatially clustered into discrete neighborhoods and districts, whereas households at Ix Kuku'il were more randomly distributed across the landscape. The Uxbenká NNA modeled a Z-score of -3.24 (P-value: 0.001184), suggesting a > 99% likelihood that the overall distribution of settlements across the landscape is clustered (Fig. 3) and that this pattern is not random (Prufer et al., 2017a: 59). The mean observed distance between settlement groups at Uxbenká is 165 m, which is a reflection of both settlement choices and topography. The mean observed distance was used to determine the search radius distance for the Kernel Density (KD) analysis in ArcGIS, which produces a map showing increasing buffers around each settlement with a maximum distance of 165 m. If the buffers touch or connect, the settlement groups are less than 165 m from each other and may have been within the same social sphere or neighborhood. The resulting map was employed to visually group clusters of settlements into neighborhoods based on their proximity to each other, density of structures, and geographic boundary features, such as permanent watercourses (Hendon, 2012), that may separate one group from another. While all data points were used in the NNA, outliers were not always incorporated into the visualization of neighborhoods due to unknown social relationships, with nearby settlements that are often separated by waterways (see Fig. 8) (Prufer and Thompson, 2014; Prufer et al., 2017a). Continued settlement survey and updated datasets result in differences in the mean observed

Table 2
Uxbenká's neighborhood and district designations based on ArcGIS NNA geospatial statistics, compared to cluster analysis in R for 3 and 19 groupings. Most of the groups geospatially correlate regardless of method.

Settlement Group	ArcGIS Neighborhood	R K-means Cluster (19)	ArcGIS District	R K-means cluster (3)
1	1	7	N/A	1
3	2	16	D3	1
4	3	10	D3	1
5	4	11	D2	2
6	3	10	D3	1
7	5	8	D2	2
8	5	8	D2	2
9	5	8	D2	2
10	5	8	D2	2
13	4	11	D2	2
14	1	7	N/A	1
18	4	11	D2	2
17	3	10	D3	1
19	3	10	D3	1
20	6	17	D1	3
21	7	17	D1	3
22	8	15	D1	3
23	9	3	N/A	3
24	9	3	N/A	3
25	5	5	D2	2
26	8	15	D1	3
27	8	15	D1	3
28	5	5	D2	2
29	4	11	D2	2
30	10	17	N/A	3
31	N/A	3	N/A	3
32	N/A	3	N/A	3
33	11	1	N/A	3
34	11	1	N/A	3
35	12	15	N/A	3
36	13	18	N/A	2
37	6	15	D1	3
38	13	18	N/A	2
39	13	18	N/A	2
42	11	1	N/A	3
43	11	1	N/A	3
44	11	1	N/A	3
45	12	15	N/A	3
46	N/A	12	N/A	1
47	14	8	D2	2
48	8	15	D1	3
50	2	2	D3	1
51	2	2	D3	1
52	2	19	D3	1
53	2	13	D3	1
54	2	2	D3	1
55	2	13	D3	1
56	N/A	12	N/A	1
57	2	2	D3	1
60	2	19	D3	1
62	3	10	D3	1
63	4	11	D2	2
64	14	6	D2	2
65	14	6	D2	2
66	N/A	6	N/A	2
67	5	6	D2	2
68	5	6	D2	2
69	5	4	D2	2
70	14	8	D2	2
71	5	6	D2	2
72	14	6	D2	2
73	5	5	D2	2
74	1	4	N/A	1
75	1	4	N/A	1
76	15	14	N/A	1
77	N/A	16	N/A	1
78	3	16	D3	1
79	3	16	D3	1
80	3	16	D3	1
81	14	8	D2	2
83	10	17	N/A	3
84	10	17	N/A	3
87	1	4	N/A	1
88	15	14	N/A	1
89	15	14	N/A	1
90	15	14	N/A	1
91	2	19	D3	1
92	2	19	D3	1
93	2	19	D3	1
94	2	19	D3	1
105	2	13	D3	1
106	2	13	D3	1
107	2	2	D3	1
108	2	2	D3	1
109	2	2	D3	1
110	2	2	D3	1
111	2	2	D3	1
112	1	7	N/A	1
113	1	7	N/A	1
114	1	7	N/A	1
115	N/A	16	N/A	1
116	N/A	13	N/A	1
117	16	9	N/A	1
118	16	9	N/A	2
119	16	9	N/A	1
120	3	10	D3	1
121	3	10	D3	1
122	16	9	N/A	1
123	16	9	N/A	1
124	3	10	D3	1
125	1	7	N/A	1
F	7	17	D1	3
I	2	2	D3	1
L	6	17	D1	3
M	5	5	D2	2

distance between settlement groups than have been reported in previous publications (see Prufer and Thompson, 2014; Prufer et al., 2017a), but the overall trends in the settlement distributions (extremely clustered) remains the same throughout several iterations of this analysis with increased datasets.

At Ix Kuku'il the NNA results indicate a random dispersion of settlements with a mean observed distance of 227 m. The NNA results yielded a Z-score of −0.40 (p-value: 0.685629) with a randomly dispersed settlement pattern (Fig. 3; Table 1). We interpret these results to indicate that, when using the NNA, households are not clustered into smaller, geospatially discrete social units. However, other analyses in this study suggest otherwise, emphasizing the importance of using multiple methods to interpret past social communities.

3.2. Directional Distribution analysis in ArcGIS

We performed a Directional Distribution (DD) analysis in ArcGIS on the neighborhoods modeled from the NNA and KD at Uxbenká. The results of the DD indicate three larger groupings, which we defined as districts because they are composed of multiple neighborhoods, have public architecture, and elite residential areas (per Smith, 2010; Prufer and Thompson, 2014; Prufer et al., 2017a). Using these analyses, we grouped Uxbenká settlements into 16 neighborhoods and three districts (Fig. 4; Table 2). District 1's (D1) centers are the Early Classic residential area Group L and associated monumental architecture of Group A (Prufer et al., 2017a; Thompson et al., 2013). D2's center is SG 25 which contains both elite residences and a temple/shrine building. SG 25 was founded in the Early Classic (Prufer et al., 2017a; Prufer and Thompson, 2016; Thompson et al., 2013). D3's center is Group I, characterized by monumental and public architecture, including a temple and a ballcourt, in association with an elite residential area (Prufer et al., 2017a). All three district centers have Early Classic

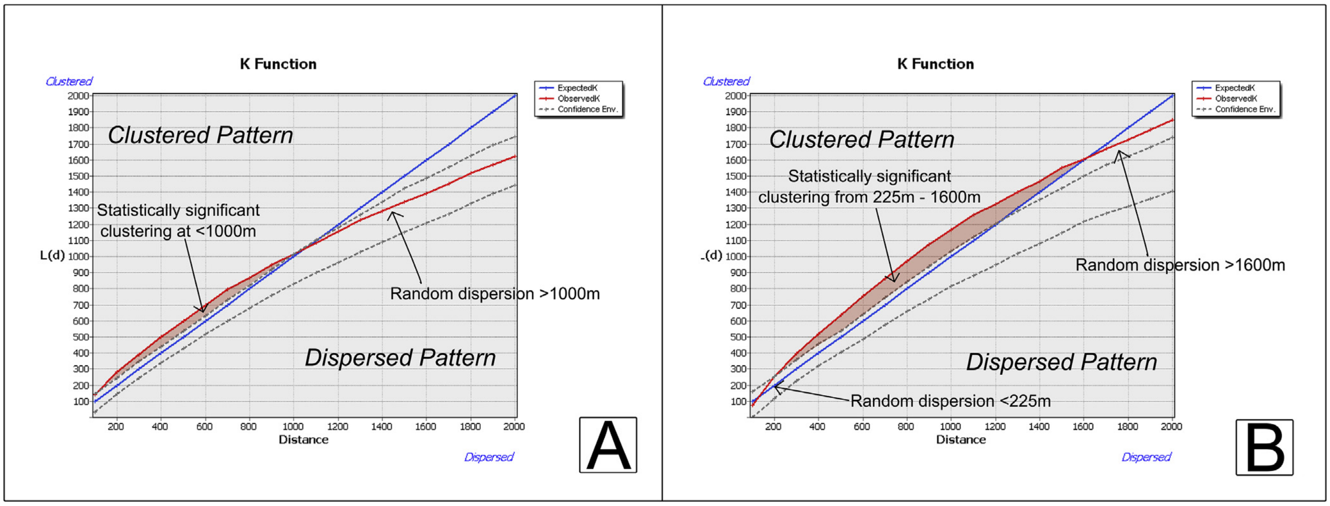

Fig. 5. Ripley's K Function outputs reflecting statistically significant clustering of settlements at (A) Uxbenká < 1000 m and at (B) Ix Kuku'il between 225 and 1600 m. Ix Kuku'il settlements are randomly dispersed at distances less than 225 m and more than 1600 m whereas Uxbenká's settlements are randomly dispersed at more than 1000 m.

Table 3
NbClust Package methods and outputs for the Uxbenká and Ix Kuku'il datasets.

Dataset	Combined	Combined	Combined	Uxbenka	Uxbenka	Uxbenka	Ix Kuku'il	Ix Kuku'il	Ix Kuku'il
Method	Complete	k-means	Single	Complete	k-means	Single	Complete	k-means	Single
KL	10	16	17	5	19	7	9	11	7
CH	2	2	2	20	19	2	20	20	19
Hartigan	3	5	7	4	4	10	4	19	18
CCC	2	2	2	2	2	2	2	2	2
Scott	4	6	8	4	5	10	4	20	19
Marriot	4	6	8	4	5	10	4	5	13
TrCovW	4	3	8	3	3	7	3	3	12
TraceW	4	3	8	4	3	3	4	3	13
Friedman	13	16	20	19	19	14	18	20	19
Rubin	19	16	8	17	19	10	19	16	19
Cindex	5	7	20	2	7	14	4	19	19
DB	2	2	3	12	19	20	19	17	2
Silhouette	2	2	2	2	3	2	19	16	2
Duda	2	2	2	2	2	2	2	2	2
PseudoT2	2	2	2	2	2	2	2	2	2
Beale	2	2	2	2	2	2	2	2	2
Ratkowsky	2	2	2	3	3	3	4	3	14
Ball	3	3	3	3	3	3	3	3	3
PtBiserial	2	2	2	3	3	3	5	3	13
Frey	4	4	4	1	1	1	2	1	4
McClain	2	2	2	2	2	2	2	2	2
Dunn	2	2	2	20	19	2	2	20	2
Hubert	3	6	8	7	3	2	2	5	7
SDindex	2	2	3	6	5	3	5	3	8
Dindex	3	2	8	4	5	3	4	2	7
SDbw	18	18	20	20	20	19	20	20	20
Gamma	2	2	2	20	20	15	20	20	2
Gplus	20	19	2	20	20	15	20	20	2
Tau	2	2	2	3	3	3	3	3	13
Mode	**2**	**2**	**2**	**2**	**3**	**2**	**2**	**20**	**2**

components and continued to be occupied during the Late Classic (Prufer and Thompson, 2014; Prufer et al., 2017a).

A DD analysis was not conducted at Ix Kuku'il because the settlement groups are not geospatially clustered in the NNA.

3.3. Ripley's K function

Ripley's K Function shows the statistically significant trends in point patterns across varying distances, as opposed to the NNA, which uses a single-linkage to analyze the point patterns. The results from Ripley's K at Uxbenká indicate that clustering is significant at all scales up to 1000 m (Fig. 5a). The average household distance based on the NNA is 165 m therefore all settlements fall into clustered groups based on the Ripley's K confidence intervals.

The Ripley's K Function indicated shifting settlement dispersal trends depending on the distance measured. This analysis confirms that point patterns are dispersed at distances from 0 to ~225 m, exhibit statistically significant clustering from 225 m to 1600 m, and have a dispersed pattern greater than 1600 m (Fig. 5b). The average household distance at Ix Kuku'il based on the NNA is 227 m. The Ripley's K results indicate that household clustering is present at Ix Kuku'il, but at larger distances than the average distance between households.

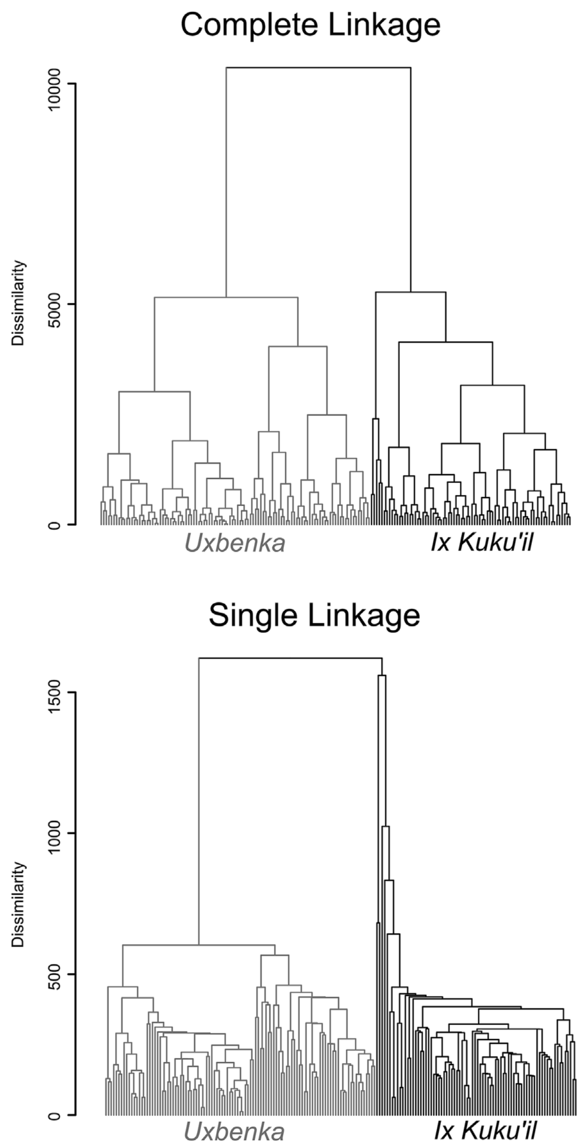

Fig. 6. Dendrogram from R indicating that, spatially, Uxbenká and Ix Kuku'il are different sites based on settlement clustering. Uxbenká's settlement system exhibits structured clustering using both single and complete linkages whereas Ix Kuku'il's settlement system is less structured, as evidenced by the "stepped" appearance of the single linkage method.

3.4. Cluster analysis in R statistical software

Analysis of the combined dataset produced a mode of two clusters when analyzed using the single-linkage, complete-linkage, and k-means methods (Table 3). Hierarchical and strict partitioning clustering utilizing the k-means, complete-linkage, and single-linkage methods all produce two clusters consistently separating Ix Kuku'il and Uxbenká. Based on this result, it is assumed that Ix Kuku'il and Uxbenká are separate sites for further analysis.

When applied only to Uxbenká settlement groups, cluster validation proposes two, three, and 19 or more clusters as the most likely clustering (see Table 3). When gap statistic is computed using the preferred method in Tibshirani et al. (2001) if the 1 standard error range for a maximum exceeds the variance of all data points, a value of one cluster is produced as is the case for the Uxbenká dataset. Although the large standard error in k-values can be partially attributed to the small sample size of Uxbenká settlements, the extremely small range of k-values produced at any number of clusters supports a relatively homogeneous distribution of unclustered settlements.

When applied only to Ix Kuku'il's settlement groups, two, three, and 20 are the most favored clusters numbers (see Table 3). The gap statistic, similar to the Uxbenká dataset, produces the default value of 1 cluster. In both the Uxbenká and Ix Kuku'il datasets, k-means clustering does not appear to produce consistent, meaningful clustering patterns. Although major distinctions are visible at high levels (groupings identified as districts), the small clusters produced at the neighborhood level are generally indistinguishable using k-means clustering (see Table 3).

Hierarchical agglomerative clustering of both groups separates Uxbenká from Ix Kuku'il using k-means, single-linkage, or complete linkage methods. The results of clustering using each method are similar at the local level, but vary considerably at higher levels of organization between single and complete linkages. In each case, however, considerable variation exists between the Uxbenká and Ix Kuku'il clusters. Uxbenká consistently has a more structured and orderly organization between higher level clusters than can be seen in the Ix Kuku'il cluster (Fig. 6). Uxbenká clustering also demonstrates more consistent numbers of settlements at each level of clustering compared to Ix Kuku'il.

The NNA analysis identified sixteen neighborhoods at Uxbenká but none at Ix Kuku'il. The NNA analysis is ideal for smaller spatial groupings (i.e., neighborhoods) [Fig. 7], whereas the cluster validation in R and the DD in ArcGIS spatially correlate groupings of settlements into larger clusters (districts). The R analyses resulted in two or three distinct spatial groups at Uxbenká (Fig. 8) and a variety of results for Ix Kuku'il (Fig. 9; Table 3) but with most analyses creating clusters of 2, 3, or 20 + groupings. The three district groups from the hierarchical clustering identify larger clusters of settlements. Thus, the areas identified as clusters within the cluster validation and hierarchical clustering correspond to the districts identified in the DD (Table 2) and represent larger clusters of settlement groups (Fig. 8).

4. Variations in settlement patterns and community organization based on geostatistical results

Variations in settlement choice and community organization at Uxbenká and Ix Kuku'il are indicated by the differences in results in the NNA, DD, Ripley's K Function, hierarchical clustering, and k-means clustering analyses. Regardless of method, Uxbenká's settlements can be lumped into geospatially discrete clusters of neighborhoods and districts. Ix Kuku'il household distributions vary greatly depending on the method although the results of the Ripley's K and cluster validation analyses trend towards clustering at various levels whereas NNA, hierarchical clustering, and k-means methods do not illuminate a clear pattern in the geospatial distribution of Ix Kuku'il settlements. First, we will address the differences in methods and then discuss the interpretations of the results in relationship to community organization.

How do different geostatistical analyses reflect scales of community interactions and distributions? Geospatial analyses in both R and ArcGIS are mathematical constructs that identify patterns that are interpreted based on the archaeological record. For example, the resulting clusters from the cluster validation and k-means clustering are methods that result in our interpretations of archaeologically identifiable social communities. All methods analyze dispersion trends of input data points, in this case, ancient Maya household locations. However, the NNA and KD approaches allows the user to consider environmental influences and exclude outlaying data points (visually) whereas Ripley's K, cluster validation, and simple mathematical clustering lump all settlements together indiscriminately.

Rarely does archaeological research on settlement patterns account for or incorporate methods involving first-order and second-order processes (Bevan et al., 2013b; Bevan and Conolly, 2006) nor include discussions regarding the impact of linkages used in the analyses. In identifying neighborhoods at Uxbenká, these methods take two

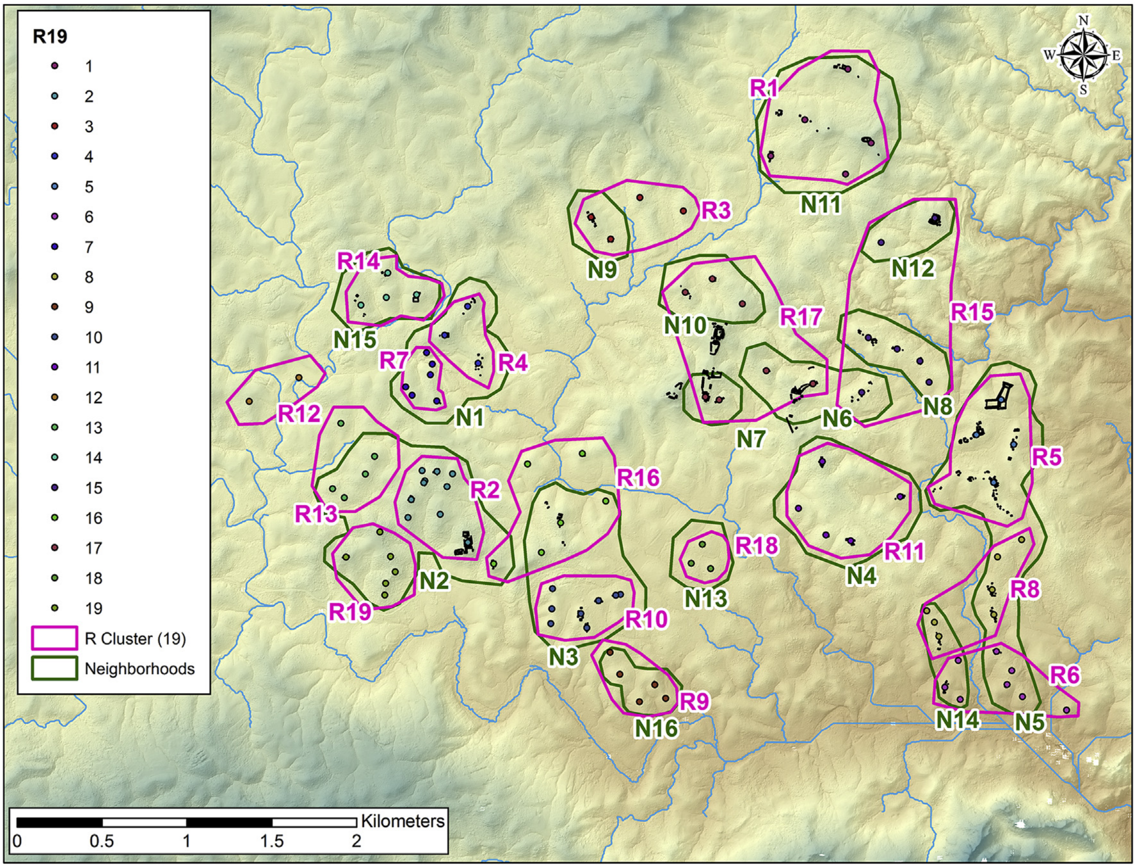

Fig. 7. A comparison of neighborhoods at Uxbenká as identified using NNA (green) and the ideal number of groups based on the NbClust package (pink). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

different approaches: NNA, single-linkage, and hierarchical clustering are agglomerative and tend to lump longer appendages geospatially, resulting in the manifestation of both globular (e.g., N11 in Fig. 7) and longer, thin neighborhoods (e.g., N5 in Fig. 7) whereas the k-means, and complete-linkage methods are punitive of irregular shapes manifesting into globular patterns (e.g., R2 in Fig. 7).

The ideal number of larger groupings from the DD and NbClust results suggest three clusters (Fig. 8). The general trend of these clusters is the same but the NbClust analyses take into account all data points and uses complete-linkages (i.e., the average closest cluster of groupings for each data point). Therefore some of the groups are oddly lumped visually (e.g., SG 118 which using this method is statistically in R Cluster 2 but was more likely a part of the western most social cluster of R Cluster 1/District 3).

4.1. Discussion

This study suggests that the use of different geostatistical methods can result in significantly different models open to multiple interpretations regarding human behavior. For example, if the NNA alone was used on our datasets, it would be assumed that there was no tendency towards Ix Kuku'il settlement clustering. However, the implementation of the NbClust Package and Ripley's K Function indicate that households are clustered in the Ix Kuku'il dataset, although at differing scales, distances, and structures than for Uxbenká. These results emphasize the importance for researchers to clearly describe how they created and defined neighborhoods and to consider using multiple methods for their analyses. Additionally, discussing how intra-site communities (i.e., neighborhoods, districts) are defined will enable comparative approaches across modern and ancient complex societies alike. Returning to our basic research questions:

Are there differences in settlement distributions across the landscape at two contemporary Late Classic communities? If so, what causes the differences in settlement patterns? There are differences in the settlement distributions of Uxbenká and Ix Kuku'il. All geospatial analyses indicate that Uxbenká's settlements are high structured and clustered, whereas the settlements of Ix Kuku'il have a less structured pattern overall, although with some clustering present between households in close proximity to each other (Fig. 9). These differences in the geospatial patterns at Uxbenká and Ix Kuku'il support variations in community organization between the two ancient Maya polities.

It is expected that contemporaneous sites located on similar and proximate landscapes would have similar geospatial patterning of households. Multiple methods indicate that Uxbenká has distinct, structured geospatial clusters, which we interpret as neighborhoods and districts (Figs. 4, 7, 8 and 10). However, Ix Kuku'il settlements are distributed across the landscape in a less structured manner with varying results between the NNA and hierarchical clustering and the Ripley's K Function and NbClust package, and we cannot readily infer the presence of neighborhoods and districts from those data, though forms of smaller social communities were likely present. Further, at Uxbenká, several of these geospatially defined clusters contain public or administrative architecture. Based on Smith (2010), we have defined these as districts seats encompassing multiple neighborhoods. The differences between the spatial organizations of these ancient communities may be influenced by the duration of each site's occupational, which likely impacted access and control of socially and economically important resources, and the temporal occupation of each site in relationship to the overall regional geopolitical history. Early founders of Uxbenká during the Late Preclassic likely had relatively unimpeded access to the landscape, and settled on the most economically productive areas. Moreover, they lived in a region with few geopolitical

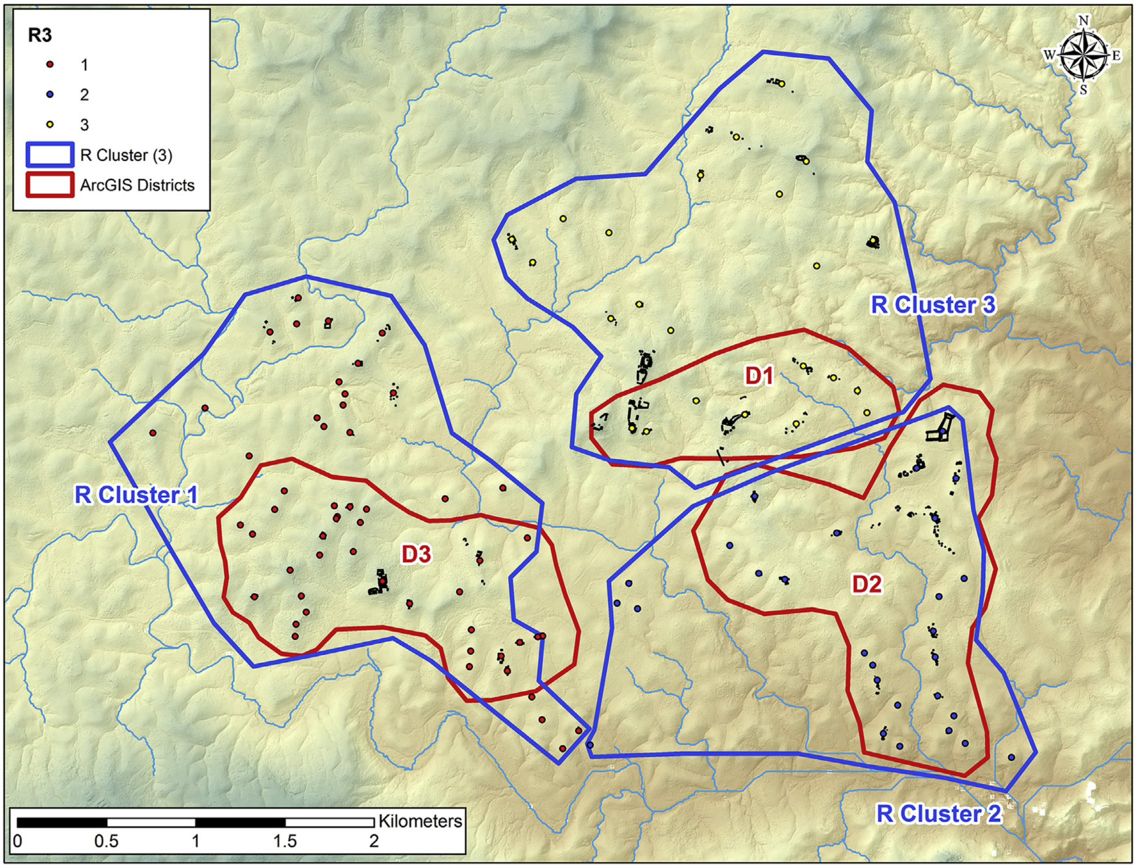

Fig. 8. A comparison of districts at Uxbenká as identified using DD (red) and ideal number of groups based on the NbClust package (blue). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

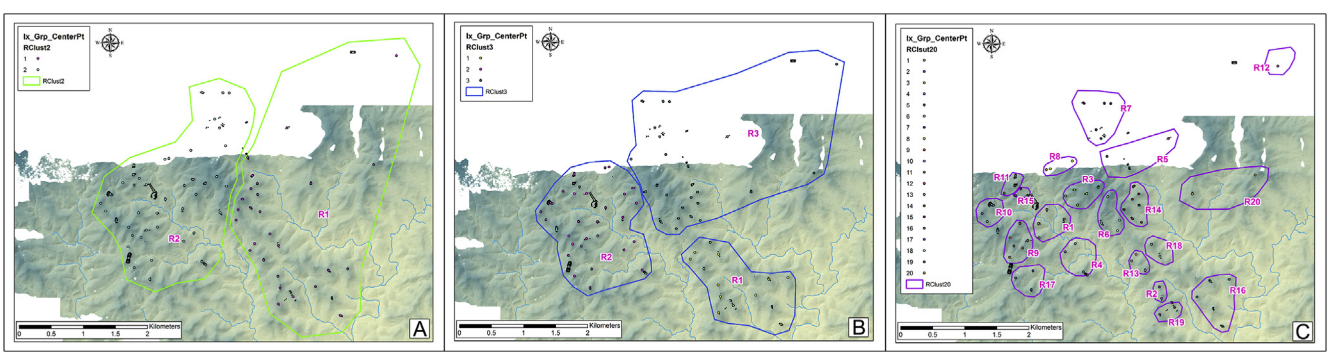

Fig. 9. Visualization of household cluster groupings at Ix Kuku'il based on the NbClust package outputs (A) 2 clusters; (B) 3 clusters; (C) 20 clusters.

competitors, and were able to develop the polity unimpeded by political boundaries. As populations grew, descendants of those who initially settled on socially and economically favorable locations on the landscape likely increased their status as a result of controlling favored resources, a status inherited by subsequent generations (Bell and Winterhalder, 2014; Prufer et al., 2017a). The Late Classic clustering pattern seen at Uxbenká may be part of a long-term “attraction” process (Bevan et al., 2013b) where grouped households attract more occupants over time for a sense of social community and solidarity.

Ix Kuku'il, as a polity, was founded during the Early Classic several hundred years *after* Uxbenká, and residents colonized the landscape under vastly different circumstances. Since Uxbenká and Ix Kuku'il are situated in similar, hilly landscapes, we suggest that the differences in geospatial distributions result from social factors based on the history of occupation at each center. However, Ix Kuku'il is located on an area of transitional bedrock, with silty mudstones in the southern portion of the site and karst limestone in the northern portion of the settlement area and limestone outcrops present across the landscape, whereas Uxbenká is located almost exclusively on mudstone bedrock (Wright et al., 1959). The underlying mudstone of the Toledo Beds are fertile (Keller et al., 2003) and among modern farmers produce higher crop yields (Culleton, 2012) compared to the poorly-drained karstic limestone bedrock to the north of Ix Kuku'il. There, farming is uncommon due to the poorer quality soils and therefore lower crop yields; it is reasonable that the difference in underlying bedrock, and hence soils, influenced settlement choices at these sites.

Despite their differences in clustering patterns, both ancient communities have administrative areas and elite residences situated across the landscape, representing households of varying sociopolitical status with multiple nodes of power akin to heterarchy (Crumley, 1995, 2003). Uxbenká’s power is distributed among three geospatially distinct district seats, which were founded in the Late Preclassic and Early

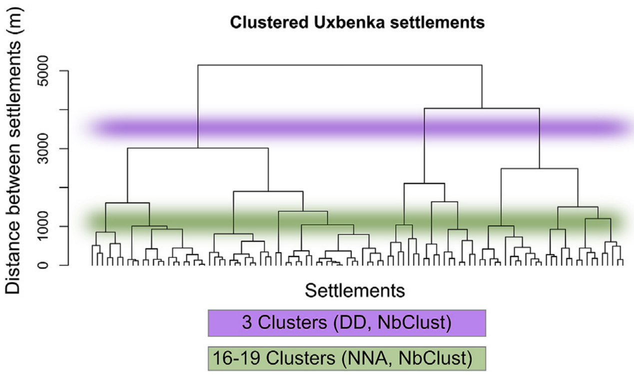

Fig. 10. Dendrogram from Uxbenká's settlement system visually showing how different geostatistical analysis (R, ArcGIS DD, ArcGIS NNA) categorize clusters and therefore influence archaeological interpretations of past social communities.

Classic as small farming houses but later developed into seats of power during the transition to ruling despots (Prufer et al., 2017a). At Ix Kuku'il, administrative areas are also spread out across the landscape (Thompson and Prufer, 2016), but not into geospatially confined and discrete arenas, which is the case at Uxbenká.

The spatial distance between household groups reflects social distance, or the level of interaction among families (Arnauld et al., 2012b; Lemonnier, 2012; Wilk, 1997), wherein the greater the distance between households, the less likely they are to interact on a daily or regular basis. The distance between households at Uxbenká and Ix Kuku'il is visually identifiable in the cluster analysis dendrogram output (see Fig. 6). Ix Kuku'il's settlement pattern is vastly different than Uxbenká's. Uxbenká's dendrogram distribution is a hierarchical, highly-ordered cluster scheme whereas Ix Kuku'il's has no overriding pattern and is generally less structured. Households at Ix Kuku'il and Uxbenká are between 235 m and 165 m apart, respectively, this difference isn't enough to decrease social interactions among closely settled community members. Ethnographically and ethnohistorically, this trend has been noted among modern Maya communities as well (Baines, 2015; Wainwright et al., 2015; Wilk, 1997). In modern Maya communities, reciprocal labor relationships are often formed among family members and neighbors residing in close proximity to each other; this practice, called *usk'inak'in* ("a day for a day" in Mopan Maya), is common during planting and harvesting of maize and house construction (Baines, 2015: 60; Downey, 2009). The close spatial proximity of households is a reflection of social distance and the clustered ancient Maya households may have worked together as neighboring modern Maya households in the region do today.

5. Conclusions

This study addresses differences in geostatistical methods to identify multiscaler social communities such as neighborhoods and districts using a case study of settlement systems at two Classic Period Maya centers in Southern Belize. The geostatistical analyses conducted in ArcGIS and R succeeded in identifying social communities but at multiple scales of social interactions. This study emphasizes the need for archaeological correlates and ground-truthing in conjunction with geospatial data to tease out prehistoric social communities; new technology, such as lidar, can assist with, but not substitute for, on-the-ground survey. Furthermore, when identifying archaeological social communities, discussing how these communities were defined and using multiple methods to analyze settlement systems will enable comparative approaches across modern and ancient complex societies. Using similar methods to analyze social groupings enables interdisciplinary scholars to compare broader processes of urbanization and human settlement systems.

Uxbenká and Ix Kuku'il, although settled on similar landscapes in the southern foothills of the Maya Mountains, southern Belize, have distinct settlement patterns. All of the geostatistical analyses confirm that Uxbenká's households were clustered into structured and discrete neighborhoods and districts, whereas Ix Kuku'il's settlement system was less structured; some analyses (NNA, hierarchical clustering) indicate that Ix Kuku'il households were distributed across the landscape with no statistically significant pattern or clustering while others (Ripley's K Function, NbClust) indicate that clustering was present. Both centers had several nodes of power with decentralized public architecture, likely, in part, due to their location on the landscape. Uxbenká, the earliest Maya center in the region, was founded during the Late Preclassic, and early occupants selected the best patches of land, developing into minor elites who resided in district seats. Later families were pushed to more marginal parts of the land, forming their own kin-based neighborhoods (Prufer et al., 2017a) Ix Kuku'il was founded during the Early Classic around AD 400 and the settlement system was less structured, perhaps in part due to the slight variation in topography or due to the differences in the political landscape during the time of the foundation. Regardless, this study emphasizes 1) the need to discuss how archaeologists are identifying past social communities and the influence that our methods and analyses have on our interpretations and 2) the heterogeneous nature of contemporary communities and diversity in human behaviors.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.jas.2018.06.012.

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