10 CLASSIC PERIOD MAYA WATER MANAGEMENT AND ECOLOGICAL ADAPTATION IN THE BELIZE RIVER VALLEY

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Archaeological research investigating prehistoric water management in the Maya lowlands has identified the diversity and complexity of ancient human adaptations to changing environments and socio-economic landscapes. Our research at the medium-sized Maya center of Baking Pot, located in the Belize River Valley, has explored a water management system composed of a lattice system of ditches located in the southwestern periphery of the site. In this paper, we report the results of spatial analyses of LiDAR remote sensing data that has helped to reveal the nature and extent of this ditch system. Field reconnaissance conducted in 2015 confirmed the presence of ~23.5 linear km of ditches. Residential mounds interspersed between ditched areas were also recorded, perhaps indicating that ditches may delineate spatially distinct settlement clusters. We suggest that water management at Baking Pot became increasingly important during the Late Classic Period (AD 600-900) in the face of population increase, anthropogenic degradation of the landscape, and climate change. Models of settlement and migration derived from human behavioral ecology may provide insights into the role of the ditch system as an adaption that allowed the inhabitants of Baking Pot become more resilient in the face of changing social and natural ecological systems.

Introduction

Water played an essential role in daily life in Classic Period (AD 250-900) Maya society. Archaeological data suggest that, at the most fundamental level, the availability of this important resource impacted the locations people chose to settle and their agricultural schedules. Reservoir systems located in the monumental site cores of major polities in the central Petén and western Belize (Tikal, Calakmul, Caracol), where perennial surface water is scarce across the karstic landscape, supported large populations by offsetting the seasonal availability of rainfall (Wyatt 2014). Water management also played a prominent role in the broader social, political, and ideological systems under which the ancient Maya lived (Barthel and Isendahl 2013; French et al. 2012; Scarborough 1998; Wyatt 2014; Helmke and Zralka 2013). Several researchers have suggested that elite control of water and performance of water rituals formed the foundation for political power and dynastic rulership at many large polities (e.g., Lucero 2002, 2006; Lucero et al. 2011; Scarborough 1998, 2003; Scarborough et al. 2012; Zralka and Koszkul 2015). The abandonment of civic and ceremonial spaces by elite Maya during the Terminal Classic Period "collapse" (~AD 750-900/1000) has been attributed in part to climatic variability and drought (e.g., Beach et al. 2009; Iannone 2014; Kennett et al. 2012; Webster et al. 2007), and perhaps shortages of vital water resources. Recent research from other regions of the Maya lowlands, where water is more abundant (e.g., northern Belize and Chiapas), is revealing the wide diversity and complexity of ecological adaptations that centered around Classic Period Maya water management systems. Water control features in these regions may have become more important through the Classic Period in the face of population increase, anthropogenic degradation of the landscape, and climate change (Beach et al. 2009; Beach and Luzzadder-Beach 2013; Kennett and Beach 2013; Luzzadder-Beach et al. 2012).

In this paper, we describe the role of water management in ecological and social adaptation during the Late Classic Period at the site of Baking Pot, a medium-sized Classic Period Maya center in the Belize River Valley (Figure 1). Settlement survey and excavation conducted at the site by the Belize Valley Archaeological Reconnaissance (BVAR) Project have previously explored a multi-component water management system composed of a drain system within the palace complex that directed water from courtyards into multiple *aguadas* (rain fed reservoirs) around the monumental site core (Audet 2005). Our research has focused on documenting a lattice system of ditches located southwest and uphill from the Baking Pot monumental site core (Awe et al. 2015). Recent airborne LiDAR remote sensing survey conducted in the Belize Valley as part of the West-central Belize LiDAR Survey (see Chase et al. 2014) has revealed the nature and spatial extent of this system, and has aided in mapping approximately 23.5 km of ditches (Ebert et al. 2015). Spatial analyses and ground-truthing survey also recorded the presence of several small house mounds interspersed between ditched areas,

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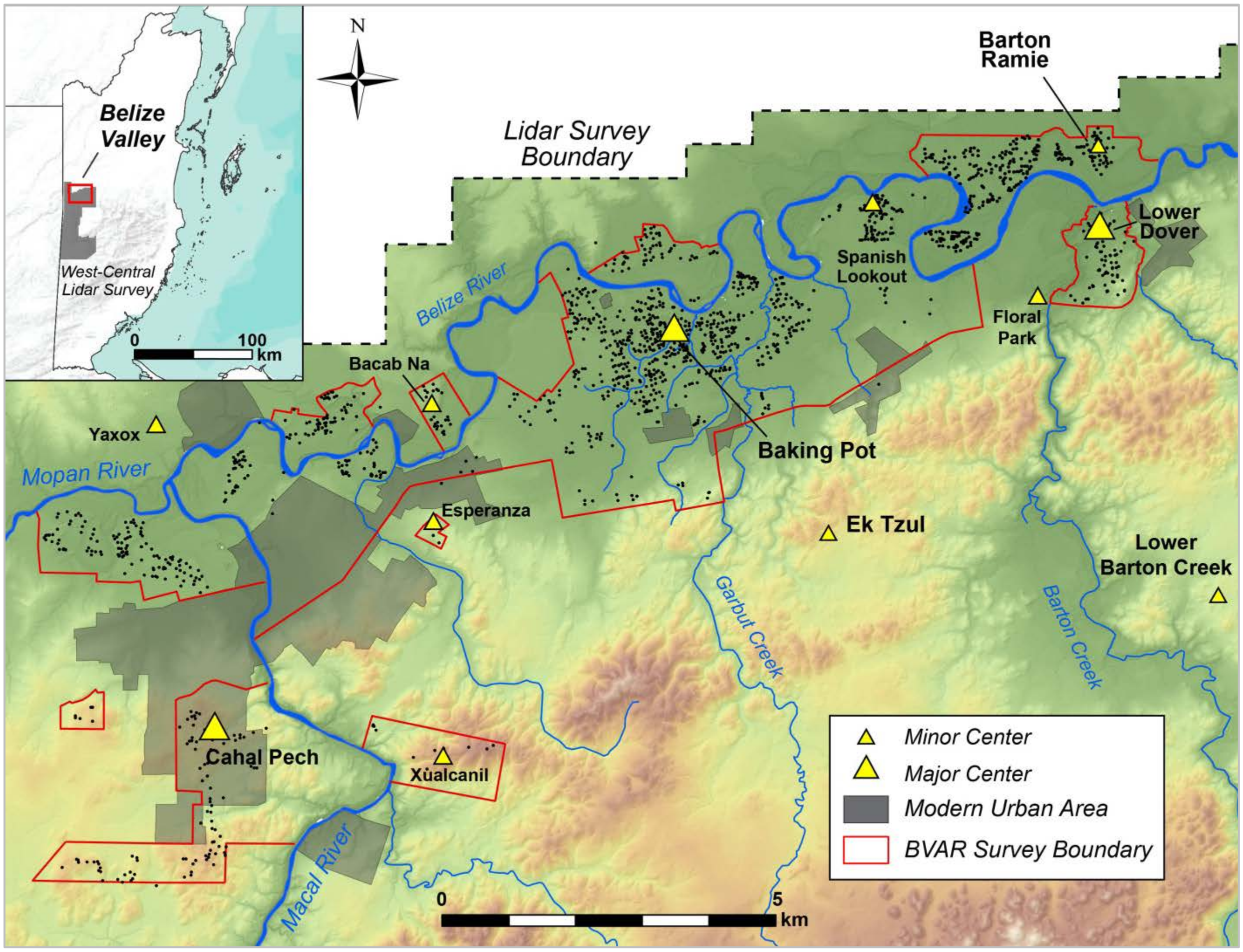

Figure 1. Map of Belize Valley Archaeological Reconnaissance (BVAR) Project survey area, showing location of Baking Pot.

perhaps delineating spatially distinct residential settlements (Awe et al. 2015; Ebert et al. 2015, n.d.). The ditch system is located in a flat, swampy area that often floods during the rainy season, and we suggest that its primary function was to drain water away from settlement located in this area. Additionally, we hypothesize that the ditch system may have been constructed and maintained through communal organization efforts. Models of habitat settlement derived from human behavioral ecology may help us to understand the role of water management as an adaption used by the Classic Period Maya living at Baking Pot to improve their access to ecological and social resources.

Water Management at Baking Pot

Baking Pot is located ~9.4km downriver of the modern town of San Ignacio, in the Cayo District of west-central Belize (Figure 2). Archaeological investigations by BVAR began at the site in 1992, and early research focused on excavations in the ceremonial center (Aimers 1997; Audet 2006, Cheetham 1995; Conlon 1996; Ferguson 1998). Research by BVAR also focused on mapping and test excavations within areas of residential settlements around Baking Pot (Conlon 1993, 1995; Conlon and Ehret 2000, 2001; Hoggarth 2012; Hoggarth et al. 2010). The results of radiocarbon dating indicates that Baking Pot was occupied as early as the Middle Preclassic Period, between 400-200 cal BC, and construction in Group A of the site core was initiated by the Late Preclassic Period (ca. 100 BC-AD 250; Hoggarth et al. 2014). Monumental construction is first documented during the Early Classic Period (ca. AD 250-600), with a peak in construction between AD 600-750 during the Late Classic Period corresponding with the growth of population around the site. The presence of a royal

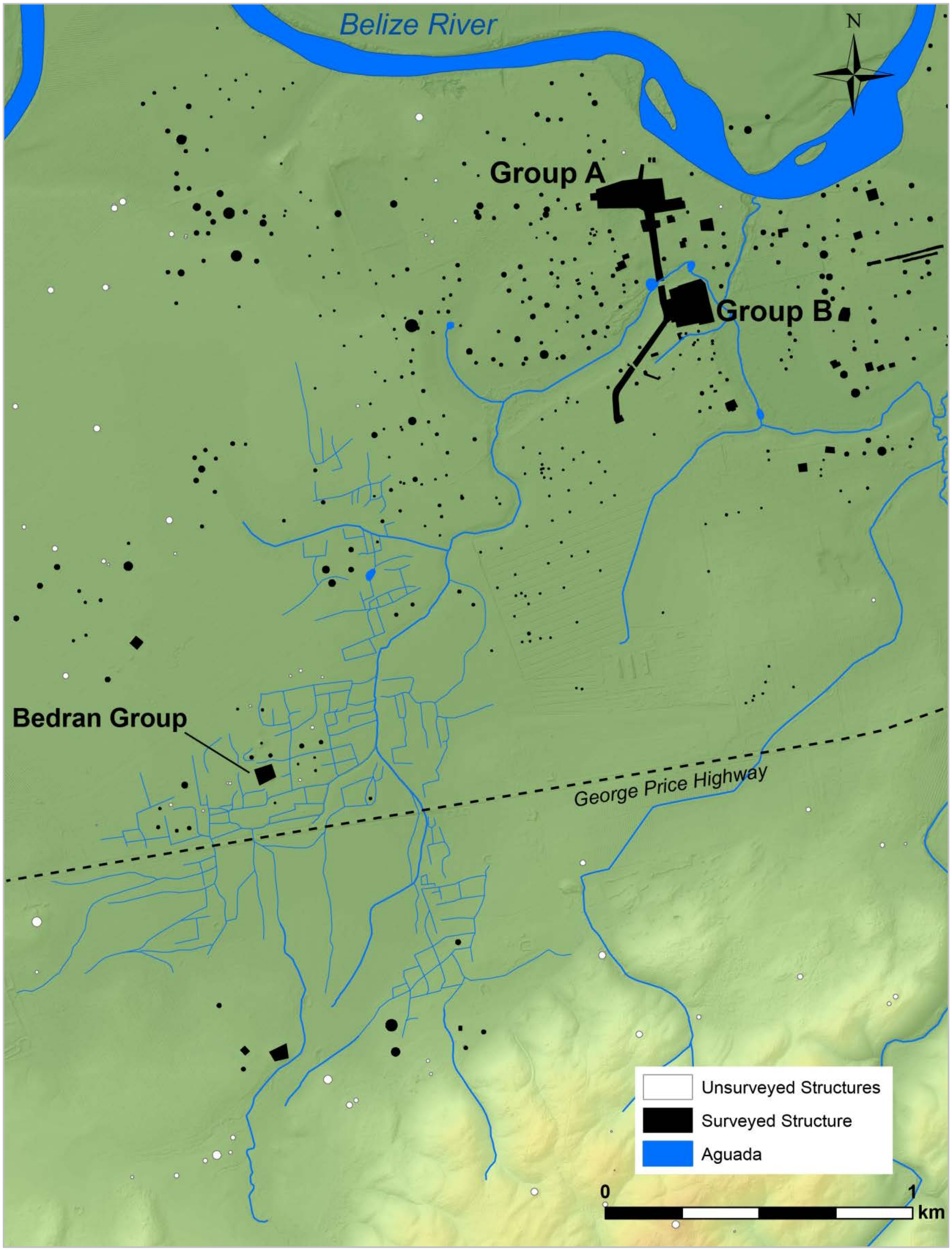

Figure 2. Map of Baking Pot monumental site core and portions of settlement. Ditches identified from LiDAR data are located in the southern portion of the settlement.

title, a possible emblem glyph, and rich elite burials at Baking Pot suggests that this site was ruled by a dynastic linage comparable other large Belize Valley polities (Helmke and Awe 2013).

Several lines of evidence indicate that water management was politically and ideologically important to the Classic Period rulers of Baking Pot. A cacao drinking vessel bearing a PSS from the high-status Bedran Group, located approximately 2km southwest of the site core, includes a place name for Baking Pot, which has been tentatively translated as "*Chan te' ha*," or "four water place" (Helmke and Awe 2008). The presence of four *aguadas* adjacent to the monumental groups at the site may offer support for this interpretation. Excavations in Courtyard 1 at Group B have also revealed evidence for a complex drainage system in place (Audet 2005). A drain in the northeast corner of Courtyard 1 in the palace complex of Group B drains water beneath a stairway and upper room into the system of seasonal streams that feeds into the *aguadas*. Survey data has also indicated that seasonal streams located around the site served to spatially delineate settlement clusters (Hoggarth 2012), and perhaps served symbolic purposes for political authority (Lucero 2002).

The water management system adjacent to the ceremonial center is connected to a more distant system located in Baking Pot's periphery through a series a natural seasonal streams that feed water downhill into the primary *aguadas*. Based on the analysis of aerial photographs and very limited ground reconnaissance, Kirke (1980) noted a lattice system of ditches concentrated around the Bedran Group in southwestern periphery of Baking Pot, which is also connected to these seasonal streams. The ditches were visually identified by contrasting vegetation patterns compared to the surrounding landscape. Based on his observations, Kirke proposed a three-type classification system ranging from narrow, shallow ditches (Type A) to steep-sided, meandering creeks (Type C). While his observations were focused on describing the system immediately around the Bedran Group, Kirke (1980:282) also suggests that the system extended 1km south towards the limestone foothills and drained towards the Belize River in the north.

Conlon and Awe (1995; see also Conlon and Powis 2004) revisited the area in 1994 as part of the BVAR Baking Pot settlement survey, during which time they produced a more detailed and expanded plan of the ditch system immediately around the Bedran Group. Elevations taken along the ditches indicate that the system flowed from south to north and from west to east towards the Belize River (Conlon and Awe 1995). They also conducted limited test excavations of the ditches, reporting that ceramics from those sections indicate that the ditches were constructed during the Late Classic Period (Conlon and Awe 1995; Conlon and Powis 2004:79). Based on those data, Conlon and Awe (1995: 66) argued that, "the ditched field system of the Bedran Settlement Cluster was a fully functioning irrigation system, not simply a drainage system, and should be referred to as ditched rather than drained since some systems sole function was drainage rather than managing a continual supply of water." Continued settlement survey around Baking Pot has documented some additional portions of the ditch system to the north of the Bedran Group (Hoggarth et al. 2008) indicating that the system was more extensive than initially documented by Kirke and other BVAR researchers.

Methods and Results

In 2014, BVAR integrated visual and quantitative spatial analysis of airborne light detection and ranging (LiDAR) data within the settlement survey program to identify archaeological features including house mounds, ditches, and agricultural terraces not previously documented (Awe et al. 2015; Ebert 2015; Ebert and Awe 2014; Ebert et al. n.d.). Accurate and high-resolution LiDAR data have become increasingly important over the past several years for the discovery and visualization of complete archaeological settlement systems in the densely vegetated Maya lowlands (Chase et al. 2014). We conducted spatial analysis of LiDAR recorded for Baking Pot using the Topographic Position Index (TPI), a method for classifying landscapes within a Geographic Information System (GIS) (Awe et al. 2015; Ebert et al. n.d.). TPI analysis has been applied to geospatial studies in geography and geology; landscape, forest, and animal ecology; and climatology (see De Rue et al. 2013). In archaeology, several researchers have used TPI analysis to understand large-scale regional settlement patterns in relationship to landform classes. Here we use TPI analysis of LiDAR data to detect more discrete landscape features at smaller, local scales. TPI analysis was performed using an open-access extension for ArcGIS 10.3 following methods described by Awe and colleagues (2015; see also Ebert et al. n.d.). TPI values reflect the difference between the elevations in a particular cell on a 1m digital terrain model (DTM) derived from the LiDAR point cloud. Based on the TPI results, approximately 27km were digitized within GIS (Figure 3). TPI analyses also helped to distinguish several previously undocumented mounds and residential groups located in and around the ditch system (Awe et al. 2015).

Ground-truthing of the ditches and mounds was conducted in March of 2015, during which time we verified the presence of 23.5km of ditches within an area of ~2.45km^2 (see Figure 2). Reconnaissance found that some of the linear features identified by computer analyses were not prehistoric, but rather modern features along fence lines and around cattle corrals. Measurements of ditch depth and width were also recorded during ground truthing. Based on these data, we propose two classes of ditches. Type 1 ditches measure between 50cm to 1m wide, and Type 2 ditches are between 1m and 2m wide. All ditches recorded during the 2015 survey measured between 40cm to 80cm deep. While our proposed classes conform generally to Kirke's (1980) typology, we have eliminated his Type C ditches, which are naturally occurring waterways. The size and appearance of ditches recorded in the most recent survey are likely heavily altered because of increased grazing by cattle in the area. Several small residential mounds were also recorded interspersed between ditched areas, perhaps indicating plots between ditches that may have been associated with specific residential units.

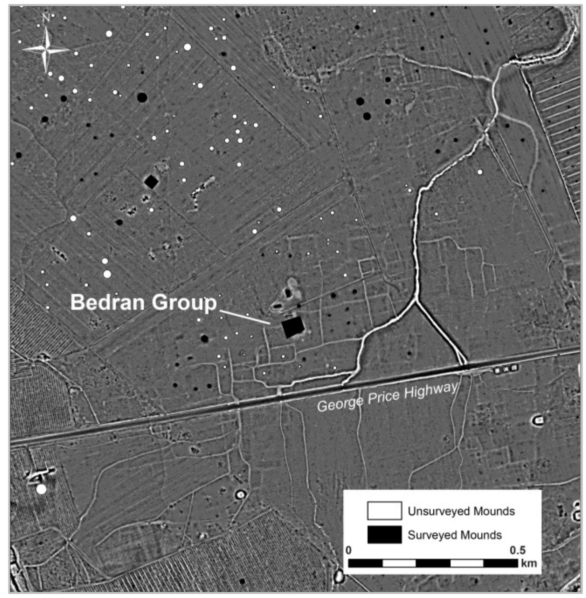

Figure 3. Map of ditched area around Bredan Group, showing results of TPI analyses. Ditches (negative TPI values) are highlighted in white.

Discussion

There is increasing amounts of archaeological and paleoecological evidence for ancient water management across the Maya lowlands, and recent applications of remote sensing are helping to reveal that these systems were more complex and widely distributed than previously believed. Paleoclimate reconstructions show anomalously high levels of rainfall at beginning of the Classic Period (ca. AD 440-660), which may have contributed to the exponential growth of populations recorded across the lowlands during this time (Kennett et al. 2012). Due in part to the infilling of the landscape, there is a growing body of evidence for varied adaptive responses by the Classic Maya to mitigate the impacts of ecological problems (Kennett and Beach 2013). In addition to water collection and storage features that guard against shortfalls during the dry season and longer unstable climatic periods, the Classic Maya developed water management systems to aid in drainage and flood control. At the site of Palenque, Chiapas, French and colleagues have described an extensive system of constructed underground aqueducts that was used to divert water flow through the site core as a form of flood management (French et al. 2013; French and Duffy 2014). Classic Maya communities in northern Belize used ditch and canal systems to drain waterlogged wetland areas, as well as to supply water to fields in the dry season (Beach et al. 2009; Luzzadder-Beach et al. 2012; Siemens and Puleston 1972; Turner and Harrison 1981).

Our investigations at the site of Baking Pot have focused on using LiDAR remote sensing data to document the extent of the Late Classic ditch system. The system flows steadily downhill over 23.5km from karstic foothills north towards the Belize River, however the system has been heavily impacted by modern agricultural activities and was likely more extensive in the past. Previous researchers have hypothesized that the ditches may have been used for irrigation and functioned to bring water to raised fields as part of intensive agricultural production (Conlon and Awe 1995). Based on our preliminary analyses of LiDAR data and ground-truthing, we suggest that the primary function of the Baking Pot ditch system was for drainage. In modern times, the settlement around Baking Pot is prone to flooding, especially during the rainy season from June through December when average monthly rainfalls can reach an excess of 250mm (Figure 4; Webster et al. 2007). Drainage of this area would have allowed for settlement around the site as populations increased throughout Late Classic. While we have not yet found evidence that water was transported directly to facilitate irrigation agriculture, drainage of the area may have also functioned to create soils more suitable for maize agriculture or house lot gardens.

Large canal systems developed as ecological and social adaptation in tropical environments in other regions of the world, many of which relied on communal organization effort for their construction and maintenance. Perhaps the best known ethnographic example for communally organized complex canal systems comes from the island of Bali, Indonesia where extensive water management facilities were used for rice paddy irrigation (Geertz 1972; Scarborough et al. 1999; Scarborough 2008). Balinese canal systems were organized around water temples, or *subak*, which functioned to delineate collectively owned sections of canals and other associated water control features (e.g., check dams). The *subak* also served to bind people in the local community into a corporate group consisting of farmers using sections of canals through annual rituals (Geertz 1972; Lansing 2006). Each *subak* was responsible for coordinating labor scheduling for the maintenance of the section of canals, ensuring the smooth operation of the system. We hypothesize that the ditch system at Baking Pot, though it functioned in a different capacity from the Balinese canal systems, may have also been constructed and maintained through similar communal organization efforts. In modern Maya

Figure 4. Photo of Baking Pot ditches, located south of the George Price Highway, after rainstorm (June 29, 2015).

communities of southern Belize, large-scale construction projects are often carried out communally under the *fajina* system. *Fajina* tasks require all adult males in the community to work for one to two days on community service project including bridge maintenance, construction of community buildings, and clearing of waterways for irrigation and drainage (Wilk 1997).

One way to test this hypothesis is through applications of models of habitat settlement and migration developed in human behavioral ecology such as the Ideal Free Distribution (IFD). The central premise of the IFD is that habitats can be ranked in terms of suitability, including the resources that they possess and fitness those resources provide (Kennett 2005; Kennett and Winterhalder 2008; Winterhalder et al. 2010). The initial inhabitants will settle within the highest ranked habitats (i.e., most suitable) first based on the amount of available resources. The quality of a habitat is density-dependent and suitability declines because of competition as populations increase (Figure 5). Once the suitability of the best habitat is equal to that of the second best, individuals will begin to occupy the second-ranked habitat while population continues to slowly grow in the first. At Baking Pot, excavations and direct dating of human remains indicate that initial settlement took place by the Late Preclassic Period (ca. 400-250 cal BC; Hoggarth et al. 2014) in these locations within around the site core. This area was likely advantageous because of its close proximity to the Belize River. During the Early Classic and Late Classic periods, populations at Baking Pot expanded outwards to the west, east,

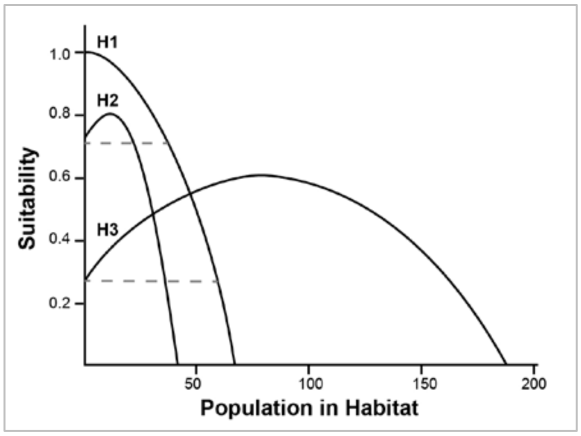

Figure 5. Example of the Ideal Free Distribution showing predicted suitability in three habitats (H1, H2, and H3) as a function of density for each habitat. Suitability in the highest-ranked habitat (H1) declines with population growth; suitability in the second (H2) and third-ranked habitat (H3) characterized by an Allee effect: at low densities, habitat suitability increases with increasing density (after Kennett and Winterhalder 2008: Figure 2).

and south of the site core, perhaps into habitats that were less desirable (i.e., lower ranked).

While the IFD provides a model to predict when individuals will settle or migrate into a new location, it also can provide insights into adaptations that people use to improve their access to resources and become more resilient (Kennett and Winterhalder 2008). Under the model, density-dependent effects (Allee effects) increase the suitability of a habitat by increasing certain components of fitness. In the case of Baking Pot, the construction of drainage ditches south of the site core may have served to offset the impact of increasing population during the Late Classic Period, either by providing an additional (and previously unsuitable) location where people could settle, or by improving upon that patch of land making it available for cultivation. While the small square plots formed by ditch segments may have delineated the house lots, the Baking Pot ditch system may have been organized in a similar fashion as the Balinese *subak*. Groups of households that were connected logistically through certain segments of ditches and/or socially through kinship or other types of communal rituals, may worked together in the maintenance of ditches and the smooth functioning of the system. Settlement survey and LiDAR data show several large, formally organized house groups, such as the Bedran Group, interspersed along this system (Figure 2). These groups may have served as the focus of local community activity, where high status individuals organized labor task groups and conducted rituals for the 'neighborhood'. This type of social organization, with a single large house group associated with spatially discrete residential clusters, has been identified within other areas of the settlement around Baking Pot (Hoggarth et al. n.d.). Through the construction and maintenance of the ditch system, the Baking Pot community adapted to the challenges posed by their natural and social environment.

Conclusions

Environmental changes associated with population expansion and climatic variability during the Late Classic Period in the Maya lowlands were varied spatially and temporally, as did the adaptive responses to mediate these impacts. Novel approaches to document these adaptations, such as LiDAR remote sensing, are beginning to reveal the complexity of these human-landscape interactions in the Belize Valley (Awe et al. 2015). We presented preliminary observations on the Baking Pot ditch system based on spatial analyses of LiDAR data and ground survey. Future research will focus on building an absolute chronology using high-resolution accelerator mass spectrometry (AMS) ^{14}C dating to understand the construction and use of the ditch system. Additionally geospatial analyses will also help us to understand the form, function, and water capacity of ditch systems through hydrological modeling that will integrate high-resolution climate records within a GIS platform. Ditches are easily visible in satellite and aerial imagery and analysis of this imagery from wet and dry seasons, as well as from years with extreme weather or climatic anomalies such as El Niño years, may provide additional insight into this ecological adaption. The region around Baking Pot possesses some of the most productive soils, at the widest extent of the valley floor, in the Belize River Valley. These attributes have led some scholars to argue that the site's wealth stemmed from its access to agricultural land (Audet 2006). Continued exploration of the vast expanse of ditches in Baking Pot's southwestern periphery, coupled with paleobotanical analyses will also be used to test the possible presence of agricultural production, may offer additional evidence to test this hypothesis.

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