Urban Life at Caracol, Belize

Neighborhoods, Inequality, Infrastructure, and Governance

by

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ABSTRACT

This research combines traditional archaeological analysis with lidar data to investigate infrastructure, residential architecture, and neighborhoods in a completely new way. Taken together, these analyses show the shape and form of this city during its apogee in CE 650, while providing a deeper understanding of its civic administration through the use of multiple urban levels (citywide, district, neighborhood, and residential/*plazuela*). Independently, any one of these results may provide an incomplete picture or inaccurate conclusion, but, when conjoined, the analyses interdigitate to shed light on the city as a whole. This research showcases the physical infrastructural power of this city through the widespread distribution of its urban services among the city's districts while still highlighting tiers of urban services among districts. It reinforces the idea of household architectural autonomy through the lack of standardization in the built environment, while also highlighting the relative equality of residences. And, it emphasizes both citywide and neighborhood-based similarities in categorical identities that would have facilitated collective action among individuals in the past by reducing the friction to initiate collective endeavors. Taken together, these results suggest both autocratic and collective governance, and views from different urban levels when combined provide a more detailed perspective on the multiple interacting and concurrent processes that determined urban life and structure in the past. These analyses also hold the potential to shed light on other governance practices in future comparative urban research on archaeological, historical, and modern cities. However, the initial findings reported in this dissertation suggest that Caracol enjoyed a more collective system of governance processes despite the hieroglyphic record of a lineage of rulers.

DEDICATION

In memory of Edward and Christine Zaino.

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1 URBANISM, GOVERNANCE, AND THE ANCIENT MAYA

Ancient Maya urbanism is frequently characterized by both a relatively dispersed population spread over a large contiguous area and a reliance on seasonal precipitation for agriculture and subsistence. While Maya rulers, mostly known from stone-monument texts, reigned over Late Classic Period (550 CE – 900 CE) cities and polities, court officials and support staff likely handled day-to-day administrative tasks. As such the ancient Maya provide an excellent case-study to review the role that both top-down and bottom-up processes can play in the day-to-day governance of ancient cities. The research that follows better defines the nature of ancient Maya governance, using the built environment and material record to answer the following two-part question. What was the urban structure of Late Classic Period Caracol, and how does that structure reflect the governance of this ancient Maya city?

The ancient Maya occupied most of southern Mexico, Guatemala, and Belize as well as parts of Honduras and El Salvador. Their Classic period archaeological remains span about three centuries, and their urban centers display long histories of occupation. Additionally, they built their cities in distinctive ways that only vaguely resembled modern cites. Instead of dense urban cores surrounded by rural agricultural fields, Maya cities consisted of mixed urban green places with farming, orchards, and kitchen gardens interspersed with residential and monumental architecture. For the most part, these "garden cities" sustained ancient Maya urbanites, in some cases for over 1000 years of continuous occupation, generation after generation. The sustainability practices of the ancient Maya may yield important lessons for modern urbanism. However, we need more information about the administration and governance of these ancient cities to understand how the social, economic, and political systems of the ancient Maya permitted them to persist in the same urban centers for over a millennium.

The past two decades have seen a paradigm shift in research into the ancient Maya. The research focus has changed from an elite-centric model of courtly politics (Inomata and Houston 2001a, b) to a more dynamic model focused on every-day households with access to open markets and multiple levels of civic administration (Masson, et al. 2020). These newer models have contributed to advancements in understandings about the Maya past that demonstrate a higher quality of life and more widespread wealth distribution for average urban residents than previously assumed by earlier elite-centric models.

This paradigm shift both resulted from a renewed focus on residential excavations and from new datasets provided by a laser-based technology called Light Detection And Ranging (LiDAR or lidar). Lidar allows archaeologists to use computers instead of machetes to remove the modern jungle (without actually removing a single leaf) and look at the surviving architecture and landscape modifications of the ancient Maya. In fact, this technology permits a virtually deforested landscape that includes the palimpsest of all settlement and occupation over generations; each new lidar dataset contributes to an ever-updated understanding of the large-scale settlements and urban complexity of the ancient Maya.

The following dissertation research combines lidar data, computational archaeology, archival research, and archaeological investigations conducted specifically for this dissertation – all of which are needed in order to investigate the governance of the ancient Maya city of Caracol, Belize. This research further uses archaeological data gathered by the existing project at Caracol, which has had 36 continuous years of field research (broken only by a global pandemic in 2021). The decades of excavation data both enable and enhance the interpretation of the continuous settlement in the over 200 square kilometers of ancient Caracol investigated through lidar survey. Combining these archival and digital datasets to inform new excavations provides a rich foundation for answering research questions about the seventh most populated city in the world of 700 CE, according to Modelski (2003, however, this specific dataset on city sizes over time should be systematically updated).

To better understand the structure of ancient Caracol, I investigate infrastructural architecture, residential architecture, and neighborhood groups as three built environmental datasets to help measure aspects of governance. As will be seen in the flowing chapters, looking at the distribution of buildings that provided urban services to residents in the past - such as architectural assemblages interpreted as sports facilities or performance locales (ballcourts), social spaces or marketplaces (formal plazas), and ritual-civic centers (e-groups) – demonstrates the widespread dissemination of infrastructure present at ancient Caracol. The lack of standardization among physical measurements of household features – including their agricultural terraced fields, rectilinear reservoirs for potable rainwater water, and extended family *plazuela* groups of four to twelve structures around a central plastered plaza (DZ Chase and Chase 2017d:213-215) – sheds light on the lack of urban regulation on Caracol's household level by showing high household architectural autonomy. *Plazuela* occupants could construct their local landscapes with few top-down or bottom-up constraints. Finally, the relative similarities in intra-neighborhood ritual materials versus inter-neighborhood dissimilarities in such items provides an indication of the potential for neighbors to engage in collective action. The greater the shared practices among neighbors, the less friction to starting collective endeavors among residents in those neighborhoods. Additional shared traits, including the focus on eastern ritual shrines through tomb, burial, and caching practices increased this sense of cohesion through citywide ritual similarities.

Each of these aspects of ancient governance (physical infrastructural power through more widespread services, household architectural autonomy through a lack of standardization among non-monumental garden city features, and collective action potential through multiple overlapping categorical and relational identities) provides a different perspective on ancient Maya society. More distributed and widespread infrastructure would have required more bureaucracy and recordkeeping to maintain. More autonomous households would mean less management and less oversight from the city's governing apparatus. Finally, established neighborhoods with strong and overlapping local identities could engage in higher levels of cooperation to affect bottom-up changes in their society. When combined, these three aspects of governance, with differing but complementary perspectives, help interpret urban form. Each aspect helps shed new light on ancient Maya civic administration by highlighting potential needs for, interactions with, and uses of urban administration in the past with both archaeological datasets and lidar palimpsests.

This research advances our understanding of ancient Maya cities by investigating how they were administered and governed. This analysis moves beyond the simple ideas that the ruler micromanaged society or that collectives of residences dominated the political landscape. The governance framework presented here (as defined in detail in chapter 2) along with these analyses provide scaffolding for more nuanced views of the past. Maya garden cities proved to be sustainable (in terms of long-term occupation) urban centers that exhibited continuous, long-term settlement and modification of landscapes in areas where no modern cities are built today. Research into how the people who lived in these past cities managed to not only survive but also thrive may help inspire new ideas in modern sustainability practices (see for example Anderies 2006; AF Chase and Scarborough 2014; Fisher 2020; Scarborough, et al. 2012; ME Smith, et al. 2021a; van der Leeuw 2014); however, an understanding of the governance and urban forms that supported past sustainable initiatives provides a necessary foundation to understand how and why certain practices worked so well for so long (and why others did not).

1.1 Caracol, Belize and Ancient Urbanism

The Classic Period Maya city of Caracol in modern-day Belize provides an excellent case study for analyzing ancient Maya governance by looking at a broad perspective of what is known about its government. At first glance, Caracol would appear to exhibit autocratic rule. The city had lineages of named rulers from roughly from 300 CE until 900 CE, and those same rulers' stone-monument texts suggest autocratic rule (AF Chase and Chase 2021; DZ Chase and Chase 2014c:145-150; 2017d:203-208; Martin and Grube 2000:100-115; Schele and Freidel 1990). However, occupation and settlement at Caracol precedes this hieroglyphic record by almost a millennium. This includes the initial conurbation of downtown Caracol, Hatzcap Ceel, and Cahal Pichik into the city of Caracol sometime before the founding lineage established itself in 331 CE (see Figure 1.1 and Table 1.1). Before that date, the governance structure at Caracol likely incorporated a more dispersed, but collective, system built upon the unification of these three formerly independent centers.

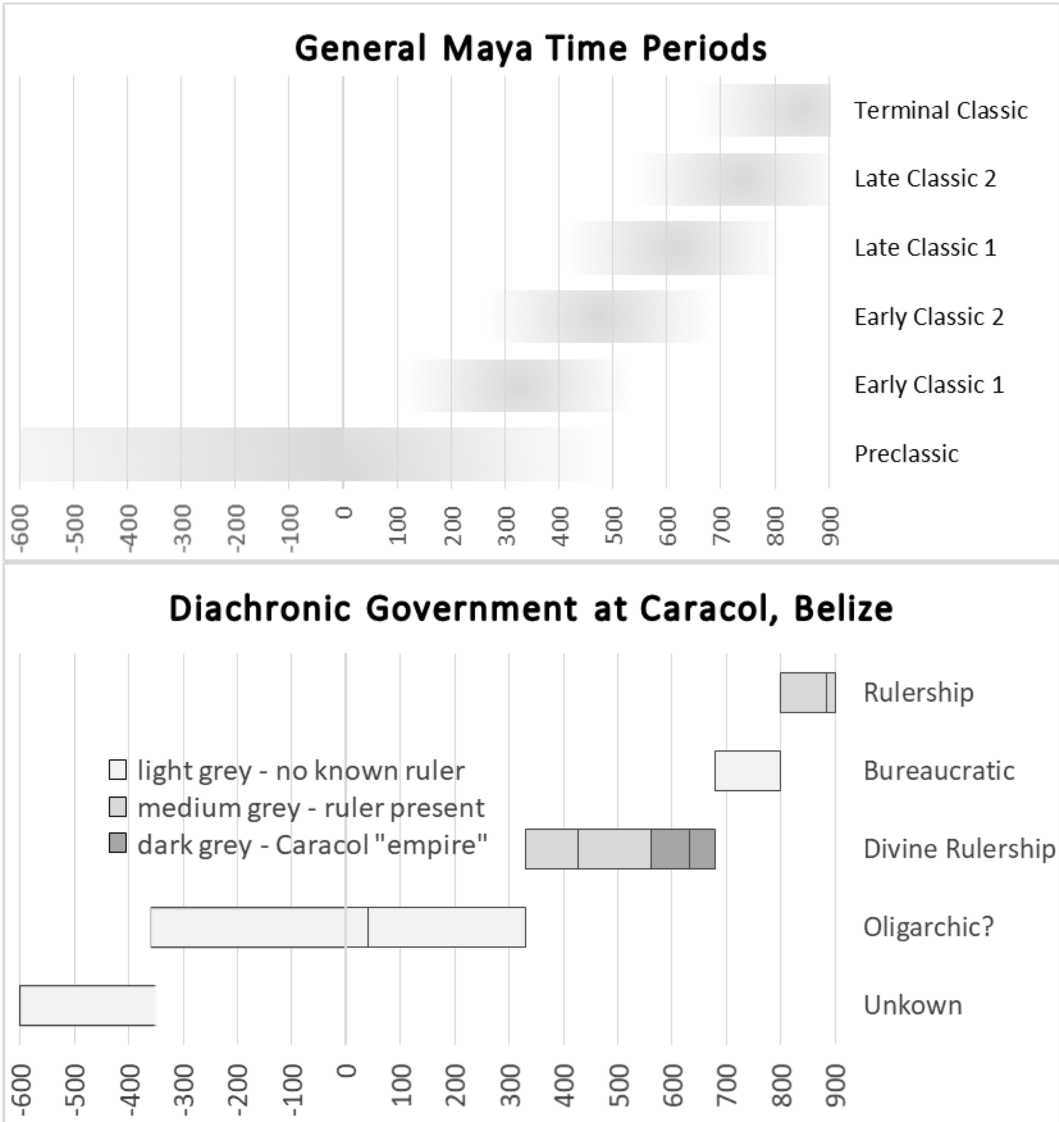


Figure 1.1: Time Periods and Hypothesized Government Form at Caracol, Belize
The relative dates of time periods at Caracol are shown in the upper Figure juxtaposed with the known government form and specific events (from Table 1.1) on the lower image. Both Rulership and Divine Rulership indicate regimes of more autocratic governance while Bureaucratic and potentially Oligarchic (as rule by many based on the conurbation of three settlements into one) indicate regimes of more collective governance but require additional investigation and future research.

Date		Major Political Event
900	CE	(roughly) Collapse of Caracol the city
798	CE	New rulers with short reigns
680	CE	Defeat of Caracol & End of divine rulers
631	CE	Caracol conquers Naranjo
562	CE	Caracol conquers Tikal
426	CE	Copan dynasty founder from Caracol
331	CE	Caracol divine rulership lineage founded
41	CE	Temple of the Wooden Lintel constructed
360	BCE	(roughly) E Group focus begins
600	BCE	(roughly) first residents within Caracol

Table 1.1: Important dates and events at Caracol, Belize
These dates are illustrated as vertical lines and period endings in Figure 1.1's lower image (the dates are from AF Chase and Chase 2017b; DZ Chase and Chase 2017d).

Reviewing the chronology and specific dates in Figure 1.1 and Table 1.1 highlights the long period of Caracol's history with no known rulers. Instead, urban governance went from three dispersed centers to one unified system, as is reflected in the E Groups serving as community structures pre-conurbation (AF Chase and Chase 1995; DA Freidel, et al. 2017). In other words, the distributed and more collective nature of Caracol governance pre-dated the ruling lineage, and, unlike contemporaneous cities such as Tikal, Guatemala or Teotihuacan, Mexico, Caracol continued to exhibit a more distributed urban landscape with less centralization around its urban core than its contemporaries (ASZ Chase and Cesaretti 2019; AF Chase, et al. 2020b; AF Chase, et al. 2009). Put another way, the focus on the ruling lineage and the actions of those rulers only provides a partial view of the historical processes that took place within this city – and only limited information about urban governance. The presence of the ruler and descriptions of events pertaining to those rulers – as derived from hieroglyphic texts –

suggest strong, autocratic rule, but several built environment features and archaeological datasets hint at the presence of a more collective form of governance – as explained in this dissertation.

Decades of research by the Caracol Archaeological Project has identified multiple lines of evidence highlighting more collective behavior during the Late Classic Period. Despite the size of the city during its apogee – around 700 CE with a population of more than 100,000 people across about 200 square kilometers (DZ Chase and Chase 2014c:142-143; 2017d) – excavation has exhibited widespread household participation in market exchange and relatively equal wealth distribution (ASZ Chase 2017; AF Chase and Chase 2009, 2015; AF Chase, et al. 2015; DZ Chase and Chase 2014b, 2017d). As for the city's infrastructure; a system of formal plazas were constructed throughout the urban core that served in part as marketplaces (AF Chase, et al. 2015; DZ Chase and Chase 2014b, 2020c); a dendritic causeway system integrated these formal plazas with the city epicenter (AF Chase and Chase 2001:276-277; 2003a:110-111); and, a variety of urban service facility features were co-located in these same formal plazas (ASZ Chase 2016b:25-26).

This more "collective" period corresponds with both the apogee of Caracol's political power and with a time of relative silence in terms of the monumental record that seemingly ended with the resurgence of monumental construction and stela erection that occurs just a century before the collapse of Caracol (Figure 1.1 and Table 1.1). Existing evidence suggests a more collective (or corporate) structure for the governance of ancient Caracol (following the logic of Blanton, et al. 1996; Carballo 2020; Carballo and Feinman 2016; Lane F Fargher, et al. 2011b). During the Terminal Classic era, the relatively equal wealth distribution ended along with a shift in material patterning that shows internal disjunction in the accessibility of some goods (AF Chase and Chase 2007:21-22; 2008; DZ Chase and Chase 2014c:143; 2017d, 2020c). Before this final change occurs, the material record at Caracol demonstrates a more collectively integrated city with a specific and unifying "pan-Caracol" identity (AF Chase and Chase 2009; DZ Chase and Chase 2004b:142-144; 2014c:148-151). While investigations have studied this shift, they have not specifically focused on questions related to urban governance.

Nearly four decades of archaeological investigation at ancient Caracol have included both residential and monumental excavation in addition to both field survey and lidar mapping. This large, systematically collected dataset provides a unique opportunity to operationalize new methods to better our understanding of governance at a large ancient Maya city. The lidar flights in 2009 and 2013 (see AF Chase, et al. 2014b; AF Chase, et al. 2012; AF Chase, et al. 2011a) provided the raw data necessary for the creation of a completely denuded landscape (see JC Fernandez-Diaz, et al. 2014a) showing the last phase of occupation (~650 - 900 CE) – and the subsequent lack of occupation and modern land-use, aside from the sporadic collection of hardwood, has preserved the palimpsest landscape of the ancient Maya.

Initial analysis and ground truthing have already yielded a new understanding of the high degree of landesque capital at Caracol, showcasing the completely anthropogenic nature of the landscape (ASZ Chase 2016a, b, 2017; ASZ Chase, et al. 2017a; ASZ Chase and Weishampel 2016; AF Chase and Chase 2016a, b). In addition, the Caracol Archaeological Project completed a research program from 2012-2014 that investigated neighborhood organization near downtown Caracol (AF Chase and Chase

2012b, 2013a, 2014a); another research program from 2018-2020 looked at material distributions in contiguous residential settlement near other district nodes located in the northeast sector of the site (AF Chase and Chase 2018; AF Chase, et al. 2019). My own research investigations, carried out with NSF SBE DDIG (National Science Foundation directorate for Social, Behavioral and Economic Sciences Doctoral Dissertation Improvement Grant) funding (Grant No. 1822230), helped to build the sample of investigated residential groups in the vicinity of Puchituk Terminus. The combined settlement work by the Caracol Archaeological Project has generated a large dataset of archaeological materials from various neighborhoods that have been used for this dissertation research, permitting comparisons and contrasts to be made among neighborhoods near downtown Caracol and those near other district nodes.

1.2 Overview of Chapters

This dissertation provides a unique perspective on ancient Caracol with a methodology that can be applied to other ancient (or modern) cities. The next three chapters lay out the framework, datasets, and analyses that follow in the subsequent set of three chapters. That second triad of chapters focuses on identification of different aspects of governance with specific analyses to highlight urban life within this ancient city.

Chapter two presents the framework and theory behind this dissertation. Primarily, this outlines a system of "urban levels" representing different scales for looking at an urban landscape: *plazuela*/residential, neighborhood, district, and citywide. Each of these urban scales provides a distinct way to aggregate and compare data. For each level, the level above aggregates any top-down forces, while the level below provide bottom-up forces – with each of these forces falling along a continuum from more collective to more autocratic governance (building on Blanton and Fargher 2008; M Mann 1984). At either end of this scale, the urban levels incorporate other echelons – individuals at the smallest (most zoomed-in) and polities at the largest (most zoomed-out). Importantly, the polity level should help counter-balance outdated notions of ancient Maya city-states (e.g., Mathews 1991). Both the archaeological and epigraphic datasets demonstrate the presence of regional states of varying sizes with shifting interactions and regional power over time (sensu Adams and Jones 1981; AF Chase and Chase 1998a; AF Chase, et al. 2009; Martin 2020:33-34, 383), and the individual level helps keep the focus of analysis on the lived experiences of residents (sensu Hegmon 2016).

Chapter three provides a background for lidar methodology – and the uses of datasets derived from lidar – focusing primarily on 2.5-D digital elevation models. This chapter aggregates fundamental information on conducting archaeological analysis with lidar and presents novel uses of lidar data that augment more traditional geographic information systems projects in archaeology. In particular, these high-resolution digital landscapes facilitate least cost analyses, hydrology, viewsheds, and volumetric measurements in ways that permit the analyses that follow in chapters five, six, and seven. This chapter also covers several visualization methods and techniques to augment manual feature extraction. While future research will facilitate the increasing ability for automated extraction techniques, manually extracted feature datasets will provide material for testing and refining these new capabilities.

Chapter four provides an overview of the different datasets used in the following three chapters as data domains. Specific architectural features located in monumental nodes comprise the first data domain along with district reconstructions. The garden city landscape and its more residential architecture make up the second data domain. Lastly, eight sampled neighborhoods and their excavation data provide the third data domain with the recovered archaeological materials being tested against reconstructed neighborhoods. This overview (in conjunction with the prior two chapters on the dissertation's framework and methodology) sets the stage for understanding the datasets used to identify physical infrastructural power, household architectural autonomy, and collective action potential that follow in the subsequent three chapters.

Chapter five investigates the physical infrastructural power present at Caracol through the diversity and distribution of urban service facility features at the citywide and district levels. The distribution (e.g., presence, absence, and co-location) of these features provides a four-tiered hierarchy of monumental nodes. Then, the chapter explores formal plaza use and population along with intra-urban scaling more broadly for formal plazas, ballcourts, formal reservoirs, and E groups. Finally, the chapter explores the accessibility of the feature types that exhibit clear urban scaling: formal plazas, ballcourts, and E groups. Taken together, these analyses showcase expected urban dynamics of a walking city along with the widespread distribution of urban service facility features across the city.

Chapter six focuses on aspects of household architectural autonomy at Caracol, as demonstrated through household architectural standardization and inequality metrics primarily at the *plazuela* level since Gini indices simply represent the "unevenness of a distribution" (Peterson and Drennan 2018:39). The garden city features consist of residential reservoirs, agricultural terraces, and extended family *plazuela* residential groups. None of these features exhibits standardization of form and, in fact, the *plazuelas* overlap in size with the city's raised acropoleis. This suggests that acropoleis, often treated as "elite" residences, simply represent the growth of well-to-do *plazuelas* over time. The lack of significant breakpoints in this data echoes the general findings of five Gini metrics for both Caracol the city and "greater Caracol" that this city had relatively low inequality due to the robustness of its residents in the middle socio-economic levels. The only potential status breakpoint that emerges represents a very slight change in architectural area on the upper end of the distribution, potentially lining up with the model of a "power elite" (AF Chase and Chase 1992a:3; DZ Chase and Chase 1992b:315-316; Mills 1956:3-4; see also Winters 2011); however, this group includes both *plazuelas* and acropoleis and still leaves some acropoleis below this potential breakpoint in residential size. This focus on mixed status and the diversity of residential architecture is in alignment with the expectations of a walking city where residences of diverse incomes co-exist side-by-side (AF Chase and Chase 2016b:365; Storey 2006:9-10). No two-tiered system of hierarchy existed at Caracol, and the data suggest the presence of social mobility in the past that is in accord with the results and interpretations of many other Mesoamerican scholars (AF Chase 1992a; AF Chase and Chase 1992a; DZ Chase 1992b; Elson and Covey 2006; Hutson 2020; Masson and Pereza Lope 2005; Murakami 2016; Walden, et al. 2019); however, this section also showcases a high level of household architectural autonomy at the *plazuela* level through this architectural diversity.

Chapter seven highlights the role of neighborhoods in cities more broadly and uses this analytical unit to understand the collective action potential of this social and spatial unit common to cities worldwide. First, the chapter sets out to provide a model of neighborhoods along with specific definitions. Second, it presents the operationalization of that model to reconstruct potential neighborhoods at ancient Caracol based on the definition of "frequent, repeated face-to-face interaction" common to most neighborhood definitions (following ME Smith 2010:139). Finally, the archaeological record provides the dataset to test this neighborhood reconstruction for eight neighborhoods among three districts at Caracol. These results support those reconstructed neighborhoods in a statistically significant fashion and highlight the role of intra-neighborhood similarity that facilitated potential collective action in the past.

Finally, chapter eight provides an overview of the findings of this dissertation research as a whole. In summarizes the most important results of the prior three chapters on aspects of governance and provides a perspective on the resulting implications by highlighting the more collective nature of governance demonstrated at Caracol despite a known ruling lineage. This chapter also provides a brief comparison of Caracol with Tikal – one of its contemporaries – to demonstrate, in a piecemeal way, the utility of this approach and framework for comparative urban research. Future research will expand this type of analysis to other urban contexts and explore settlement systems beyond the boundaries of ancient urban Caracol.

1.3 Major Findings

Taken together, the three aspects of governance (i.e., physical infrastructural power, household architectural autonomy, and collective action potential) in this dissertation provide information on the nature of urban life at ancient Caracol during its apogee by showing the distribution of district infrastructure, the juxtaposition of standardized eastern shrine ritual patterns against the lack of standardization in residential architecture, and the unique neighborhood material patterns within the aforementioned standardized eastern shrine ritual system. Taken together, these analyses demonstrate differences from ruler-centric assumptions of governance based on the hieroglyphic record alone. In addition, historically, this time period under consideration corresponds with the fewest known monuments of any of the official rulers at this city (AF Chase and Chase 2021; DZ Chase and Chase 2017d:215-216), and residential patterns demonstrate an unprecedented level of wealth distribution across this walking city (DZ Chase and Chase 2020c). In sum, these findings add to an understanding of the complexity of this ancient city's governance.

The residents of Caracol built their public infrastructure and monumental nodes to widely distribute urban services across the landscape. This suggests strong power vested in the city through its infrastructure, but that same infrastructure does not appear among the neighborhoods or *plazuelas*. Unlike a modern city with services directly integrated into residential life (e.g., wires, roads, mailboxes, water, and sewage systems), Caracol's infrastructure focused on citywide and district level services. The lack of built environmental features indicating urban services at more local levels suggests a limit on overall infrastructural power in civic life. However, the widespread distribution of these services across the landscape suggests greater physical infrastructural power than existed at many of its urban contemporaries suggesting a more collective governance system as a whole (see also Feinman and Carballo 2018:13).

In contrast to the public infrastructure, the *plazuela* residential units, in which extended family groups at Caracol lived, exhibit a high degree of household architectural autonomy. While the people in these households practiced similar rituals related to tomb, burial, and caching practices in over 70% of eastern *plazuela* structures, the physical measurement of this vernacular architecture suggests more residential freedom to construct and modify their local environments by the people living in these residential groups. This suggests a more autocratic state following the logic of additional oversight in collective states and lack of oversight in more autocratic ones in Blanton and Fargher (2008), but contrasts with the infrastructural power outlined above. Thus, Caracol exhibits both more autocratic and more collective processes depending on the scale of analysis.

Finally, similar practices in eastern ritual shrines involving tombs, burials, and caching existed across the city (AF Chase and Chase 2009). However, analysis of a sample of eight neighborhoods in three districts (four epicentral and four non-epicentral) demonstrates greater within neighborhood similarities and higher between neighborhood dissimilarities among these residential materials. While the citywide system of eastern ritual shrines would have built a common set of practices among all urbanites at Caracol, these more local neighborhood similarities would also have helped facilitate collective action. The shared citywide and neighborhood ritual and material practices both raised the potential capacity for collective action. This, again, suggests a more collective system of governance at Caracol, at least at the local neighborhood level.

In essence, Caracol exhibits aspects of both autocratic and collective governance, and views from different urban levels, when taken together, provide a more detailed perspective that highlights some of the multiple interacting and concurrent processes that determined urban life and structure in the past. The longevity of ancient Caracol may be related to its infrastructure, shared ritual practices, and high degree of wealth sharing in contrast to other Maya cities. However, a better understanding of governance requires both diachronic analyses and additional comparisons with contemporaneous cities in future research. In general, the initial findings reported in this dissertation suggest that Caracol enjoyed a more collective system of governance processes despite the presence of a lineage of autocratic rulers.

2 AN ANCIENT GOVERNANCE FRAMEWORK

Understanding how ancient Maya cities were governed has been hampered by binary definitions of top-down or bottom-up processes based either on hieroglyphic texts focused on individual rulers or on settlement archeology focused on households. When set up as a dichotomy, top-down forces are processes whereby an individual, a small but powerful group, or an institution imposes its will onto others in society, while bottom-up forces are processes whereby a group coordinates through collective action. However, the perspective on the nature of these processes is relative; a bottom-up process among districts may be seen as top-down among their residents.

This research aims to create a methodology for exploring the relationships between top-down and bottom-up processes across several socio-political levels of analysis (citywide, district, neighborhood, and residential/*plazuela* groups) called urban levels in this dissertation. Governance, the "processes of governing" (Bevir 2012:1-3), will be explored by considering: 1) physical infrastructural power, 2) household autonomy, and the 3) potential for collective action (all defined and operationalized below). Each of these aspects of governance uses spatial data from lidar to identify civic and non-civic architecture, while the last uses archaeological data from excavation of household assemblages. As a whole, they begin to answer this overarching research question: What was the urban structure of Late Classic Period Caracol, and how does that structure reflect the governance of this ancient Maya city?

Caracol, like other Classic period Maya cities, was notable for the incorporation of agriculture within the urban environment. However, in other ways, it was a city similar to other premodern cities around the world. It had a city center (downtown Caracol), a network of roads (its causeways), social neighborhoods (see Chapter 7), and monumental architectural features – concentrated in district nodes – that provisioned urban services (see Chapter 5). This dissertation focuses on how these various parts of the city fit together.

The city itself includes its administration, its infrastructure, its residential spaces, and the built environment and material remains that represent these features. However, not all of these components are simple to define using archaeological data alone. Discussions of administration, for example, remain more speculative because the hieroglyphic record only addresses a singular institution, that of rulership by individuals and dynasties (Martin and Grube 2000; Okoshi, et al. 2021; Schele and Freidel 1990). The ancient residents of Caracol provided no detailed written information on the institutions, economic systems, or other elements of civic governance beyond those related to rulership at Caracol (Beetz and Satterthwaite 1981; Helmke, et al. 2019). Instead, archaeological data provides information related to how past systems – such as market and economic systems (AF Chase, et al. 2015; DZ Chase and Chase 2014b; King 2015; Masson and Freidel 2012; LC Shaw 2012) functioned in the Late Classic period – information not recorded in the hieroglyphic texts.

In order to consider governance processes in the past, I examine the theoretical perspectives of both Blanton and Fargher (Blanton 2009; Blanton and Fargher 2008, 2011, 2012, 2016; LF Fargher, et al. 2020; LF Fargher, et al. 2019; LF Fargher, et al. 2011a) and M Mann (1984, 2008, 2019). Blanton and Farger identify states on a continuum from collective to autocratic while Mann identifies infrastructural and despotic power as two primary aspects of state power. While each set of scholars cites the other, the two bodies of theory are difficult to fully integrate and neither set of scholars has focused on investigating these processes archaeologically. As such, this research combines these two bodies of theory (following ME Smith 2014b) to investigate governance in a multi-level urban framework.

This framework utilizes three aspects of governance: (1) physical infrastructural power builds on M Mann (1984, 2008, 2019) to better understand the provisioning of urban services at the citywide and district levels through the presence of multiple urban service facility features; (2) household architectural autonomy builds on of the assumptions of household archaeology (see Ashmore and Wilk 1988; Robin 2003) to better understand the degree of independence that plazuela housemound groups had from urban authorities in day-to-day life through the absence of standardization or conversely the restrictions on this autonomy due to standardization present due to top-down or bottom-up processes; and, (3) collective action potential, which builds on the theories of collective action by Blanton and Fargher (2008, 2011, 2012) as well as on categorical and relational identity (Nexon 2009:48; Peeples 2018:25-28; Tilly 1978:63), provides a means to test the cohesiveness of reconstructed neighborhoods through shared material culture related to ritual practices at eastern household shrines.

Each of these aspects of governance uses separate data domains (see Chapter 4) and focuses on particular sets of urban levels. While this dissertation could have focused on a single aspect of governance, the individual aspects can provide misleading perspectives about the overall system (see Chapter 8). Each of these individual lines of evidence can lead to a different conclusion about ancient governance, potentially mischaracterizing the overall system if used in isolation. However, when taken together, these three aspects of governance provide a more detailed consideration of how ancient Caracol functioned and permit a more comprehensive (and satisfying) attempt at understanding governance.

As a whole, this framework simultaneously lays the groundwork for future research by opening discourse into fundamental concepts of Maya urbanism and its civic governance beyond a simple dichotomy of elites versus ordinary residents. This perspective also moves discussions of governance in Maya archaeology beyond considerations of rulership and the elite versus collective action by households – i.e., a simple dichotomy of top-down equals elite and bottom-up equals non-elite – towards a framework for understanding how and why governance practices may have occurred. To do this, this research considers the archaeological manifestations of governance processes at four urban scales or levels (city and district in Chapter 5, residential/*plazuela* in Chapter 6, and neighborhood in Chapter 7) to investigate aspects of governance at multiple spatial scales (physical infrastructural power in Chapter 5, residential standardization and inequality in Chapter 6, and neighborhood reconstruction and analysis in Chapter 7).

2.1 Assumptions about Maya Governance

Top-down and bottom-up forces acted as two integrated aspects of social stasis and change in a dialectic relationship, thus consideration of both is important (Furholt, et al. 2020). Top-down forces result from an individual, a small but powerful group, or an institution imposing its will onto others in society, while bottom-up forces include both collective group organization as well as individual actions that result in larger changes.

However, these forces are rarely clear-cut. While a ruler making a proclamation represents a top-down action by an individual over a larger group, that proclamation itself may be in reaction to or contention with other bottom-up or top-down processes. In other words, it is best to consider top-down and bottom-up processes together. In terms of the ancient Maya, hieroglyphic texts and research on water management have often used more top-down narratives, while household archaeology generally provides more bottom-up narratives.

2.1.1 Hieroglyphic Record.

Due to the nature of the hieroglyphic record, and its focus on the singular institution of rulership (Martin and Grube 2000; Okoshi, et al. 2021; Schele and Freidel 1990), researchers sometimes inappropriately frame all governance processes in the Maya area as direct correlates or synonyms for the ruler and elites as top-down, where residences/households may be managed by those elites with little, if any, bottom-up impact (e.g., Lohse and Valdez 2004). This view hinders cross-cultural comparisons and more detailed investigation of governance processes.

The hieroglyphic record often describes the births, lives, and (sometimes) deaths of rulers along with ceremonies, wars, and other political events (Martin 2020; Martin and Grube 2000; Schele and Freidel 1990). However, these records represent a fraction of all ancient records because few bark papers books have survived the same taphonomic processes as ceramic and stone materials. Most preserved textual sources are recorded on stone, plaster, or ceramics – and were written by and for elites (Marcus 1992).

While incredibly useful, these written records provide an inherently top-down approach to understanding the history (and ideology) of the ancient Maya. As such, models based on the hieroglyphic dataset tend to exhibit a strong tendency to focus on top-down governance processes and the activities and interactions and relationships among rulers at the polity level (Fash 2001; D Freidel 2008; Houston 1996); however, network-based approaches with models of interactions derived from the hieroglyphic record provide for both top-down and bottom-up processes among a subset of elite individuals at multiple polities (JL Munson and Macri 2009; Scholnick, et al. 2013). Additionally, while marketplaces and market economy have been identified and widely described in the Maya region in the last few years (King 2015; Masson and Freidel 2012; Masson, et al. 2020; LC Shaw 2012), identification of ancient Maya economic systems alone also does not provide sufficient explanation for the operation of entire ancient Maya cities or of all the specific institutions influencing past governance practices (see also Holland-Lulewicz, et al. 2020; Kowalewski and Birch 2020).

These records generally neither provide insight into the lives of most members of ancient Maya society nor substantially illuminate the economic and daily governance of ancient Maya cities and polities other than that of the institution of rulership itself. In Maya archaeology, understandings of institutions and governance have relied on the written record (Martin 2020; Martin and Grube 2000; Okoshi, et al. 2021; Schele and Freidel 1990) or reactions against this elite-focused narrative embedded in residential agency (e.g., Ashmore and Wilk 1988; Murtha 2015; Robin 2003; Webster and Murtha 2015) that effectively treats households as institutions. While investigation of societal institutions is important to the study of ancient and modern cities and states and also provides a key area for future archaeological research (e.g., Anderies 2006; Haldon, et al. 2020; Haldon, et al. 2018; ME Smith, et al. 2012), it requires additional information that the glyphs do not necessarily provide.

2.1.2 Water Management.

Another example of a highly top-down model of governance comes from applications of work by Karl Wittfogel (1955, 1957, 1972) who provided an evolutionary model of water management and its role in creating “oriental despotism” – in the sense of Marx’s "Asiatic mode of production” – as a form of social control. The ancient Maya built most of their large Classic Period Maya cities at some distance from rivers, lakes, and other standing bodies of water. As such, the potential importance of water management as water control has resulted in Maya research on governance centered on top-down, elite control over water.

This includes both control over both water resources and water rituals through exclusive elite knowledge and practices (Lucero 2006a, b). In this example, elite power and the acquiescence of elite control over society rests on this multi-faceted power over water. However, these Maya-centric models do also acknowledge limits on elite control, especially given the dispersed nature of settlement and the difficulty of complete control over water resources in the local environment (Scarborough 2003; Scarborough and Lucero 2010).

In much the same way as household archaeology arose in reaction to elite narratives (described below), top-down governance models of water control have shifted in focus to explore bottom-up systems of water management. Survey and excavation work post-dating this initial research into water systems have provided additional data and alternative bottom-up perspectives that highlight the role of residential reservoirs and other local water management features managed by households (Brewer 2018; ASZ Chase 2016a; Johnston 2004; Weiss-Krejci and Sabbas 2002; Wyatt 2014). However, both interpretations exist in unnecessary opposition to each other and rely on different datasets (i.e., formal reservoirs versus residential reservoirs as described in Sections 3.7, 5.2.4, and 6.2.4).

While recent research has tried to incorporate both top-down and bottom-up perspectives on the control of water systems (ASZ Chase 2019; Seefeld 2018:425-430), most perspectives on ancient Maya water management still use a dichotomous set of models. This lines up with worldwide archaeological research on water management systems as either bottom-up or top-down (see summary by Klassen and Evans 2020:1), and Wittfogel's model still holds substantial power (Davies 2009; Harrower 2009; Obertreis, et al. 2016). Just as with other aspects of archaeological governance a syncretic governance framework is required.

2.1.3 Household Archaeology.

Household archaeology arose in Maya archaeology to directly challenge older elite-focused narratives of the ancient Maya (e.g., Sabloff 2019; as compared to Willey, et al. 1965). Newer approaches to this research focus on providing agency for individual residential units by excavating, uncovering, and theorizing about the day-to-day lives of the rest of society (Ashmore and Wilk 1988; Robin 2003). As such, Maya researchers pursuing household archaeology implicitly use bottom-up processes to study and understand ancient Maya society, often in direct opposition to elite-centric approaches.

Moving beyond a simple dichotomy of top-down as elite and bottom-up as households provides other benefits in understanding ancient societies, and, considering multiple processes and their interactions, provides synergistic insights into the past. Understanding both process types through a dialectic relationship (Furholt, et al. 2020) facilitates better understandings of how those processes played out in the past, and it also prevents the fusing of them into an amalgamation of top-down/bottom-up (Heredia Espinoza 2021) or middle-out processes (Fredericks, et al. 2016; Kinchla and Wolfe 1979; Zavestoski, et al. 2017). Rather, multi-causal approaches can investigate the dialectic of interacting top-down and bottom-up processes instead of looking for a unicausal model. At the same time, this perspective does not diminish either bottom-up interpretations from household archaeology or the top-down interpretations from the hieroglyphic record. Instead, it contextualizes both in order to understand governance more broadly.

2.2 Social Science and Governance Models

Governance has been defined as the "processes of governing" (Bevir 2012:1-3). This might seem like a trivial, self-referential definition; however, it is meant to emphasize that while states and polities govern and comprise the government, governance as a process also applies to non-state individuals, organizations, and interactions within a polity. As such, governance provides a broad label for social process of managing populations regardless of the number of individuals involved. For example, small communities can self-govern to successfully manage common pool resources (Ostrom 1992, 1993, 2015). Also, additional mechanisms such as rules, norms, and enforcement (Ruggie 2014:5) help facilitate interactions between individuals working together at multiple social levels (Bevir 2012:2-3; Kjaer 2004:3-4) to provide governance mechanisms. The use of governance instead of government helps move archaeologists further away from that rulership-centric notion of Classic Period Maya built primarily from the hieroglyphic record (Martin and Grube 2000; Okoshi, et al. 2021; Schele and Freidel 1990) toward a more widespread model that can apply to broader elements of civic life.

2.2.1 Autocratic and Collective Governance.

The Blanton and Fargher (2008, 2011, 2012) model used in this research considers governance along a continuum from collective to autocratic. Autocratic governance exists if the system allows the ruler (or rulers) with absolute power to enact their will without consulting other groups or considering the will of the governed (sensu Blanton and Fargher 2008:290-299) mirroring despotic power described in the next section. In contrast, collective governance relies on both collective action and internal taxation. Collective action among the governed allows them to identify and articulate their needs while internal taxation supports the creation and maintenance of necessary infrastructural services (sensu Blanton and Fargher 2008:12-22). As such, this model posits that these autocratic actions by the ruler (or rulers) are fundamentally at odds with a more collective system focused around provisioning services and providing for the needs of the governed (Blanton and Fargher 2008:5-24).

Perhaps one of the most counterintuitive notions from Blanton and Fargher (2008) and their research on historic states is that more autocratic states tend to ignore the day-to-day lives of their citizens. Following their results, greater interference and services are found in those states that are most dependent on citizens as a source of revenue. Blanton and Fargher (2008:287-289) identify collective states as providing more institutions and record-keeping that would have affected the lives of residents, conversely, they identify autocratic states as providing both fewer services and less bureaucratic and infrastructural oversight. As such, autocratic states may have residents with higher levels of freedom from state oversight (i.e., household architectural autonomy) due to a focus on external revenues (I explore this topic further in Chapter 6 of this dissertation).

To identify either end of the continuum from collective to autocratic, Blanton and Fargher (2008, 2011, 2012) focus on tax records. This variation among state focus on internal versus external taxation suggests that higher internal taxation correlating with more collective governance and services (following Levi 1988). In particular, the role of taxation in providing government revenue and the resulting focus of the state's governance form based on its taxation model cannot be understated within this model.

However, as mentioned above, the hieroglyphic record written by the ancient Maya documents actions by the ruler without mentioning topics such as taxation. Without these taxation records future research will need to be conducted that can operationalize these concepts with archaeological data. It may appear safe to assume that the ruler and ruling elite could operate without consent from the governed given the nature of the hieroglyphic record (Martin and Grube 2000; Schele and Freidel 1990). Yet, some of this interpretation may simply be the result of taking ancient propaganda at face value

(Marcus 1992). While the lack of tax records hampers direct use of the methods Blanton and Fargher employ elsewhere, other operationalizations to identify more collective and more autocratic aspects of governance using the archaeological record are more fully explored in Chapters 5, 6, and 7.

2.2.2 Despotic and Infrastructural Power.

Mann's (1984, 2008, 2019) model uses two forms of state power: despotic power and infrastructural power. Despotic power is the ability of the ruler (autocrat) or rulers (oligarchy) to undertake actions without the consent or input of the governed (M Mann 1984:188-189; 2008:355; 2019:173-174). It also corresponds with more autocratic states within the work by Blanton and Fargher (2008:19-22). In other words, regimes with higher despotic power can run roughshod over their citizens and provide fewer opportunities for collective action or endeavors to change the nature of governance.

In contrast, infrastructural power, the ability of the state to inject itself into civil society (M Mann 1984:189; 2008:355; 2019:173-174), provides a concept that can be operationalized in the past based on architectural features that would have provisioned urban services (Stanley, et al. 2016:121-124; contra Yoffee 2016:1055) while not relying specifically on an understanding of the rulers and their motives (or their tax records). Additionally, states with more infrastructural power would be considered more collective under Blanton and Fargher's (2008, 2011, 2012) model. While infrastructural power incorporates both physical and social infrastructures (see M Mann 2019:173), the physical infrastructure is better preserved in the archaeological record of the built environment.

In Mann's (1984, 2008, 2019) initial formulation, despotic and infrastructural power act as two axes formulated to separate states into four broad categorical types (with slightly different labels in each of those three articles): feudal (low despotic power and low infrastructural power), autocratic (low infrastructural power and high despotic power), democratic (high infrastructural power and low despotic power), and authoritarian (high infrastructural power and high despotic power). Using the concept of governance, the same basic processes of political control and infrastructure can be explored within individual cities and, as such, we would expect this system to be somewhat fractal (i.e., the larger observable patterns of political form repeat at in a similar form at lower levels when changing the scale of analysis).

2.2.3 Integrating Both Models.

While neither set of scholars has integrated their model with the other, the four-way plot of political power created by M Mann (1984, 2008, 2019) can be combined with the governing continuum from Blanton and Fargher (2008, 2011, 2012). Taken together, more collective governance corresponds to the combination of low despotic power and high infrastructural power while more autocratic governance corresponds to the combination of high despotic power and low infrastructural power as shown in Figure 2.1. This intersection on the graph shows the overlap between these two models; however, fully conjoining both models is complicated by the two extreme cases (the high, high and low, low of both despotic and infrastructural power) that are not separately designated by the continuum from collective to autocratic governance.

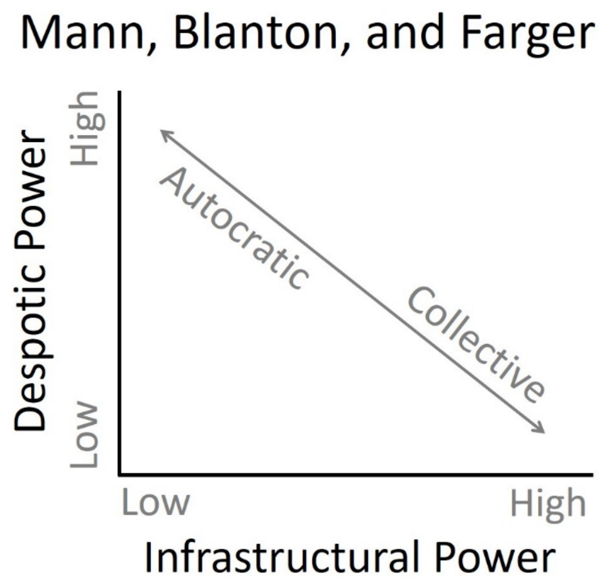


Figure 2.1: Mann, Blanton, and Farger
A reinterpretation of infrastructural and despotic power from Mann (1984, 2008, 2019) while incorporating the Collective to Autocratic continuum from Blanton and Fargher (2008, 2011, 2012) to show how the two governance models intersect.

The low despotic power and infrastructural power quadrant of Figure 2.1 is described as a “feudal” government by M Mann (1984:191; 2008:356; 2019:174), in contrast Blanton and Fargher (2008:15) do not focus on this type and focus on the level of collectivity present in any feudal data they have. As for the high despotic power and infrastructural power quadrant of Figure 2.1, it likely represents rarer forms of government that may not be present in the vast majority of ancient societies. The union of strong infrastructure and despotic power requires a great deal of state revenue to be invested in internal systems and other social infrastructure like bureaucracy to reinforce the ruler(s) agenda. For this type of state, M Mann (1984:191-192; 2008:356-357; 2019:174) provides only modern examples from Communist and Fascist governments of the 20th century. This relates to the advances in record-keeping technology and administration present in more modern states, which both act to increase the baseline for infrastructural power.

2.3 Aspects of Governance

In order to better understand the nature of governance at ancient Caracol, this dissertation makes uses of three separate aspects to measure dimensions of governance separate from the potential despotic power from the ruler. *Physical infrastructural power* (more fully explored in Chapter 5) is the ability of the urban governance system to provision urban services at particular urban levels within the built environment and is based on one facet of state power from M Mann (1984:189; 2008:355; 2019:173-174). *Household architectural autonomy* (more fully explored in Chapter 6) is the ability of residential groups – in this specific case extended family units living in residential *plazuela* groups – to maintain their independence from larger urban governing systems in their residential built environment. *Collective action potential* (more fully explored in Chapter 7) is the capacity for collective action that results from multiple overlapping relational and categorical identities (see Nexon 2009:48; Peeples 2018:27-28; Tilly 1978:63). Each provides one perspective on the structure and governance present at Caracol.

2.3.1 Physical Infrastructural Power.

Michael Mann (2019:173) writes about infrastructural power in terms of both physical and social components; "IP comprises both *physical* infrastructure like roads or radios or schools, and *social* infrastructures, the human relationship through which the regime persuades others to implement and enforce its laws and dictates throughout the realm. IP comprises all means – physical or social – by which commands are actually implemented." Taphonomic processes limit the ability to study the social component in the archaeological record; however, the physical component can often be identified in the built environment of features left on the landscape and can be used to interpret the social component.

For Mann (2019:173), infrastructural power represents, "the capacity of the state to actually penetrate civil society and so get its actions logistically implemented throughout its territories." Following this, *physical infrastructural power* operationalizes the physical component to investigate the ability of the urban governance system to provision urban services at particular urban levels and, thus, provides the first aspect of governance investigated in Chapter 5. The provisioning of urban services represents a form of infrastructural power that provides openings for the exercise of power by urban governance over households, and that as such, urban services serve as one proxy for top-down control at the *plazuela* level.

Physical infrastructural power focuses on tangible infrastructure in the built environment (e.g., D Wilkinson 2018) instead of social intangible infrastructure related to administration (e.g., Yoffee 2016:1055). These respectively correspond with physical infrastructure and social infrastructure as outlined by M Mann (2019:173). While bureaucracy, administration, and other social infrastructures were important, they do not leave the same archaeological evidence as physical infrastructure.

From a citywide perspective, the more widespread the services, the more the governing body has inserted itself into daily life and the less autonomy residents maintain from that civic governance system. At the same time, if infrastructure exists only at the local level, that indicates a lack of physical infrastructural power at higher social levels. For example, Abu-Lughod (1987:169-171) describes historical neighborhoods self-organizing services despite an autocratic central government. As such, it shows local governance instead of centralized governance with a more bottom-up expression of infrastructural power.

Perhaps the best archaeological evidence for physical infrastructural power and the provisioning of urban services are what have been called urban service facility features (the market, assembly, and religious features in Stanley, et al. 2016). Following Mann (2019:173), more widespread and frequent urban service facility feature locations would provide evidence of physical infrastructure and its penetration into civil society. Widespread services also likely entail the creation of additional positions related to bureaucratic matters and record-keeping (i.e., more services over a wider area required more people to manage information) – and potentially even the rise of the middle class to keep those records (sensu ML Smith 2018:305-307). Thus, social aspects of infrastructure (Yoffee 2016:1055-1056) and physical manifestations of infrastructure in the archaeological record (D Wilkinson 2018) are entangled under the concept of infrastructural power M Mann (2019:173).

Taphonomy affects the archaeological record of social infrastructural power. While hieroglyphic records on stone, stucco, and ceramics have survived, all but four bark paper books have perished either through intentional destruction (for example Landa 1978) or as the consequence of preservation in the alternatively wet and dry sub-tropical environment. None of the existing Maya texts focus on economic or infrastructural data, but it is not a logical leap that ancient Maya scribes could have used glyphs, paint, and bark paper to keep other written records about taxes, tribute, or even governance itself – or that the conquistadors and priests burnt books that may have contained some of these records. However, if not textually recorded, these bureaucratic positions and activities are difficult to identify in the archaeological record. Bark-paper books do not easily survive taphonomic processes like stone or ceramic materials, and bureaucratic professions may not leave their mark on the bones of the deceased.

While the level at which infrastructure manifested may be apparent, the motivation and actions that were responsible for the creation of that infrastructure are more difficult to ascertain. For example, while the construction of urban service features have often been interpreted to require a top-down administrative effort, bottom-up desire and collective action to agitate for a given service may have been a catalyst for top-down planning efforts as well (following Blanton and Fargher 2008:12-24). Urban service facility features – e.g., E groups, ballcourts, formal reservoirs, formal plazas, and causeways (see ASZ Chase 2016b) – provide a dataset that archaeologists can actively investigate.

In addition to the presence or absence of these urban service features, the physical dimensions of these features, and their spatial distribution on the landscape provides additional information. Through the built environment we can investigate how centralized or distributed these services were, as well as how well-integrated these services were into the daily life of residents. More concentrated services may have been less frequently required or exhibit a greater focus on centralized power, especially when located only in the city center. At the same time, more dispersed services would have either been used more frequently or demonstrate a greater focus on collective power by people to agitate for services (sensu Blanton and Fargher 2008; Getis and Getis 1966).

2.3.2 Household Architectural Autonomy.

Household architectural autonomy is the ability of residential groups – in this case extended family units based in *plazuelas* – to maintain independence from urban governing systems in their residential built environment. It relates to existing social-science concepts about agency (Dobres and Robb 2000; Joyce and Lopiparo 2005) and personal autonomy (Oshana 2006, 2015; Taylor 2005) as well as household and settlement pattern archaeology (Ashmore 1981b; Ashmore and Wilk 1988; Robin 2003). Instead of assuming high agency in residential contexts, household architectural autonomy, as a subset of agency and autonomy theory, provides a method for measuring and testing this idea with material indicators in the archaeological record.

Architectural standardization provides a dataset for investigating both top-down infrastructural forces and bottom-up collective action, or autonomy through the absence of those forces. Historic examples of building codes in ancient China (Guo 1998) provide an example of low household architectural autonomy through strict standardization. Government housing projects for native peoples as in 20th century Canada (Dawson 2003, 2006, 2008) provide an example of outwardly low household architectural autonomy with high household architectural autonomy through actual use and reconstruction within dwelling units. And, initial high household architectural autonomy exhibited in historic New York city was lost due to its redevelopment into a grid system that standardized household exteriors and locations (Rothschild 2006).

The presence of standardization does not inherently provide a rational for either a top-down or a bottom-up process behind that standardization. While civic administration of households through ordinances or more local governance systems both provide top-down limits on household architectural autonomy, shared practices and labor pools can also result in reduced household architectural autonomy through bottom-up standardization. Looking at the absence of standardization through household architectural autonomy provides insights that can be investigated through future research to identify processes behind any standardization if present. Additionally, lidar data provides a tool for investigating architectural standardization within much larger areas and sample sizes than possible with on-foot survey.

This approach builds on concepts from the inherently bottom-up perspective of household archaeology in the Maya region (see Ashmore and Wilk 1988; Murtha 2015; Robin 2003; Webster and Murtha 2015), and collective action theory in archaeology (see Carballo and Feinman 2016; Carballo, et al. 2014b; Feinman and Carballo 2018). These approaches emphasizes agency, partially due to the development of household archaeology (Ashmore and Wilk 1988; Robin 2003) as an academic response to overly elite focused narratives (e.g., JES Thompson 1966). However, this idealized independent household model provides the antipode to the centralized state, presenting each as an extreme case. The reality is likely somewhere in between.

All residences have some degree of autonomy, but how do bottom-up and top-down practices reduce that autonomy? Following collective action theory and based in examples from historic contexts, more autocratic states tend to ignore the day-to-day lives of their citizens because their primary revenue source lies outside of the polity

(Blanton and Fargher 2008). On the one hand, residences in autocratic societies enjoy more liberty from their governing bodies, on the other hand, they receive far fewer services. Correspondingly, more collective societies tend to be more restrictive in what they will permit people to do while at the same time providing additional services.

One measure of household architectural autonomy rests on spatial measurements of standardization among those residences. While standardization can result from top-down imposition of building codes and ordinances it may also result from bottom-up processes, including "meanings" in the built environmental (Hall 1966; Rapoport 1988) or communal construction efforts (Carballo 2013). However, over a larger spatial area, such as the 200 plus square kilometers of Caracol the city, it is likely (but not impossible) that bottom-up standardization would break down without top-down imposition or support to augment those bottom-up process. Material indicators of household architectural autonomy include orientation, size, and location of plazuelas, residential reservoirs, and agricultural terraces that may be seen through geospatial, univariate, f", or Lorenz Curve analyses of these datasets.

2.3.3 Collective Action Potential.

Finally, while collective action is the result of cooperative group efforts, the *collective action potential* is the capacity for collaborative action that results from multiple overlapping relational and categorical identities (see Nexon 2009:48; Peeples 2018:27-28; Tilly 1978:63) and provides the third aspect of governance investigated in Chapter 7. The physical results of past collective action can be seen archaeologically (see Carballo and Feinman 2016; Carballo, et al. 2014b; Feinman and Carballo 2018) and represent a “kinetic” manifestation of collective action in the same sense that kinetic energy represents a release of stored potential energy. As such, collective action potential is the “potential energy” or capacity for collective action that can be measured through overlaps in shared material culture, architectural practices, ritual practices, or other aspects related to perceived similarities between individuals (i.e., multiple, overlapping categorical identities) and physical interactions between people (e.g., strong relational identities) (following Peeples 2018:25-28). The more shared categorial and relational identities within the group, the stronger the collective action potential of that it possesses (Tilly 1978:63).

Relational or categorical identity can be manifested through shared cultural practices, shared architecture, shared material culture, or shared rituals (Carballo 2013, 2020; Carballo, et al. 2014a; Carballo and Feinman 2016). However, these perceived similarities in categorical identity (Nexon 2009:48; Peeples 2018:27-28; Tilly 1978:63) ensue from a mixture of processes, encouraging a confluence of both top-down and bottom-up influences. Together, these would reduce the threshold for collective action by minimizing perceived social differences within cities including at Caracol (AF Chase and Chase 2007, 2009; DZ Chase and Chase 2017d:215-216). It is the overlapping nature of categorical identities (plural) among the residents of *plazuelas* that would facilitate collective action; however, these specific perceived similarities can, again, occur and interact at multiple levels.

Neighborhoods are by definition collections of spatially co-located individuals with frequent, repeated face-to-face interaction, and this leads to the possibility for a locally shared “neighborhood identity” as a specific category of identity (see ME Smith and Novic 2012:4). As such, within these social neighborhoods there should be high potential for collective action due to this potential union of both relational and categorical identities in the same social unit. In other words, these personal interactions would over time result in similarities within material culture that may evolve into a perceived category of identity at the neighborhood level. However, not all modern neighborhoods exhibit these features of social neighborhoods described above (see Talen 2019), leaving room for both administrative and social neighborhoods. This dissertation research reconstructs neighborhoods at Caracol and then uses specific ritual and cache material from eastern mortuary shrines within residential units in order to test if the relationally defined neighborhoods do share a ritual-based categorical identity. While residences at Caracol collectively engaged in widespread practices related to burials, and caching in eastern shines (e.g., a citywide ritual-based categorical identity) – these neighborhood analyses represent local variations on those larger citywide practices.

Prior to the last hundred years or so before the city's depopulation and abandonment, Caracol exhibits shared material culture, higher average residential wealth, suppressed elite wealth, and a shared eastern shrine residential form throughout most of the Classic Period (AF Chase and Chase 2009; DZ Chase and Chase 2017d:213-217). Fundamentally, these processes all relate to types of categorical identity and social leveling that would lower the threshold for collective action thereby increasing collective action potential through these perceived similarities at the citywide scale. However, this system of sharing breaks down in the Terminal Classic Period just prior to the end of occupation at Caracol concurrently with a social breakdown into haves and have-nots indicating a fundamental change in the market system (AF Chase and Chase 2007, 2020a;

DZ Chase and Chase 2014c). This suggests that some aspects of that shared culture related to the reduction of perceived inequality may have been required for the successful governance of this ancient city and its longevity.

In other words, Caracol's data presents evidence for the importance of collective processes during its most prosperous era, and the end of that system just before its decline involved a sharp increase in perceptible inequality in material goods and residential contexts. This earlier era of perceptible similarities helps highlight the complementary role of collective action which remains more likely the more similarities in relational and categorical identity groups possess. At the neighborhood level, these overlaps should help reconstruct (via relational identity) and test (via categorical identity) this intra-urban unit following the idea of neighborhood categorical "identities" within cities (ME Smith 2010:139; ME Smith and Novic 2012:4). The dataset used to test that categorical identity relies on a larger citywide categorical identity of shared cultural practices involving eastern ritual, burials, and caching at Caracol (AF Chase and Chase 2009; DZ Chase and Chase 2017d:213-217). In any case, this suggests the presence of multiple, overlapping categorical identities embedded in these neighborhoods indicating a higher collective action potential at least within those neighborhoods themselves.

2.4 Urban Levels of Analysis

Urban levels are units of analysis covering different scales of settlement from the individual residential unit to the city as a whole for situating urban analysis. These separate levels of settlement simply represent different spatial and organization scales that focus on separate social units of urban aggregation. As such, they present a process similar to the use of focal lenses of a microscope by permitting different levels of magnification for studying these separate social units with a more zoomed-in or zoomed-out perspective, as necessary.

These urban levels include (1) the residential level of urban residences, also called the *plazuela* level in this dissertation given the common residential form at Caracol. This reinforces the *plazuela* as the fundamental unit of analysis instead of a single mound structure sometimes used at other sites. (2) The neighborhood level, consisting of groups of adjacent *plazuelas* whose residents would have engaged in frequent and repeated face-to-face interaction (following Hutson 2016:60-73; ME Smith 2010:139-140). Due to this interaction, these neighborhoods also represent loci with a union of high relational and categorical identities (following Peeples 2018:25-28). (3) The district level of administrative subdivisions within a city (following ME Smith 2010:140). And (4) the citywide level focusing on the entire city and settlement system as a whole. In addition, Figure 2.2 below includes the polity level that focuses on the set of cities contained within the same state.

Top-down and bottom-up processes take place at each of these urban levels. Thus, *plazuela* residents can have bottom-up impact on the neighborhood, district, or city; and the city, district, and neighborhood administrators can have top-down impacts on the residential plazuela units. In other words, the urban level in question changes the perspective and potentially the top-down or bottom-up nature of the processes under analysis. This framework not only provides a more detailed and nuanced view of the organization of ancient Caracol but should provide a means for comparative urban analysis among cultures or different societies by highlighting not only the units of analysis but also the spatial scale used.

Archaeologists in the Maya area have discussed these and similar urban units using slightly different frameworks: districts and neighborhoods following ME Smith (2010:139-140); clusters, districts, wards, neighborhoods, or communities following Hutson (2016:70-73); or the initially defined clusters, minor centers, and major centers following Bullard (1960). However, few archaeologists test the validity of these units. This dissertation tests the validity of reconstructed districts in Chapter 5 and reconstructed neighborhoods in Chapter 7 using archaeological datasets derived from lidar and excavation. These analyses do not inherently transform these intra-urban units from etic to emic categories, but instead help demonstrate that the etic categories defined by this research match some underlying emic patterns in the data itself.

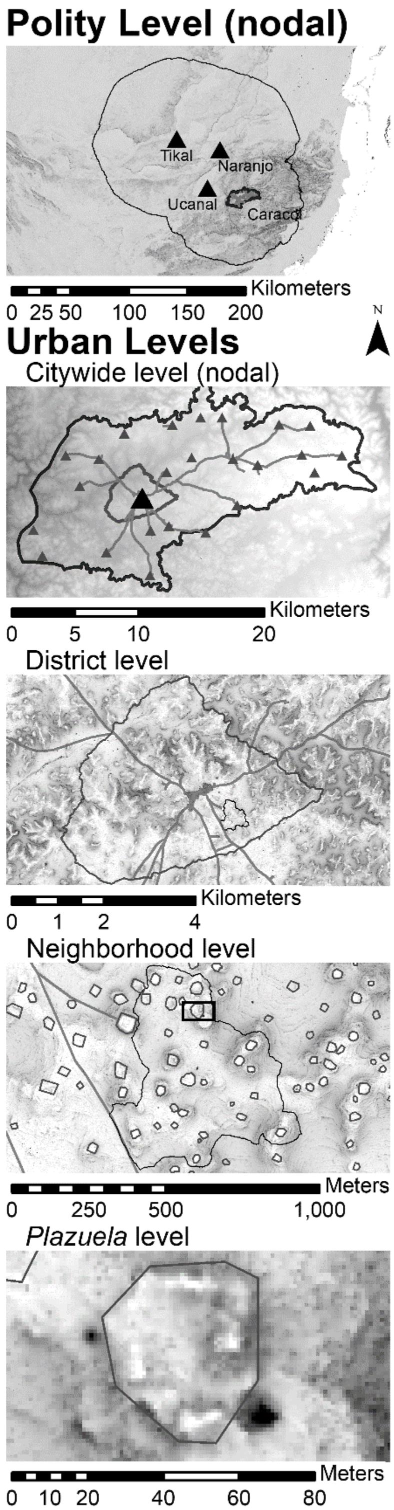


Figure 2.2: The four urban levels at Caracol with a superimposed polity level.
Each level is shown separately, and visible on the next highest order level above it. The plazuela level shows the resolution available one-meter by one-meter DEM cell.

2.4.1 Residential Level.

From the standpoint of this dissertation, the household-scale of the raised *plazuela* group provides the smallest, most zoomed-in, level of urban analysis. The only smaller level would be that of individuals and it can be difficult to identify specific individuals in prehistory (see Hill and Gunn 1977). While other contexts may have slightly different patterns of residential units that comprise a household such as a single housemound structure (Culbert and Rice 1990) or a dwelling unit in an apartment compound (ME Smith, et al. 2019), each of these features still provides the primary residential feature on its urban landscape. In particular settlement analysis at other Maya sites tends to focus on individual mounds as residential features such as at Tikal (e.g., Culbert, et al. 1990; Haviland 1969, 1972), with some exceptions (Becker 1982 uses plazuelas); however, research at Caracol has focused on the *plazuela* as the fundamental unit of residential settlement (see AF Chase and Chase 1987).

Each of these *plazuelas* at Caracol are thought to have been home to an extended family group. Surveyed residences consist of four to twelve structures around a central plastered plaza and nearly all of them contain an eastern ritual structure (DZ Chase and Chase 2017d:213-215). This allows for all the functional parts of the residence – the variety of non-occupied, residential features contained within the *plazuela* that would be counted as mounds including kitchens, sweat baths, range structures, and the previously mentioned eastern shrine structures – to be considered together as one residential unit and minimizes the possibilities of over-estimating the numbers of individuals living within any individual structure (see AF Chase and Chase 2014a:Table 1). The plazuela group also has the benefit of being easier to accurately identify through remote sensing than individual structures (see AF Chase, et al. in press 2021b).

From this residential perspective, we can look for top-down processes from other urban levels (e.g., neighborhood, city, district). This could, for example, take the form of standardization imposed by an edict, or by communal construction efforts. At the same time, the actions of individuals living within these residences may result in bottom-up processes. For example, collective action would be useful for facilitating additional construction and general residential interactions can change the resulting residential form. As household archaeology has repeatedly shown, this residential level is a dynamic unit of archaeological analysis.

2.4.2 Neighborhood Level.

A neighborhood is composed of a series of adjacent residential groups that would have had engaged in frequent and repeated face-to-face interaction in the past (following Hutson 2016:60-73; ME Smith 2010:139). Due to this interaction, these neighborhoods also represent loci where a union of high relational and categorical identities created social neighborhoods (following Peeples 2018:25-28), but not guaranteed for administrative neighborhoods with relational but not categorical identity. At the same time, social neighborhoods may also have facilitated urban administration or provisioned urban services, but it is not a requirement.

These intermediate social units should exist in most urban contexts; however, they might be less prevalent today than the socially integrated units often described (see Talen 2019). Modern information and transportation technologies have fundamentally changed the nature of daily social interactions in cities, both tying people together across greater distances as well as socially distancing those living in proximity to each other; as a result, highly interactive social neighborhoods have become less common than they probably were in the past. These neighborhoods require frequent and repeated face-to-face interactions in order to form the strong social bonds that lead to strong neighborhood categorical identities.

The emphasis on face-to-face interaction means that, like the *plazuela* level, this scale focuses on the people who lived in these neighborhoods. Also implicit is the assumption that residences generally continue to exist and be occupied over long periods of time or by related individuals over multiple generations. Thus, while individual interactions may change and the neighborhood boundaries could shift, given the rebuilding efforts at the same locus (at least at Caracol) it is likely that there was relative stasis in the set of residences included within any given neighborhood.

It should also be noted that more administrative neighborhoods essentially correlate with higher degrees of infrastructural power in modern cities as compared to ancient ones (e.g., M Mann 1984, 2008, 2019). However, the lack of unique community-level neighborhood buildings or features to provision urban services does not support this form of administrative neighborhood at Caracol (ASZ Chase 2016b:21), at least for a physical manifestation of such infrastructural power. Thus, the bottom-up actions of individuals and families living in these residences may impact neighborhoods in ancient cities far more than the top-down forces from the district, city, or polity levels that impact modern neighborhoods.

2.4.3 District Level.

The district level involves a change in focus from one of personal connections to one associated with urban administration and services (e.g., markets). Districts provide administrative governance to oversee aspects of the city and provide urban services (e.g., services provided at the formal plazas, ballcourts, formal reservoirs, and E groups) to its residents (see ASZ Chase 2016b; Hutson 2016:60-73; ME Smith 2010:140; Stanley, et al. 2016) as described in Chapter 5. While districts generally encompass multiple neighborhoods, neither definition technically requires this to be the case. Although ME Smith (2010:140) distinguishes between *administrative* and *social* districts, for the purpose of this dissertation I exclusively use the administrative definition that corresponds with "ward" as used by Hutson (2016:72). This definition focuses on urban service facility features and their distribution throughout the city with district reconstruction based on service accessibility (ASZ Chase 2016b). It also does not inherently require consideration of district-based social identity or social relationships, with the presence of those providing a strong argument for a social district by definition.

While the district level goes beyond social interaction to incorporate urban administration, it still exhibits both top-down and bottom-up processes. Interactions between districts and the city as a whole can also provide avenues for investigating contention in administrative practices and governance. In addition, more autocratic cities should, in theory, possess fewer administrative districts than those that are more collectively governed where districts are defined by nodes of urban service facilities features with wider distribution.

2.4.4 Citywide Level.

The citywide level refers to the settlement system of the city as a whole. In the case of Caracol, this means focusing on the administrative center of downtown Caracol and its co-located – and unique – urban service facility features in conjunction with the connective network of roads that integrated this urban system and shaped the city as a whole. Large, ancient Maya cities often included substantial urban agriculture (infield urbanism) in contrast to more traditional outfield agricultural form found in association with Old World urbanism; however, both outfield and infield agriculture exist in association with ancient Maya urbanism (AF Chase and Chase 2016a; Fisher 2014). The incorporation of agriculture within the ancient Maya city has led to these settlements being viewed differently than other modern and ancient cities (R Fletcher 2009, 2012; Christian Isendahl and Smith 2013; Scarborough, et al. 2012; ME Smith, et al. 2021b). The tendency of ancient Maya metropolises to sprawl and contain large populations over large urban areas has also been well documented (Culbert and Rice 1990; R Fletcher 1995). Caracol represents one of the largest ancient Maya cities with a population of around 100,000 people (DZ Chase and Chase 2017d), about the same as Teotihuacan in central Mexico (ME Smith, et al. 2019). However, Caracol and Teotihuacan exhibit drastically different urban layouts.

Caracol possesses a strongly dendritic causeway network connecting a distributed network of urban nodes with a centralized transit nexus in its downtown (AF Chase and Chase 2001). In the time period under analysis, the Late Classic Period (A.D. 550-900), Caracol represents a single, unified city. Yet, earlier in its history, the city of Caracol formed through the conurbation of three previously independent settlements. In particular, the three resulting district nodes of downtown Caracol, Cahal Pichik, and Hatzcap Ceel joined together in the Early Classic to form the singular city of Caracol with the creation of the first east-west causeways that connected all three monumental nodes, and this causeway sits adjacent to some of the oldest and densest settlement at Caracol.

It is possible that the process of joining together to form one city may have resulted in the high collectivity exhibited at Caracol (e.g., Feinman and Carballo 2018:13) and, thus, may explain some of the differences from contemporary cities. This provides an interesting avenue for future research, especially since less is known about the Early Classic settlement than about later period constructions that superposed them. However, this dissertation only analyzes the single city of Caracol and leaves most comparisons to other Maya and non-Maya cities for future comparative analyses.

2.4.5 Polity Level.

This final level shown in Figure 2.2, the polity level exists above the system of urban levels based on settlement and covers the extent of the ancient state. Unlike the four urban levels described above, the polity exists parallel to settlement. Multiple settlements may exist in the same polity, and this institutional level shifts in extent over time and space.

The polity boundaries shown in Figure 2.2, use marching distance as a proxy of potential territorial extent (based on AF Chase and Chase 1998a; Hassig 1991). The boundary shown utilizes 90m SRTM data (JPL 2013) and least cost analysis (White 2015) based on a three-day march from Caracol's maximum territorial extent when it subjugated Tikal and Naranjo and the rulers of Caracol the polity governed from Tikal (AF Chase and Chase 2020b; DZ Chase and Chase 2017d). It uses the epicenters of monumental architecture in all three cities but without factoring in the causeways or rivers that may have facilitated movement in the past.

While a full consideration of this level lies beyond the scope of this dissertation research, it remains important to note this scale to highlight that ancient Maya polities administered control over more than just city-states, and the potential top-down processes of the polity on its cities in general. Polity area may have involved more nodal rather than territorial control over specific resources, landscape features, and settlements (ML Smith 2005); however, this control also would have been dynamic and have shifted over time. While cities do grow and contract over time, they can shift from one polity to another more quickly.

Any shared polity affiliation would have impacted urban planning, resource distribution, and other aspects seen in the resulting built environment among its multiple cities. However, this level represents something that cannot be easily identified through analysis of settlement patterns alone and requires careful consideration of additional archaeological data (see AF Chase, et al. 2009; ME Smith 2017a). This system may also be difficult to disentangle without considering separate networks of long-distance exchange and regional trade (i.e., Jimenez 2020). However, this framework could provide a future avenue of research for testing the material remains that can be placed within a "boundary" (sensu ME Smith 2017a) as well as the potential effects from the state's management of political, military, social, and commercial interactions among the polities cities and settlements.

2.5 Framing Urban Inquiries

The framework outlined in this chapter provides a cohesive structure for investigating ancient urban governance. Instead of investigating top-down and bottom-up processes independently, this framework uses the continuum of governance from collective to autocratic at various urban levels (residential/*plazuela*, neighborhood, district, and citywide) to investigate three aspects of governance. Using this, I assess the degree to which, aspects of the built environment and archaeological including infrastructure, residential standardization, and neighborhood identities provide practical proxies for identifying governance at Caracol using the following three datasets:

1.) the distribution of urban service facility features around the city as a proxy for the level of physical infrastructural power,

2.) the degree of standardization of garden city features as a proxy for household architectural autonomy, and

3.) the similarities of neighborhood ritual artifacts as a proxy for potential collective action through neighborhood level identity.

In Chapter 5, the distribution of urban service facility features among neighborhoods, within districts, or centralized at the city level and number of urban service facility features present serves as a proxy for the degree of physical infrastructural power at Caracol. More widespread distribution indicates more physical infrastructural power while more centralized distribution indicates less physical infrastructural power in terms of the city's ability to infiltrate daily life. Exploring the physical difference between administrative features at these social levels provides additional information on the centralization of that power. This aspect of governance focuses on top-down aspects of power but also includes the potential for bottom-up agitation for these services and their resulting distributions.

In Chapter 6, the standardization of these "garden city" features (agricultural terraces, residential reservoirs, and *plazuela* housemound groups) indicates different levels of autonomy from top-down governing systems at larger urban levels or bottom-up collective endeavors. While the absence of standardization provides one metric of this, the presence of standardization has equifinality among both top-down and bottom-up process. Either way, this analysis uses the lidar data to assess the physical standardization of residential forms to provide insight into the ability of ancient residents to construct and maintain their households without larger oversight at Caracol, and it tests the fundamental assumptions of autonomy and agency from household archaeology.

In Chapter 7, the patterning and distribution of household level ritual materials in eastern shrines and their correlation with reconstructed neighborhoods serves as a proxy for collective action potential. This follows expectations for a conjoined relational and categorical identity at the neighborhood level, which would lead to a very high collective action potential. However, more similarities among residential materials and practices at other urban levels indicates a higher potential for collective action by reducing the friction for more collective endeavors.

Measuring all three dimensions of variation provides for a greater understanding and formalization of the character of governance at Caracol through the built environment and archaeological datasets. While this chapter has provided a full urban framework, the next few chapters provide detailed information on the archaeological features and datasets used in these three analyses. Each set of analyses relies heavily on lidar data for ancient Caracol but also depends on decades of archaeological research and interpretation. However, as useful as this framework is for providing insight into governance at ancient Caracol, its true value will emerge in future comparative use with other urban locales and contexts.

3 TRANSFORMING LIDAR FROM IMAGES INTO DATA

Lidar has become a popular research tool among archaeologists. This new technological application has created a paradigm shift for survey and GIS research projects in forested environments (Bollandsås, et al. 2012; AF Chase, et al. 2014a:216-217; AF Chase, et al. 2012:12916-12918; AF Chase, et al. 2016; McCoy 2021; O Risbøl, et al. 2006; Ole Risbøl, et al. 2020). While off-the shelf software provides even beginning users with substantial spatial information and access to useful visualizations, getting the most out of lidar requires computational fluency and training that is fueling the growth of archaeological data science and "computational archaeology" (Grosman 2016; Huggett 2020; White 2016). To help address this issue, this chapter addresses the internal validity of lidar data and its derived datasets while leaving the social data gleamed from lidar to the following analyses in Chapters 5, 6, and 7.

This integration of computers and computational thinking into archaeology has initiated research to answer questions that were not feasible to investigate using traditional archaeological methods including: questions of water hydrologic and hydraulic systems over archaeological features at local scales (ASZ Chase and Weishampel 2016; Šprajc, et al. 2021; Stoner, et al. 2021), questions of residential inequality and architectural variation over very large settlement areas (ASZ Chase 2017; Ebert, et al. 2016; AE Thompson and Prufer 2021), questions of urban settlement through digital surveys at scales unimaginable for on-foot investigations (Canuto, et al. 2018; AF Chase, et al. 2014b; AF Chase, et al. 2011a; DZ Chase, et al. 2011b; AE Thompson 2020), and collaborative investigation between disciplines that would not exist otherwise (Hightower, et al. 2014; AC Swanson and Weishampel 2019; Weishampel, et al. 2012;

Weishampel, et al. 2011). In each of these cases the removal of forest canopy, the finer data resolution, and the ability to apply more standardized methods at large spatial scales facilitate research and investigation that would and often could not occur without these lidar datasets (see also AF Chase, et al. 2012; McCoy 2021).

While lidar use remains relatively new in archaeology, the basic technology itself is not new. It was first used in 1963 by Goyer and Watson as an application of the then recently invented laser to meteorology by employing it to analyze the absorption of laser light by water vapor (Goyer and Watson 1963:164). Since then, lidar has been used by a multitude of disciplines as an active remote sensing method for measuring and recording landscapes (see ASZ Chase, et al. 2017a; McCoy 2018; Ole Risbøl, et al. 2020). However, even with the long history of use in other disciplines, only in the past decade has archaeology begun the widespread use and application of lidar data. In Mesoamerica, the initial tests of lidar data (Sheets and Sever 1988) were less than promising, but two decades later – with enhancements to lidar technology and processing – the lidar dataset from Caracol, Belize (AF Chase, et al. 2011a; DZ Chase, et al. 2011b) led to the introduction of multiple lidar projects in tropical environments worldwide (AF Chase, et al. 2016:Table 1), and two archaeological lidar consortiums in the Maya region alone (Canuto, et al. 2018; AF Chase, et al. 2014b).

Most lidar analysis by archaeologists to date has focused primarily on feature identification and ground truthing, much like a traditional survey project. However, there are several other analyses for which lidar data remains uniquely well-suited, including the analysis and investigation of: least-cost paths, hydrology, viewsheds, volumetrics, and landscape-wide settlement patterns. These analyses, and their increased application, underpin the paradigm shift caused by lidar that has transformed archaeology in densely forested regions of the world.

While many articles on archaeological lidar have focused on the hillshaded terrain model visualization method (i.e., using raking light to simulate aerial photographs, see Yoëli 1967), a multitude of other methods exist for producing visualizations and have proved useful for manual feature extraction, especially local area models (Hesse 2010) and sky-view factor (Kokalj, et al. 2011; Zakšek, et al. 2011), as shown later in this chapter. These visualizations may also aid automated feature extraction methods as archaeologists formalize the factors unique to these features of interest or simply use manual datasets to train machine learning and test other artificial intelligence approaches to automation. While current automated methods have begun to yield interesting results, archaeological analysis of lidar by artificial intelligence search methods has yet to truly take hold in the field at large. Thus, manual extraction and human interpretation currently remain necessary to analyze these datasets (Casana 2020; Henry, et al. 2019; Quintus, et al. 2017:9-10).

In short, lidar data provides fundamentally new research opportunities to archaeologists in landscape archaeology at large spatial scales particularly involving detailed cost distance analyses, hydrologic and hydraulic research, viewshed analyses, and widespread sub-canopy settlement surveys. While each of these research topics can be investigated with any raster dataset, lidar permits them at a much more detailed and widespread level than other currently available airborne remote sensing data source. However, these landscapes remain palimpsests, recording overlapping generations of interactions between human beings and their natural environments that also require human interpretation and excavation data to make accurate assessments. Because of computational constraints, archaeological use of lidar typically focuses on 2.5-dimensional analysis (i.e., the raster-based topography represents 3-D space in a 2-D projection) instead of full 3-dimensional use of the raw x-y-z spatial data (see AF Chase, et al. 2011a:391 footnote #2), but even these 2.5-D raster-based analysis contains many embedded decisions. Fundamentally, this data requires decision making by researchers during the creation of multiple lidar derived DEMs, visualizations and coloring methods, and even formal landscape classification systems. This chapter outlines different data manipulation, visualization, and analyses tools that can be used with lidar data, providing at least a partial specialist's toolkit that can serve as a fundamental background to lidar data use within archaeology.

3.1 Light Detection And Ranging (LiDAR / lidar)

Lidar is nothing more, and nothing less, than the use of laser pulses to record three-dimensional (i.e., x-y-z) coordinate data. The technology permits a means of quickly mapping the palimpsest of the modern landscapes at high resolutions. Airborne lidar data is currently created by shooting a laser beam at various wavelengths – such as 1550, 1064, or 532 nm for the NCALM, the National Center for Airborne Laser Mapping (J Fernandez-Diaz, et al. 2016:Table 1) – and recording the time it takes the light to reflect off another surface and return back to the sensor (see Glennie, et al. 2013:4-9). Given the speed of light, we can identify the distance traveled by the laser. In conjunction with the location and trajectory information of the sensor, this provides a physical x-y-z point location in space from the laser apparatus (although, most sensors record these points as peaks along the full wavelength of returns).

Lidar beams often yield multiple returns. As the laser beam travels, it widens (JC Fernandez-Diaz, et al. 2014a:9958-9959) and as each part of the beam reflects to the device, it creates multiple returns per emitted laser pulse; these returns in aggregate are often called a "waveform" (JC Fernandez-Diaz, et al. 2014a:Figure 4). Traditionally, for aerial laser scanning, datasets use the four greatest peaks in the return waveform as distinct points with the point of lowest elevation being classified as the default "ground" return. After the flight and initial processing, this creates a raw file often in ".las" format, containing a point cloud of x-y-z coordinates (following ASPRS 2011).

Lidar, as a measuring tool, has revolutionized the way human beings can capture a representation of their physical surroundings for digital use. As a technology, lidar is used ubiquitously in modern robotics and engineering tasks as a tool for general spatial measurement in 3-D. Some autonomous self-driving technology depends on fast and accurate lidar sensors to help detect the conditions of the road; construction companies use lidar to measure bespoke distances; and spacecraft use lidar to calculate travel vectors and measure velocity. Archaeological application varies from aerial uses of lidar to capture broad landscapes to terrestrial uses of lidar to capture three-dimensional artifact or structure renderings.

3.1.1 Archaeological Lidar.

While lidar endured a twenty year hiatus in Mesoamerica following its initial application (AF Chase, et al. 2011a; Sheets and Sever 1988), it did embed itself in

European archaeology slightly earlier by building on the traditions established by early aerial photography (Bewley 2003). Circumstances, however, were different. In contrast to the situation in Mesoamerica, where lidar data did not exist and had to be secured by the researcher, archaeologists in Europe did not need to initially procure lidar data for their own use. Various government agencies (Barnes 2003:84-86) required landscape data for planning purposes, especially to plan for flooding and potential flood damage along rivers (Charlton, et al. 2003:300), and had already acquired low-density lidar datasets. Thus, European archaeologists could gain access to hillshaded terrain relief model maps (algorithm in Yoëli 1967) derived from this already-existing lidar data and then use them to identify landscape features of interest. Unlike the hydrologists, who would smooth the landscape data to remove "errors" before analysis, archaeologists were interested in small, irregular variations (i.e., "features") on the landscape.

A primary use of archaeological lidar in heavily forested environments revolves around vegetation removal algorithms that facilitate rapid survey of forested environments without cutting down a single tree. However, initial analytical methods were aligned with those of traditional aerial photography (Bewley 2003:284-286) and especially the lighting specifications of aerial photography. These methods were often used to generate initial hillshaded relief models reflecting early morning light, even though any lighting orientation could be generated from the raw dataset. Some European scholars moved beyond the initial hillshades and obtained their own raw lidar datasets, and this opened up a larger avenue of research into potential visualization methods (see Challis, et al. 2011). Others used the point cloud data to generate vegetation removal algorithms (O Risbøl, et al. 2006). These steps were all necessary precursors to large-scale adoption of lidar data by non-European archaeologists working in heavily forested environments. Without specialized visualization methods and vegetation removal, analysis of this data under forested conditions is either more time-consuming or simply impossible.

While lidar images can be viewed in much the same way as non-stereoscopic aerial photography, more complex analysis of this type of data requires a greater proficiency in computer use. A fundamental understanding of computer science data types, algorithms, databases, and other techniques allows an archaeologist both to use more than generic off-the-shelf toolkits (where the internal workings remain a mystery) and to answer more complex questions. In the long term, these skills may become more integrated into formal education of archaeology students along with more training in statistics. However, in the short term, initial use of lidar worldwide has focused primarily on remote feature identification and the creation of interesting and useful visual aids, rather than on an exploration of the depth lidar enables in the creation of new data and use of new analytical techniques. In particular, lidar's more detailed landscapes facilitate least-cost path analysis (White 2015; White and Barber 2012:2687-2688), landscape-scale hydrology (ASZ Chase and Cesaretti 2019; ASZ Chase and Weishampel 2016), area and volumetric analysis (ASZ Chase 2017:32-34), visibility analysis (Dungan, et al. 2018:908-913) at a local scale, and settlement-scale analyses (ASZ Chase 2017). While not all the citations above use lidar data explicitly, the methods and analyses employed work very well with lidar datasets.

These analyses do all use Digital Elevation Models (DEMs) – rasterized grids (i.e., like a very large chess board) of elevation values stored in each grid cell. Lidar-derived DEMs provide a meter (or even sub-meter) grid of raster cells instead of common satellite-based DEMs of 30 to 90 meter range (e.g. JPL 2013). The creation of the DEM is the first step in transitioning from three-dimensional point data to flat representations of the dataset compatible with GIS programs. Use of algorithms in pre-processing removes the vegetation, identifies the ground points, and interpolates the bare-earth surface to create a DEM from three-dimensional point cloud data (JC Fernandez-Diaz, et al. 2014a; JC Fernandez-Diaz, et al. 2014b).

When the lidar sensor records data, the last return generated from each pulse is the furthest from the sensor. These last returns are assumed to be the ground surface, and often this is the starting point in removing the forest canopy and classifying the rest of the point cloud. Algorithms begin with these known points and use the height of other points from the generated surface to aid in classification of the overlaying features before filtering out potential noise (i.e., low vegetation returns) among the ground points. Then, the entire dataset is rasterized and the surface interpolated to populate the entire raster with elevation data, usually with a kriging method (Humme, et al. 2006; Oliver 1990). The end result generates a DEM that is easier for archaeologists already familiar with GIS to use; however, some scholars are pioneering full analysis of lidar point cloud data in three-dimensional space – an aspect of this dataset currently underutilized by archaeologists (see R Opitz and Herrmann 2018; RS Opitz and Cowley 2013).

DEM analysis has a long established history in GIS programs like ArcGIS and GRASS GIS (see Conolly and Lake 2006; Neteler and Mitasova 2008). Methods and techniques can be easy to explain with chess-board analogies to manipulation of raster data. In addition, GRASS GIS remains an entirely free and open-source software package, ensuring affordable analysis to anyone. ArcGIS, the common paid version of GIS software, also has ubiquity through its market-place dominance. Other GIS packages, such as QGIS, provide an alternative free (and more user-friendly) software application using underlying GRASS methods. All common GIS systems can utilize "map algebra" as a limited language to implement DEM algorithms. Often map algebra looks like an algebraic equation where the variables are raster datasets, and their common use ensures parity between both paid and free systems of GIS software. Of course, this requires archaeologists to use map algebra in their methods section or specify both the ArcGIS and GRASS GIS methodologies for analysis to maintain parity and ease of use. This open sourcing of methods facilitates both open science (Marwick, et al. 2017) and decreases the barrier inherent to the digital divide (Bezuidenhout, et al. 2017). Future use of lidar and its integration into archaeological practice will likely entail both a continued focus on usability and for current specialists to democratizing their methods and analyses for use by other researchers regardless of paid or open-source software use.

In any case, the currently available GIS software permits full manipulation of the DEM generated from lidar data; however, several additional steps remain. First, most projects want a representation of features in a vector – points, lines, and areas – shapefile format. While some researchers have automated some feature-sets in specific environments (Davis, et al. 2019:167-169; Freeland, et al. 2016; Soroush, et al. 2020; Trier and Pilø 2012; Trier, et al. 2015), most researchers remain dependent on and recommend manual feature extraction at present (Casana 2020; Henry, et al. 2019; Quintus, et al. 2017:9-10). In either case, the goal transforms from creating a standard DEM into one of facilitating feature identification through visualization and, eventually, algorithms to move beyond the current unique analytical processes for each lidar project. The resulting shapefiles can then be integrated into existing excavation and survey databases, aid in the creation of more useful site maps, and permit novel research projects.

3.2 DEM Products

Initial visualization of features can be quite difficult from the primary DEM file (Figure 3.1a) unless the dataset covers a very flat area where most variation is due to anthropogenic landscape modification. For instance, at Angkor Wat (Evans, et al. 2013:Figure 3) scholars can tie any desired color ramp to the current section of the DEM being visualized and this provides a robust and sufficient visualization for feature identification on that landscape (Evans and Fletcher 2015:Figures 3, 6, & 8). However, variations in underlying geography lead researchers to use additional visualization methods beyond a color-ramped DEM (see Challis, et al. 2011:280-282). Some common methods used include: hillshaded terrain models, slope models, local relief models, openness methods, and composite methods. The choice of optimal visualization varies widely and depends on the researcher's needs for digitizing a given feature type.

3.2.1 Hillshaded Terrain Models: Simulating Raking-light.

Hillshaded terrain models (Figure 3.1b) align very closely with aerial photography visualization methods, as mentioned above. In essence, these methods focus on raking light from a given angle and azimuth like a simulated sun across the digital landscape; each cell in the DEM transforms into the degree of illumination from zero to one. The basic algorithm came into use as a manual mapping procedure that predates the widespread use of computers (Yoëli 1967); however, algorithmic variants exist. Most archaeologists start investigating their lidar with hillshaded relief models, and the visualization itself remains intuitive (Henry, et al. 2019:1523). However, this visualization method has some inherent issues. A single illumination will always underrepresent some features on the landscape in direct simulated light or the shadows of hillsides. Instead, researchers need to inspect multiple azimuths and angles, increasing the time required for analysis. Principal component analysis hillshades (PCA hillshades) provide one solution to reduce multiple hillshades into one visualization by taking hillshades illuminated from multiple angles and generating an RGB composite image with the color weighted to the three highest components explaining variations in the images (Devereux, et al. 2008:472-478). For users who want to use an illumination method, PCA hillshades remains highly recommended, but other visualization methods may be better for a given feature type.

3.2.2 Slope Methods: Steep or Flat?

Slope methods (Figure 3.1e) all rest on the basic equation of rise over run (e.g., slope = $\Delta z / \Delta (x + y)$) of a given set of raster cells. A variety of slope options are available, depending on the GIS platform and algorithm used. Most algorithms take a three-by-three cell "window" for slope and store the largest change in degree slope within the central raster cell as the slope; however, some algorithms use a five-by-five window, radian slope values, slope in only a specific direction, or a derivative of slope (see examples of these in the r.slope.aspect within the GRASS GIS toolkit). Slope provides a useful generic method for quickly identifying large changes in landscape surface. On a relatively flat landscape, the features highlighted may isolate the archaeological features of interest, but on a hilly landscape, there are many areas with variable slope that obfuscate desired features. In this situation directional slope, derivative slope, or color ramps (see next sub-section below) might prove more useful for feature identification. Regardless, researchers need to specify the method (i.e., "algorithm") of slope used.

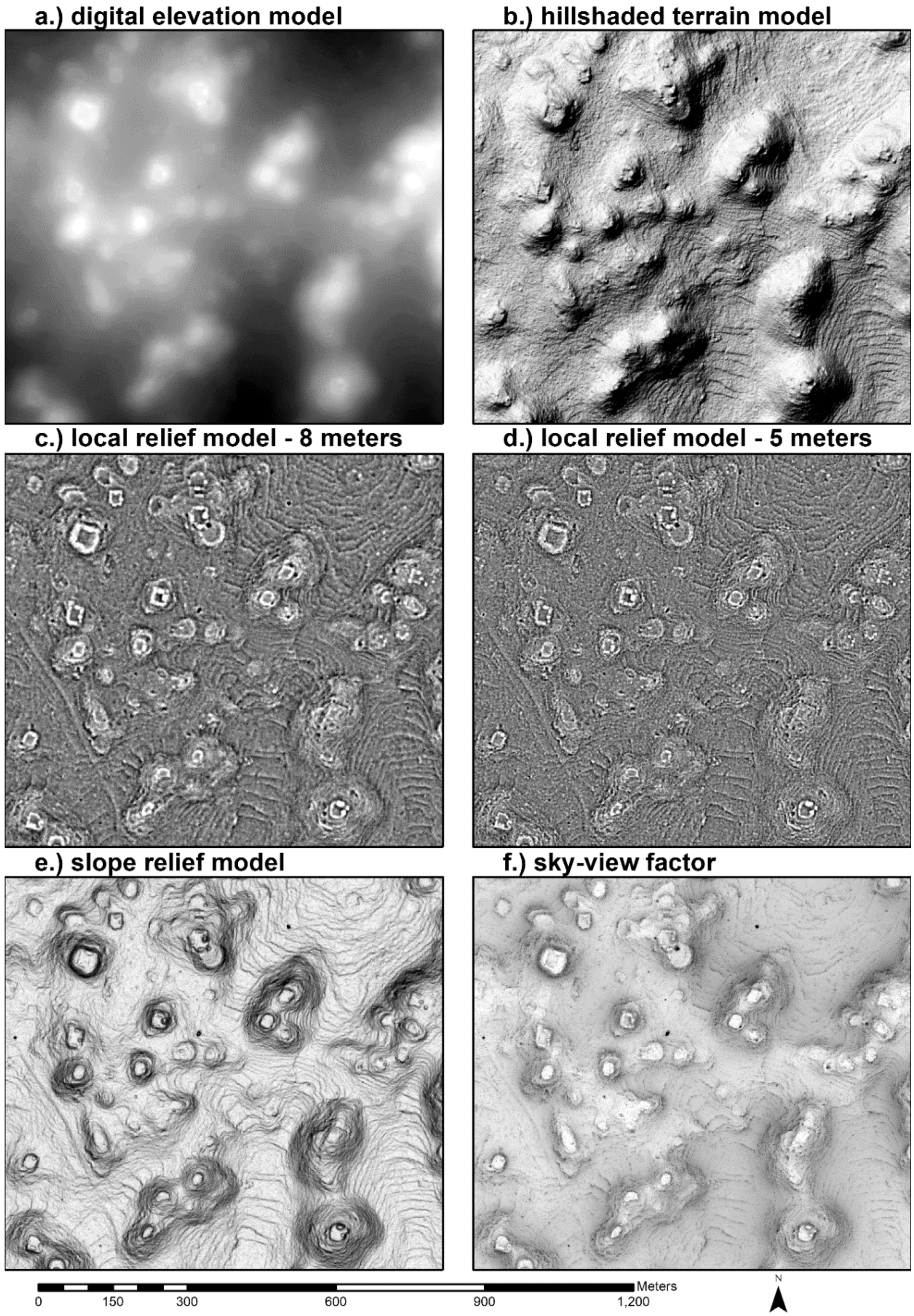


Figure 3.1: Multiple lidar derived DEM visualizations
Six visualizations of the Machete neighborhood southeast of the epicenter

3.2.3 Local Relief Models: Finding Small Features.

Local relief models (Figure 3.1c,d) partially solve the issue created by slope models in hilly landscapes (Hesse 2010:68-71). These types of methods remove the overall landscape's slope from the visualization. In essence, this method focuses on the idea of a moving window – in this case a donut shape – to identify the average elevation around a raster cell and remove that average from the cell itself – the donut hole (see ASZ Chase 2016a:890-891). The result is that local differences in elevation are highlighted over the landscape elevation. Depending on the scale of analysis (i.e., the outer and inner radius of the donut), this can also help identify mounds or hilltops (e.g., higher than the averaged, surrounding landscape), and ditches or basins (e.g., lower than the averaged, surrounding landscape). This visualization method may be the least intuitive to look at, but tends to highlight the most features of interest to archaeologists, especially when using smaller values (Mayoral, et al. 2017:20). In contrast, hydrologists and flood planners want to remove these small variations in elevation to aid their models of water flow over a landscape.

3.2.4 Openness: Cones of Visibility.

Openness represents a suite of archaeological methods focused on a visibility cone directed towards the sky or into the earth. In a sense, this provides a hybridized method between a local relief model and a hillshade that illuminates all directions at once. While the primary openness methods focus on upward positive openness and downward negative openness (Yokoyama, et al. 2002), one of the most useful derivatives of this method is sky-view factor (Kokalj, et al. 2011; Zakšek, et al. 2011). Sky-view factor (Figure 3.1f) essentially asks what proportion of the sky is visible from a given point looking out to the horizon in multiple directions. As a result, this method highlights local differences in elevation through stark visual contrasts. For example, a wall blocks off visibility of a large portion of the sky to either side of it. This appears as a higher visibility line on top of the wall sandwiched between two edges of lower visibility to either side of that wall.

3.2.5 Other Methods.

Some archaeologists have used additional visualization methods that mix the DEM algorithmic manipulation with coloring methods like the red, blue, and green of the PCA hillshade. For example red-relief visualization mixes openness and slope (Chiba, et al. 2008:1073-1075) while bone mapping utilizes slope at various window sizes (Pingel, et al. 2015:20-22). The archaeological projects using these visualization methods have been successful in identifying features, and each project tends to have its own idiom of visualization methods on which it depends (see Ebert, et al. 2016; AE Thompson 2020). In part, this is probably due to the plethora of methods that are used, including those few listed above and the many others that are not. This multitude of algorithms contains many that may or may not be better suited for the identification of specific archaeological features over others; other composite visualization methods have incorporated more visualization of features and have evaluated the results' utility (Kokalj and Somrak 2019; Mayoral, et al. 2017). However, the primary emphasis here lies in using additional manipulation of these DEM products to enhance their utility for archaeological feature visibility. While many useful algorithms exist, the results need to consider the landscapes and features under observation. In essence, the archaeologist needs to be cognizant of the features they wish to identify and select methods to complement those goals.

3.3 Coloring Methods

After generating an alternative raster data model, like any of those discussed above, the color visualization of the resulting data itself can be manipulated. This includes selecting the color ramp, inverting the color ramp, changing the color ramp into discretized bins, and using RGB raster coloration from three datasets or principal component analysis results. This form of data analysis remains completely open-ended, depending on research needs and desired outcomes. Individual color ramps can include one color (saturated to desaturated), or multiple colors added as desired along the color ramp. GIS programs ship with a variety of color ramps, but researchers can create their own color ramps, allowing for complete adjustment to cover the desired color spectra.

3.3.1 Color Ramps.

Within the application of any given color ramp, the color can be inverted. In the case of sky-view factor, flipping the coloration can highlight built features through contrast. The method of fitting the color ramp to the data can also be adjusted. Statistics from the DEM allow for various color ramp adjustments, including: linear min-max scales where the color ramp is stretched; histogram equalization where every color in the ramp covers cells equally; standard deviations to stretch the colors over multiple values; etcetera. Depending on the desired results, the colors should highlight specific archaeological features of interest. For example, if the interest is in mounded features from a local relief model, then the color ramp should emphasize degrees of elevated mounded-ness by including more colors for values above zero and fewer values for depressions or features below zero.

3.3.2 Color Bins.

The next method of manipulating the color ramp uses color bins. An excellent example of this exists in the identification of Hawaiian terraces. Here, the researchers determined specific slope values for the terrace field, the ditch around it, and the surrounding landscape to create a three-bin coloration that highlights only the features of interest (McCoy, et al. 2011:2148). Classifying the raster into color bins is a potentially powerful method. It requires scholars to know what specific values define their features of interest – and could be used to great effect in automated feature detection (see also Davis 2020).

3.3.3 Composite Colors.

Finally, the last method involves creating a composite color dataset. This is easier to accomplish in GRASS GIS than in ArcGIS. In this case, analysts can load three datasets along the red, green, and blue spectra to be displayed to the monitor as a single, colorful image. A similar effect can be created by layering datasets with transparency in ArcGIS; however, the color adjustments made through an alpha transparency value do not result in the same mixture of colors and the order of the layers will alter the resulting coloration. Providing a great example of this method in practice, the PCA hillshade method loads the first three components from its hillshade analysis to red, green, and blue coloration (Devereux, et al. 2008:472-478).

3.3.4 Coloring Overview.

As with the data manipulation conducted from the digital elevation model raster, manipulation of color in datasets can help create excellent visualizations for the manual extraction of landscape features. The possibility space of potential visualizations is huge and, as a result, a multitude of projects have used and created a myriad number of visualization methods. However, while many may use color ramp manipulation, it is often not well documented in the methods sections of archaeological publications. Ideally, each feature analysis in a publication should indicate the visualization, color ramp, and stretch that was used so that the image can be reproduced from the original dataset.

3.4 Landscape Classification

The DEM algorithms for slope, openness, local relief, etcetera all result in ordinal data manipulations. Another group of algorithms can take a DEM as input and produce categorical data instead, creating a landscape classification system. Geomorphons and topographic position index provide two potential methods for categorizing the type of landscape feature present in every raster cell. These two landscape classification algorithms show two potential methods, but for any specific research goal a number of additional tools could be created. These methods can also be adjusted to highlight specific landscape features of archaeological interest.

3.4.1 Geomorphons

Geomorphon analysis builds off of openness and looks at the eight possible values of cells surrounding each raster cell (Stepinski and Jasiewicz 2011:110-112). For each cell and its neighbors, the relative positive or negative elevation value compared to the central cell and the magnitude of the differences between the central cell and its other neighboring cells allows for the categorization of the landscape into 498 possible types (after removing isomorphs); however, most are not common on earth and, thus, the set can be reduced into roughly 10 common forms (Jasiewicz and Stepinski 2013:148-150). The r.geomorphon tool in GRASS GIS provides a simple method for creating geomorphon classified maps showing the following potential features (see Table 3.1 below): flat (no significant elevation differences), summit (central cell higher than neighboring cells), ridge (a flat elevation line with lower elevations to both sides), shoulder (a flat area abutting higher cells), spur (an elevated point with one higher direction), slope (lower elevation in one direction and higher elevation opposite it), hollow (a depression that drains in only one direction), footslope (a flat area abutting an upward slope), valley (a flat elevation line with higher elevations to either side), and depression (central cell is below all adjacent cells). While geomorphons encapsulate the relationship between elevations of various cells, they do not include the scale of analysis (i.e. what variation in slope is considered flat?), meaning that multiple distances can be selected for desired landscape scale features (Jasiewicz and Stepinski 2013:Figure 8). For landscape level uses, large search values should be selected, while for archaeological features, smaller ones should be selected based on the expected size of the feature in question.

Category	Values	Antithesis
flat	########	
summit	--------	depression
ridge	#---#---	Valley
shoulder	#---####	~ footslope
spur	-----+++	Hollow
slope	#++++#---	
hollow	+++++---	Spur
footslope	#+++####	~ shoulder
valley	#+++#+++	Ridge
depression	++++++++	summit

Table 3.1: R.Geomorphon's common landforms
The 10 common landscape categories from GRASS GIS's r.geomorphon method, showing the eight surrounding cell values as higher (+), lower (-), or flat (#). Some variation is permitted for these categories for example, isomorphic cases (i.e., rotations). Shoulder and footslope categories are not exact opposites, but related forms. In r.geomorphon, the number of higher and lower cells provides the impetus for its categorization.

3.4.2 Topographic Position Index.

Another landscape classification method that operates at two scales juxtaposed together is the topographic position index (TPI) which uses two separate search radii, one larger and one smaller, in order to establish landform type (Ebert, et al. 2016; Jenness 2006). This method uses the average elevation of the radius against the elevation of the central cell, akin to a local relief model, but compares the value for the large and small scale against each other to assign a landscape category. This method is much more open-ended and requires manipulation from the researcher to properly calculate the slope position or the landform category. Slope position incorporates the TPI calculation with the relative slope to arrive at six categories: valley, lower slope, flat slope, middle slope, upper slope, and ridge. Landform category uses two scales of TPI to create ten categories: canyon, midslope drainage, upland drainage, u-shaped valley, plains, open slope, upper slope, local ridges, midslope ridges, and mountain tops. This alternative perspective on landscape classification provides different methods of highlighting specific features but requires thought on the part of the GIS user both to create an effective classification schema for the given research problem and to provide a rational for this schema.

3.4.3 Landscape Classification Summary.

In general, landscape classification has not been widely used in archaeological analysis of lidar data, but it has the potential to highlight local features like agricultural terraces and *plazuela* groups, if the algorithms are properly tuned (ASZ Chase and Cesaretti 2019:5-7; ASZ Chase, et al. 2017a:93-94; ASZ Chase and Weishampel 2016:362-363). These methods also require that the researcher has a solid idea of what features they wish to find and how to identify them in the landscape, as discussed below. The categorical nature of the data means that it can only effectively be used for visualization and identification purposes. As such, it provides yet another tool for archaeological lidar analysis, but possibly requires the most prior knowledge of desired features as well as a repeated cycle of tweaking and testing the algorithm and its results.

3.5 Specific DEM Analyses

DEM analysis can focus on specific aspects of the landscape involving the form and shape of that landscape itself. This can include least-cost analysis methods for analyzing potential efficient travel routes or area allocation among features, hydrological methods to reconstruct potential water flow, visibility analysis to reconstruct sightlines from specific locations, and feature measurements like area and volume for settlement-scale analyses. Each of these methods requires existing or off the shelf tools and algorithms already developed for use on DEMs within GIS toolsets. This variety of algorithms and research topics only scratches the surface of potential analyses uniquely suited for lidar-derived datasets.

3.5.1 Least-cost Analysis: Movement on a Landscape.

Least-cost analysis utilizes the elevation of the DEM to generate potential travel costs across the digitally simulated landscape. There are a wide variety of practices for conducting least-cost paths (see White and Surface-Evans 2012); however, some standards have emerged for archaeological investigation focusing on travel time for costs, using Tobler's cost function, and conducting the analysis using methods built into ArcGIS or GRASS GIS's r.walk (Tobler 1993; White 2015). While critiques focus on the overly mechanical aspects of least-cost paths, they have arisen from data solidly grounded in army research on marching (Looney, et al. 2019; McDonald 1961; Pandolf, et al. 1977; Santee, et al. 2001) and hiking and mountaineering enthusiasts (Langmuir 1984). Others critique the lack of more phenomenological data as input for potential paths, but least-cost path analysis can also use other aspects of the landscape to inform movement. For example, feature visibility during travel or water availability along travel routes can be quantified and incorporated into least-cost analysis (Phillips and Leckman 2012). All in all, least-cost path analysis provides a model of movement across the landscape that can be tested against the archaeological record. When archaeological data and reconstructed paths match, the assumptions of the model are supported; when they do not, then the research problem becomes more interesting because the default assumptions do not support archaeological observations, indicating other behaviors were at work!

The standard application of least-cost analysis focuses simply on cost in the form of time (White 2015), slope (Surface-Evans 2012), or calories (McDonald 1961) and a cost function often based on either Tobler (1993) or Langmuir (1984), although others exist (for example Pandolf, et al. 1977). This is another case where the default algorithms for a given GIS package can easily yield distinct results. Care must be taken in describing the procedures used in order to allow for replication, while also outlining potential blind spots or biases in the analysis. For example, some algorithms do not guarantee anisotropic behavior – where uphill and downhill movement are treated differently – leading to reciprocity in paths to and from a given location like the default method for ArcGIS used in this dissertation research (White 2015:412). Other algorithms tweak their cost functions or use different search spaces to model movement (i.e., cardinal direction, diagonal ordinal direction, or knights move). Since variations of these algorithms will generate multiple and often divergent paths, the methods used should be clearly identified and recorded.

Least-cost path analysis in archaeology relies on Dijkstra's algorithm for determining least-cost paths in a network (Dijkstra 1959). However, other path searching algorithms such as A* could be used instead (Hart, et al. 1968). Dijkstra's algorithm always identifies all least-cost paths from a given node to the rest of the network and runs until the entire problem has been solved. A* stops when it finds the best route from location A to location B. It uses a heuristic function (often absolute geographical distance using the Pythagorean Theorem) to prioritize exploration of potential paths that minimizes the distance to the goal in each search step. Of note to archaeologists, neither Dijkstra's nor A* are new algorithms and more recent computer science algorithms for graph search problems exist.

The raster grid acts as a unique type of graph and the interconnection of raster cells often follows three potential movement rules: vertical and horizontal cardinal direction (4 cells), diagonal ordinal directions (4 cells), or the L-shaped knight's move (8 cells). However, researchers can use other movement rules as desired by their research question (i.e., river travel could be treated as unique connections and costs to and from individually known ports on the landscape). Often least-cost path algorithms in GIS utilize only cardinal and ordinal directions, but GRASS GIS supports knight's move specifically as an option. In short, there are many options for crafting the search space used by least-cost analysis beyond the cost surface, cost function, or unit utilized. This variation reinforces the idea that researchers must avoid application of least-cost paths as a simple mystery-box algorithm (see Branting 2012; Kanter 2012).

Finally, least-cost paths are often used to identify movement from site-to-site, feature-to-feature, or place-to-place; however, methods exist for conducting non-site analysis using least-cost paths through the From Everywhere To Everywhere (FETE) algorithm (White and Barber 2012). This algorithm removes the initial supposition that all features of interest are known and allows for testing of movement across the entire landscape itself to highlight repeated avenues of movement that arise from topography alone. The resulting heat-map of likely movements can be cross-referenced against the known archaeological record of sites and trade-routes, allowing for FETE to serve as a sort of "Null model" of movement across a landscape because known sites are not considered during analysis. However, due to the large number of calculations and computational power required to calculate FETE, it also provides an excellent example of research requiring the use of high performance computing on archaeological problems (White 2016).

Instead of serving as a point-to-point route or a heatmap, least-cost analysis can also be used to allocate raster cells as areas along boundaries of travel cost between locations. The least-cost path shows one possible route, but a cost surface shows the costs of going from a given location to any other location in the landscape. Using this permits reconstruction of potential district allocations (ASZ Chase 2016b:24), identification of site catchment areas (Surface-Evans 2012), or – when combined with other methods such as xtent modeling and incorporation of factors for drop-off and enclosure of features (Ducke and Kroefges 2008; Stoner 2012) – shows potential reconstructed political maps with more refection of reality to the landscape at hand than drawing Voronoi diagrams (often called Thiessen Polygons in archaeology) or using radii of 3-day marches irrespective of the local topography (AF Chase and Chase 1998a:Figure 1). In any case, it must be emphasized here that least-cost analysis can provide area analyses instead of just linear point-to-point solutions to research problems and, thus, provides great promise for archaeological interpretations.

Water travel represents one transportation mode that needs to be better understood and defined for regional least-cost path analyses of the ancient Maya. Landscape results have been promising (Carter, et al. 2019), but could be enhanced through the inclusions of riverine and coastal navigability, rainfall patterns and the seasonality of travel, and costs to travel by canoe in differing riverine, *bajo*, and coastal environments (e.g., Laporte, et al. 2008). The seasonality of travel, trade, and exchange may also have been affected by other human factors including patterns of economic exchange and changing socio-political dynamics among ancient Maya polities.

3.5.2 Hydrology: How Water Flows.

Hydrology analyses help determine waterflow and anthropogenic landscape modification. These analyses make use of the meter and sub-meter resolution of lidar data very well. In fact, this may be one of the more useful methods to apply on the bare-earth DEM generated for archaeological interest. The primary caveat, however, is that the researcher must show that the palimpsest landscape has remained consistent enough for this analysis to reflect past land-use patterns. Another issue requires consideration of the water features in question. "Hydraulic" applies to water systems utilizing water pressure (French, et al. 2013) whereas "hydrologic" applies to natural water systems of rainfall and runoff (Wienhold 2013). Hydrological research with lidar analyzes how water flow incorporates a variety of archaeologically identified water features, but fundamentally reflects drainage patterns, soil erosion, or watersheds of the landscape as a whole.

In terms of practical results, hydrological analyses have shown that the terraces at Caracol were constructed to direct the flow of water, an aspect of the landscape that would have been reduced over time but is still preserved (ASZ Chase and Weishampel 2016). It also shows unique environmental responses to water management. The cities of Caracol and Tikal were situated in distinctive landscapes and this helps explain the distinct built environments and hydrological systems employed at these cities (ASZ Chase and Cesaretti 2019). The later analysis uses 30 meter Shuttle Radar Topography Mission data (JPL 2013) instead of lidar data; however, future research could be conducted with the same methods at a local scale using the lidar data collected by Pacunam (Canuto, et al. 2018) as a part two to this hydrological comparison. These analyses rest on some basic hydrological indices and they only scratch the surface of how ancient water management can be better studied through GIS-based methods with high resolution spatial data.

3.5.3 Viewshed Analysis: Visibility and Sightlines.

Viewshed analysis reconstructs visibility from a given location. This has been used to test the ability of ancient features to have served as watchtowers (Kantner and Hobgood 2016), if various features have interregional visibility with each other (Wheatley 1995), and to generate networks of sight communities (Bernardini and Peeples 2015; S Swanson 2003). Of all the analyses mentioned so far other than FETE, visibility analysis tends to require the most computing time and also tends to have relatively inefficient algorithms given the computational problem at hand (i.e., each cell checking visibility to every other cell or an N^2 problem space of N cells checking N-1 other cells). However, there also exists an efficient site-less inter-visibility analysis algorithm that can be deployed to test the higher-level visibility of features on a landscape (Dungan, et al. 2018). This analysis has the potential to yield results building on top of the theoretical ideas of monumentality (Trigger 1990), of performances in plazas and other urban infrastructure (Inomata 2006), and of other more traditionally phenomenological-based research through geospatial analysis to augment, build, and test these arguments.

3.5.4 Area and Volume: Simple GIS Metrics.

Finally, after digitization of archaeological features, the area (by default with shapefiles) and volume (through a variety of methods) can also be generated. While each individual feature can be filled-in (i.e. GRASS GIS's r.lake or ArcGIS's fill) as necessary, other volumetric analyses can alter the data itself to obtain volume (see Stanton, et al. 2020). One of the methods for extracting volume that does not require a solid fill line follows (see ASZ Chase 2017). First, the identified digitized features can be digitally removed from the DEM into a new DEM file. Second, the now holey DEM can be filled in through interpolation methods such as inverse distance weighting (Watson and Philip 1985), natural neighbor (Sibson 1981), spline (Franke 1982), or kriging (Oliver 1990; Royle, et al. 1981). Echoing arguments from above, each of these methods has its own perks and its own issues and, for this purpose, a spline interpolation is recommended. Spline interpolation is also called "rubber sheeting" because this image of placing a rubber sheet over known data represents the interpolation method accurately. Third, using map algebra, the original DEM and this new filled DEM can be subtracted from each other. Finally, the values in this map algebra DEM can be aggregated from the cells below each shapefile to generate its volume.

This volume measurement does not incorporate subsurface volume or labor investment in altering the rest of the landscape around the structure (AF Chase and Chase 2016b). However, I employed this method to automate the recording of *plazuela* volumes at Caracol for Gini analysis (ASZ Chase 2017), but focus on other residential metrics instead in Chapter 6. In a similar fashion, this method can "fix" erosion or modern features on a landscape. For erosion, run erosion models and then use the results to manipulate the original DEM and return the lost soil. Iteratively, this moves the landscape into a reconstructed, potential past form (Barton, et al. 2010:5280). For modern feature removal, this simply replaces those known features like roads or buildings with a potential "unmodified" landscape (Schmidt, et al. 2018). In any case, manipulation of the shapefiles and the DEM in this fashion permits archaeologists to obtain and construct additional datasets which do not actually exist. Remember that the DEM simply presents a dataset of recorded elevations and, as data, it itself can be changed.

3.5.5 Review of DEM Methods.

The sections above point to the various analyses that are enabled by high resolution lidar data, but that will work with any given DEM dataset. While initial lidar analysis focuses on feature identification and recording, analyses can help answer additional questions about the palimpsest landscapes contained within these datasets. To properly use these methods, an understanding of the history of the landscape in question and the specific dates of features are required. As such, lidar analysis opens new avenues of research, but does not prevent the need for traditional excavation and the construction of archaeological chronologies.

To repeat, each of the above methods will work with any DEM dataset, but this fact does not absolve the researcher from responsibility for asking a research question that requires the analysis in the first place. Running the analyses first and describing the results second will only yield an ad hoc argument (sensu Ek 2019; ME Smith 2015). Without a research problem and expectations, lidar data will unfortunately only continue to simply add to existing "just so" stories without testing how well those stories stack up to this new source of data. While lidar opens many possible avenues of research, it requires just as much restraint and skill to ask and test interesting questions as traditional archaeological survey and excavation-based research.

3.6 Automated Feature Extraction

Reliable, algorithmic feature extraction remains the current focus of many lidar researchers who have spent countless hours, days, weeks, months, or years to manually digitize features (e.g., Hesse 2013). Unfortunately, while some features have been extracted quite well using Object Based Image Analysis (OBIA) methods (Davis, et al. 2019; Davis, et al. 2018; Freeland, et al. 2016; Magnini and Bettineschi 2019; Verhagen and Drăguţ 2012), difficulties exist and it may be a bit longer before these methods replace manual extraction for most archaeologists (Casana 2020; Quintus, et al. 2017). Potential difficulties with machine learning techniques include: the possibility that algorithms can become highly tuned and overfitted to their specific context; differences in application of these techniques to rugged as opposed to smooth landscapes; the current focus of these techniques on simple feature types like mounds; and general resistance to widespread adoption of automated techniques by other archaeologists in the field at large.

In addition, these methods often remain "mystery boxes" where the researchers cannot see the internal logic of how the algorithm has determined which features to include or exclude. This does not mean that the internal logic itself is not worthwhile (see

Davis 2020). As an example, consider a machine-learning algorithm to automatically read and convert printed text into digital text files. The letters “c” and “e” might be the two letters most often confused by the algorithm because of variation in the single line changing a “c” into and “e” and, in cases where the ink is faint, that distinction becomes more difficult for this algorithm. However, the algorithm recognizes that the basic shape of these two letters is fundamentally similar. The ability to explain why and how the algorithm misses or incorrectly identifies features remains essential for advancing automated extraction methods and facilitating future adoption.

Currently, feature extraction methods using archaeological artificial intelligence work well in relatively flat landscapes and for mounded or depressed and often circular features; however, these methods have yet to be effectively tested in a rugged/hilly environment with more complex features such as multi-structure *plazuela* groups (especially given their diversity of form, see Bullard 1960:Figure 2). From a computer science perspective, the current issue for archaeological features is that many of them have eroded, collapsed, are covered in earth and vegetation, or do not otherwise contain the nice perpendicular shapes that aid in the automated extraction of building features in modern cities. In addition, once developed, archaeologists cannot necessarily reuse the same algorithms due to the inherent differences between the features designed to be digitized in different regions, cultures, or environments. Even with these roadblocks, it should not be too long before these critiques are no longer valid, and archaeologists can reliably ask a computer to automatically extract archaeologically relevant features for them overnight with a high frequency of success. Until then, however, manual feature extraction will remain a common practice.

3.7 The Caracol Process of Digitizing Features Manually

The manual digitization of each of the archaeological features at Caracol takes place through the following series of steps. First, all previously mapped features of that type (i.e., ballcourts, *plazuelas*, etc.) are identified in traditional field survey maps. Second, those maps are georeferenced (if they have not been georeferenced previously) and their features digitized to form the visual reference group for the desired feature class. Third, a first pass of visual inspection (using primarily local relief models, sky-view factor, and slope models) and manual digitization of the lidar dataset adds additional features matching the visual signature of the previously ground-truthed features. This process itself utilizes a 500-meter by 500-meter grid overlaid on top of the lidar data as a separate shapefile layer. After searching through the data under a grid cell, that grid is marked off (changing the data value of the grid cell from a 0 to a 1 for example). This ensures a complete, systematic coverage of the entire dataset over multiple digitization sessions. Fourth, samples of newly identified features are selected for on-the-ground investigation to fine-tune future feature identification. Ground-truthing focuses equally on features identified visually in the lidar, but missed in the original survey maps, and potential features flagged as interesting, but not confidently assessed to be the desired features of interest. Fifth, based on the ground-truthing survey results in step four, an additional visual pass and manual identification with the 500-meter by 500-meter grid through the lidar dataset identifies additional features. Urban service and garden city features identified at Caracol for this analysis utilized this process for feature identification and verification.

This process allows for a "nearly complete" collection of all features present and visible in the lidar-derived DEM dataset of its one-meter by one-meter cells; statistically speaking, it provides a "universe" of built environment data at the city-scale for this landscape. However, some caveats remain. Not all features can be seen in the lidar. In particular, smaller features will always be underrepresented, especially when compared to the representation of larger features, because they are more difficult to see and confidently identify at one-meter spatial resolution. Additionally, the late-stage forest growth on the modern landscape enhances visualization of features in this dataset by reducing the density of low-lying jungle foliage. However, specific regions of the landscape are more difficult to interpret, specifically those that have been cut by illicit logging or for agriculture, as these behaviors greatly reduce the efficacy of the lidar data in those locations due to the increased density of low-lying jungle growth. This is a known issue for other areas with low-lying vegetation and adjusting the vegetation removal algorithms improves the density of ground returns (Prufer, et al. 2015).

In terms of the forms of specific features in the dataset, different tactics are required to identify the urban service facility features and the more common garden city features at Caracol. The urban service facility features (Figure 3.2) – i.e. E Groups, formal plazas, causeways, ballcourts, large reservoirs, and monumental reservoirs – tend to be larger, tend to be co-located with each other in monumental nodes, and tend to be linked to other monumental nodes by a dendritic causeway system (ASZ Chase 2016b; AF Chase and Chase 2001). Due to feature size and co-location, sky-view factor alone is sufficient for the feature identification of urban service facilities. E Groups (Figure 3.2a) have a larger western pyramid with an elongated eastern platform across the plaza (see also Šprajc 2021:2). Causeways (Figure 3.2b) evince a strong linear aspect easily seen because of their inherent one-dimensionality, their slightly raised construction, and their formalization as roadways and paths (see also Hutson and Welch 2021b; JM Shaw 2008; Snead, et al. 2009; Trombold 1991). Formal plazas (Figure 3.2c) emerge as large, flat spaces bounded by other monumental structures; they form the fundamental architectural unit to indicate administrative districts at Caracol and exist as formal open spaces for conducting various urban activities, as necessary (Inomata 2006; Tsukamoto and Inomata 2014). Ballcourts (Figure 3.2d) consist of the space created between two elongated structures bounding the field that can either be freestanding or utilize the wall of another structure. Finally, monumental and large reservoirs (Figure 3.2e,f) are rectilinear depressions that possess a size an order of magnitude higher than the residential reservoirs at Caracol (ASZ Chase 2016a:Figure 6; 2016b:Table 2). These features are interrelated on the landscape of Caracol, and one urban service facility feature will often occur in the same node along the causeway with others of different types forming a strict Guttman-like scale where every E Group is near a ballcourt, every ballcourt is near a formal plaza, and the converse of the prior two statements are both false (ASZ Chase 2016b).

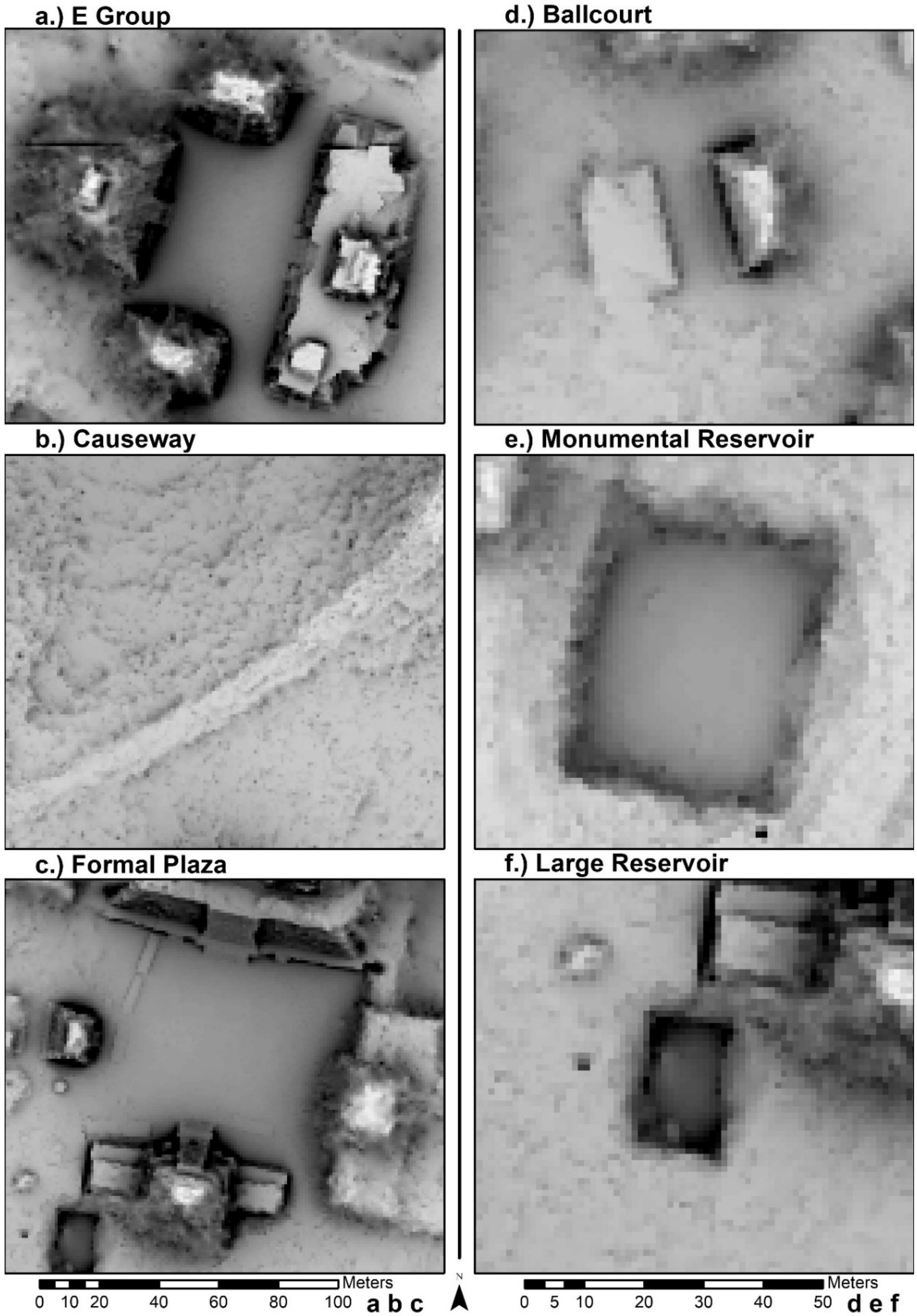


Figure 3.2: Sky-view factor visualizations of urban service features

3.7.1 Digitizing Garden City Features.

As for the garden city features (Figure 3.3) – i.e., plazuelas, residential reservoirs, and agricultural terraces – these tend to be smaller features in general and less well formally standardized in the built environment. The ancient Maya did not create identical looking *plazuelas*, reservoirs, and agricultural terraces. These attributes make them harder to identify on the landscape.

First, *plazuela* residential groups (Figure 3.3a) often are raised above the surrounding landscape, include multiple structures around a central residential plaza, have a vaguely cardinal orientation, and would have housed 11 to 18 people (Becquelin and Michelet 1994; Hellmuth 1977). Identifying these features requires a mix of local relief models and sky-view factor, but other supporting visualizations help. In particular, the plazuela groups adjacent to hillsides and terraced slopes, often with a stairway leading up to a structure on the higher elevated area, are more difficult to identify with sky-view factor alone.

Second, residential reservoirs (Figure 3.3b) also tend to be rectilinear, constructed depressions for water storage; but they are significantly smaller than the monumental reservoirs and their shapes are not standardized (ASZ Chase 2016a:892). Within Figure 3.3b the two reservoirs sit to the southeast and the west of the Dos Aguadas plazuela group, just off the residential plaza. Residential reservoirs are initially identified through local relief and sky-view factor visualization but require visual confirmation within the .las data to ensure that water would not drain from them. Multiple other "depressed" features at first glance appear similar to reservoirs, including: collapsed tombs, open tombs, and *chultuns* (ASZ Chase 2016a:888).

Finally, agricultural terraces (Figure 3.3c) form the most ubiquitous feature on Caracol's landscape (AF Chase and Chase 1998b; AF Chase, et al. 2011a:391-394). In construction, the Maya manipulated the soil down to bedrock when they built up the retaining wall (Healy, et al. 1983). It is this retaining wall that is most visible today and defining the downslope chain of terraces proves to be much easier than establishing the edges and sides of these features as they merge into adjacent slopes. At Caracol, there are terraces present in the valleys, on the slopes, and on hilltops; however, based on erosion and the pattern of terraces just beyond the urban boundary it is likely that terrace construction started in the valleys and worked up the hillslopes over time (ASZ Chase and Cesaretti 2019; ASZ Chase and Weishampel 2016; AF Chase, et al. 2020b:347). In any case, these features are easiest to see with a mix of geomorphons and classified slope visualizations to better visualize the sides of the fields adjacent to the terrace walls.

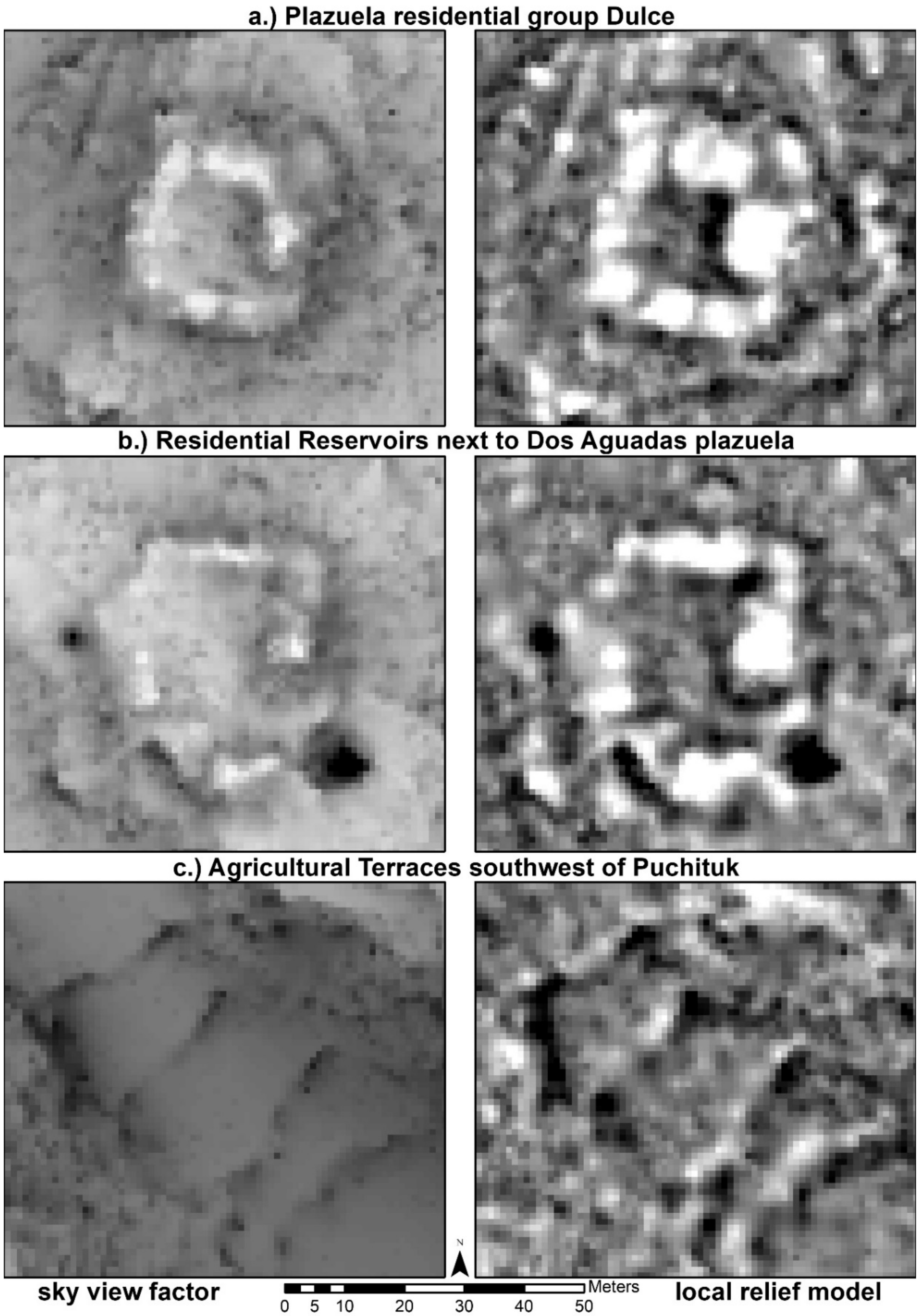


Figure 3.3: Garden city features with sky-view and local relief visualizations.

3.7.2 Manual Feature Extraction Overview.

Manual feature extraction requires patience and time as well as multiple visualization methods (Figures 3.1, 3.3). In the long term, this sample of well-established features at Caracol (and at other cities and settlements by other researchers) should provide a training dataset to test automated feature extraction techniques or train artificial search algorithms for future research. While every attempt has been made to digitize every feature in the landscape, given the one-meter by one-meter resolution and the scale of the garden city features, it is very likely that smaller features have been missed. For example, a 2.5-meter by 2.5-meter reservoir (a few that small have been identified from on the ground survey) could appear as a single raster cell depression depending on where within that meter the lidar ground returns came from. For the purposes of this analysis, a single cell depression is not identified as a reservoir, unless on the ground confirmation exists. Theoretically, the resolution could be increased to help. However, increasing the resolution would require more interpolation for cells with no known ground returns. This could lead to feature misidentification through the introduction of digital artifacts into the data from the interpolation process (a potential issue with kriging). In any case, this workflow, while time consuming, still yields substantially faster and more affordable results than traditional ground survey projects over the entire landscape at the same level of granularity; and, after the advent of efficient automated search algorithms the utility provided by this type of dataset will only increase.

3.8 Summary

Lidar data has provided a geospatial revolution for archaeologists working in heavily forested environments, allowing them to effectively survey large areas (see McCoy 2021). However, beyond remote feature identification, the lidar data and its derivatives facilitate a variety of potential analyses and research questions (such as those found in the following chapters). Archaeologists using lidar require additional computational training to ensure that algorithms do not remain mystery boxes of unknown processes and this will likely result in an enhanced computational archaeology (Grosman 2016; Huggett 2020; White 2016). Finally, the open-ended nature of lidar visualization creation and research avenues available means that research problems and questions need to be well-formulated and considered to avoid ad hoc research.

Researchers using lidar data must think through basic elements of their datasets and select methods that best match their research needs, from the raster used (hillshaded terrain model, slope, local relief models, openness, *etcetera*) to the coloring method employed for visual inspection (color ramps, color bins, and composite coloring). These initial decisions influence any higher order analyses of lidar datasets and the information they provide to archaeologists. In addition, specific methods (such as least-cost analysis, hydrology, visibility, and GIS-based feature measurements) ensure that these derivative datasets can answer a multitude of research questions. However, these lines of investigation build on longer histories of ground survey and excavation.

The next chapter provides an overview of the various data domains used in this dissertation. Taken together, these two chapters set the stage for the more detailed analyses and findings that arise in Chapters 5, 6, and 7. These analyses use the lidar dataset for Caracol and rest upon the foundation of lidar use presented in this chapter.

4 DATA DOMAINS

This dissertation focuses on three separate data domains to investigate and understand three specific aspects of governance at Caracol. Urban service facility features (data domain I) and the lidar dataset provide the fundamental material for understanding physical infrastructural power in Chapter 5. The non-monumental landscape of garden city features (data domain II) in the lidar dataset identify the role of household architectural autonomy in Chapter 6. Lastly, excavated material from decades of residential excavations (data domain III) permit the testing of reconstructed neighborhood boundaries and the collective action potential of those communities in Chapter 7. Each of these aspects relies on the lidar data collected in 2009 and 2013 by NCALM (AF Chase, et al. 2014b; AF Chase, et al. 2011a), while moving beyond feature recognition for their analyses.

Data domain I incorporates urban service facility features including: formal plazas, ballcourts, E groups, formal reservoirs (both large and monumental), and causeways. Each of these features possesses an innate monumentality that facilitates identification; however, other urban service facility features may have existed (both at Caracol and at other cities). The features used in this data domain are those with unique built environmental forms that will ease replicability at other cities. Importantly, each of these features provides information about infrastructure at the citywide and district levels of analysis through their roles as special locations from which urban services are provided.

Data domain II includes garden city features consisting of residential groups (both *plazuelas* and acropoleis), residential reservoirs, and agricultural terraces. The "garden city" attribution of these features highlights the importance of agricultural terraces and household gardens within this ancient Maya city (sensu Barthel and Isendahl 2013; AF Chase and Chase 1998b; Graham 1999). These features also comprise the non-monumental architectural landscape at ancient Caracol and make up most of the built environment. They ubiquitously occupy most of the roughly 200 square kilometers that make up the city of Caracol within Belize (another roughly 40 square kilometers exist in Guatemala outside the coverage of the Caracol lidar and are excluded from these analyses). This research provides a large sample of residential architectural features from across the city of Caracol and some that are beyond the city boundary, where both settlement density and agricultural terracing falloff. These features showcase the household and neighborhood levels of Caracol's urban landscape, but they still intersect with the district and citywide level based on their physical locations.

Lastly, data domain III includes the excavated material from a sample of neighborhoods, focusing on artifacts from caches and burials within plazuelas. Each neighborhood represents a clustered spatial community of plazuela groups that facilitated repeated face-to-face interaction in the past (ME Smith 2010; ME Smith and Novic 2012). This research focuses on eight neighborhoods located among the three districts of Downtown Caracol, Puchituk, and Monterey. Four are situated near downtown Caracol and the other four exist near other district nodes. This sample was selected to allow for identification of unique neighborhood material instead of patterns representing district market access (see the *neighborhood sample* section below). The neighborhood reconstruction builds on least cost path analysis of lidar data with consideration of networks, as outlined in Chapter 7. I test this reconstruction through analysis of this excavated material from both previous excavations (archival research) and from excavations that I conducted specifically to expand neighborhood samples for this dissertation. Taken together, the similarities (or differences) in material sheds light on the strength of these reconstructed neighborhoods with the linking argument that stronger neighborhood identity (e.g., more similarities) correlates with higher levels of potential collective action.

Each data domain provides specific information for understanding one aspect of governance at ancient Caracol. Data domain I provides information for the district and citywide levels in order to understand physical infrastructural power in urban administration. Data domain II provides information for the residential level (with implications for the other urban level) to investigate household architectural autonomy within the city. And data domain III provides information for the neighborhood level in order to understand the collective action potential of those neighborhoods. Taken as a whole, these three datasets yield significant information about ancient Caracol's urban life and governance. In addition, all three datasets make use of lidar data in novel ways that go beyond lidar's common use for feature identification.

4.1 Domain I – Urban Service Facility Features: Infrastructural Power

Data Domain I consists of urban service facility features. These features – E Groups, ballcourts, formal plazas, large and monumental reservoirs, and causeways – each helped provision various urban services to the residents of Caracol and altered the built environment in noticeable ways (following Stanley, et al. 2016). Aside from potentially one large structure along the Conchita causeway, all monumental architecture at Caracol exists solely in specific nodes of large-scale architecture situated near formal plazas, and nearly all of these nodes are inter-connected by the city's dendritic causeway system (ASZ Chase 2016b; AF Chase and Chase 2001). This system connects all site-wide causeway movement to downtown Caracol.

Each of these features also exhibits a unique built environmental form, permitting unambiguous visual identification in the lidar derived dataset. Thus, this data domain can easily focus on the spatial distribution of these features across the city. The more widespread these service features are, the more infrastructure is present, correlating with a higher degree of physical infrastructural power at Caracol. Put another way, the more accessible these features are, the more physical infrastructural power present. In addition, infrastructure and its resulting power shed light on collective action, collective governance, and can even act as a proxy for tax revenue (Blanton and Fargher 2008; Levi 1988; M Mann 1984, 2008), as outlined in Chapter 5.

4.1.1 The Boundary for Caracol the City.

One fundamental source of data for an understanding of physical infrastructural power is the boundary for Caracol. For the purposes of this thesis, the boundary is based on a falloff in agricultural terracing and settlement in the lidar-derived DEM (ASZ Chase 2016b). Within that boundary valleys, hillsides, and hilltops are often terraced. Beyond this boundary only valley terraces tend to exist. Another way of showcasing the importance of these terraces and their correlation with settlement follows.

Reviewing a slope map of the DEM showcases the degree of landscape modification at Caracol (Figure 4.1). Areas beyond this boundary have rougher (i.e., more variable) slopes. These rougher areas represent locations with fewer agricultural terraces. In other words, the reduced slope present at Caracol represents a completely anthropogenic landscape (AF Chase and Chase 2016b). Even today, over one thousand years after the end of Caracol the city, its former residents' modifications of the land still echo across time and space – and can be observed in the resulting landscape hydrology that facilitates soil retention and water distribution (ASZ Chase and Weishampel 2016) as well as the trees incorporated into the modern forest (Hightower, et al. 2014).

Analysis of ancient Maya cities has tended to emphasize the monumentality of temples and other grand architecture in city centers. In contrast, the labor investments in agricultural modification and maintenance at Caracol easily dwarf any labor estimates for its monumental constructions (ASZ Chase and Weishampel 2016:360). Excavations of terrace soils have indicated that they were heavily manipulated down to bedrock because they lack a C soil horizon or stones larger than 1mm outside of the areas for the retaining walls (Healy, et al. 1983:406). Digging and moving earth tends to be one of the highest labor costs in energetics analysis; as such, moving all of that soil around, even over short distances, requires more labor than the construction of pyramids (e.g., Abrams 1994; Erasmus 1965). Especially when considered over long periods of time, the people of Caracol concentrated more labor on the agricultural landscape itself than on the monumental architecture.

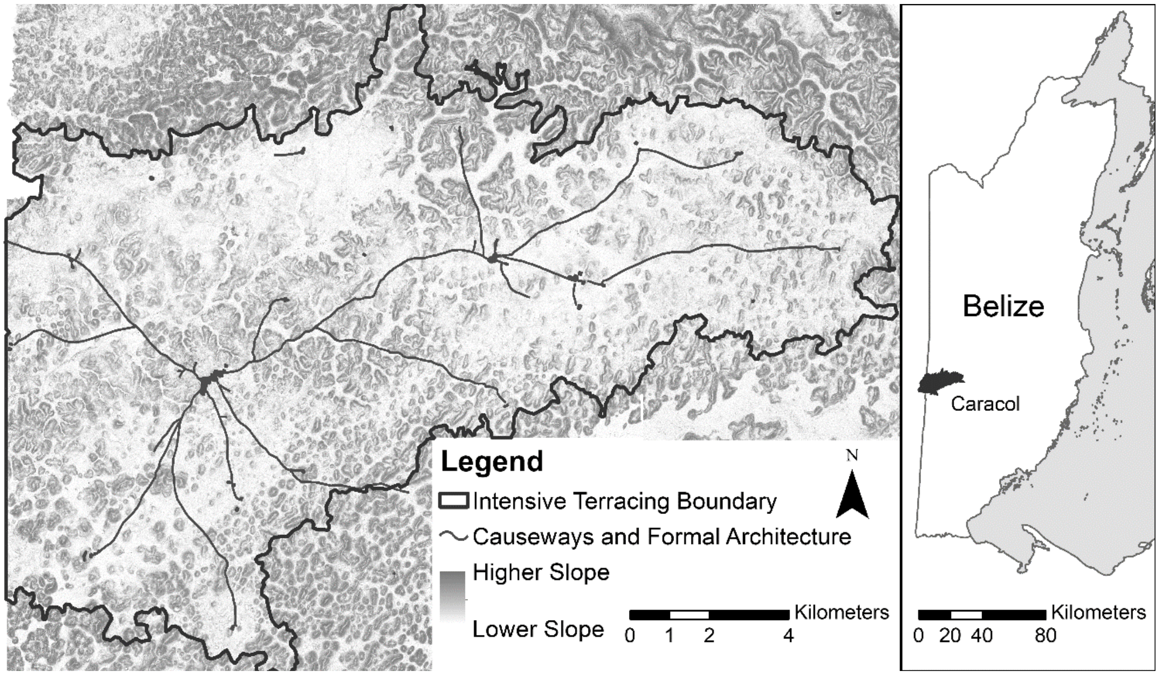


Figure 4.1: Caracol's reduced slopes
This map shows the reduced slope of the anthropogenic landscape. This lowered slope is directly related to the number of agricultural terraces present at Caracol, and in the top-left corner the terracing for another, separate settlement can be seen.

This identification of settlement and slope as anthropogenic investments in landesque capital provides the method to project a reconstruction of Caracol the city at is maximal extent, as shown in Figure 4.2. This map focuses on reduced slopes in the 30m SRTM data (JPL 2013) in conjunction with the city boundary described above. The 2009 and 2013 lidar datasets do not include any flights over Guatemala and this use of NASA data provides a means of identifying two potential new district nodes and about 40 additional square kilometers of Caracol the city. If this model of landscape modification and reduced slope indicating settlement holds over time, then Caracol at its apogee possessed 24 districts over nearly 240 square kilometers of settlement This does not include surrounding populations of individuals living closer to Caracol than another city or settlement.

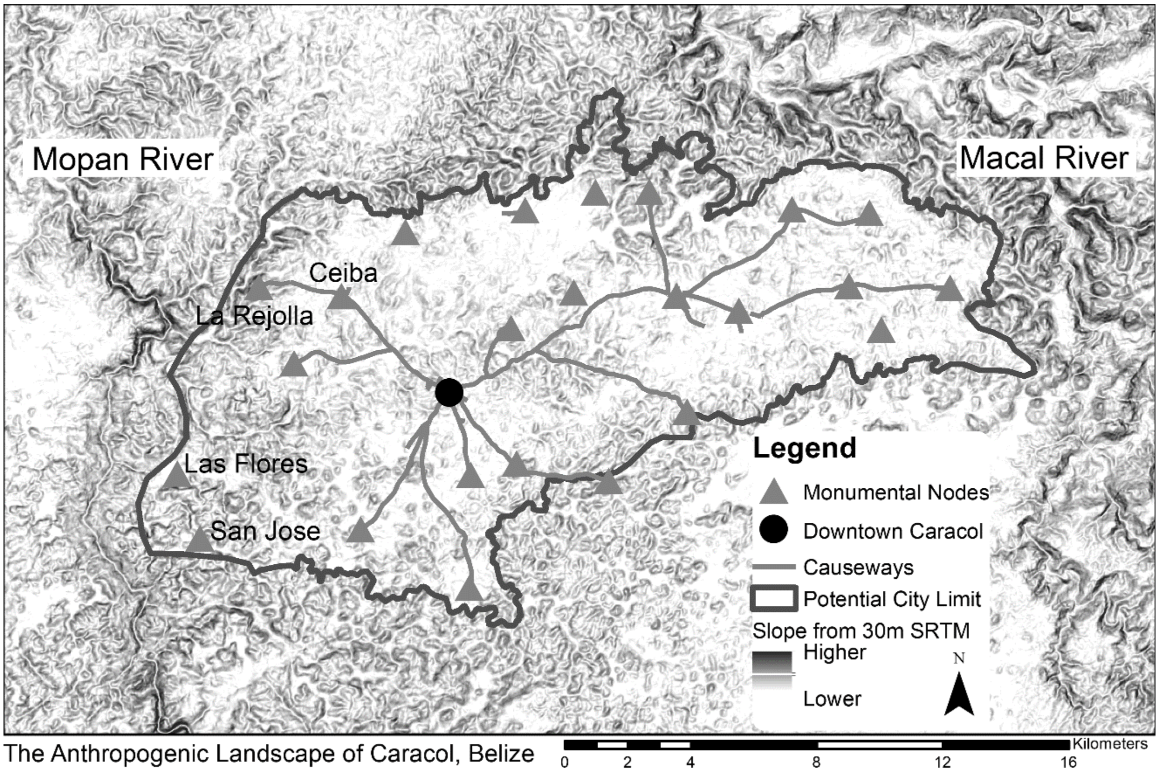


Figure 4.2: Causeway route from the Mopan river to Macal river
Map of a potential Caracol city boundary between the Mopan and Macal rivers. Using SRTM data (JPL 2013) to help identify a potential boundary in modern Guatemala.

However, this boundary requires future investigation and testing. If true, then San Jose and Las Flores Chiquibul in Guatemala (see Escobedo, et al. 2008) served as additional district nodes of Caracol the city. La Rejolla (also in Guatemala) possesses a known causeway connection to downtown Caracol through the Ceiba district node. Its incorporation into Caracol, as shown in the map above, provides an overland causeway route that effectively connects the Mopan and Macal rivers (Figure 4.2). This east-west causeway from river-to-river likely represents a specific, easily traversed road system through the city that then connected to other more formal trade-routes. These east-west routes likely ensured the passage of granitic metates and other hard stone resources from the Maya Mountains of Belize (see Graham 1987) into the Peten of Guatemala. Both Caracol and Tikal competed over their similar east-west trade routes from the Petén to the Caribbean as seen in broader archaeological distributions of ceramic and artifactual materials (AF Chase and Chase 2012a:8-11).

4.1.2 District Reconstructions.

Within the established borders for Caracol the city, I reconstructed potential districts using least-cost area analysis from the monumental nodes that contained urban service facility features and the city boundary described above (ASZ Chase 2016b). These district nodes are primarily defined by their formal plaza spaces and adjacent monumental architecture. The district shapefiles themselves provide a quick reference for which node sits closer to each *plazuela* housemound group located in this landscape.

Creating these features requires many of the same steps as a traditional least-cost path analysis. Utilizing Tobler's hiking function (Tobler 1993), and implemented in ArcGIS with map algebra (White 2015), this process generated several isotropic (having the same cost to and from) DEMs of movement-cost in hours from each node of monumental architecture. A new DEM including the identifier of the closest district node permitted the subsequent creation of district shapefiles, as shown in Figure 4.3.

This model essentially assumes that every individual in the city primarily used the closest district node. However, people do not always behave as fully rational actors who would use the closest services. As such, repeating this analysis by systematically removing one monumental node at a time allows for the reconstruction of spatially contingent natural neighbors (sensu Sibson 1981). This method provides a means to identify the closest two district nodes to every residential feature on the landscape.

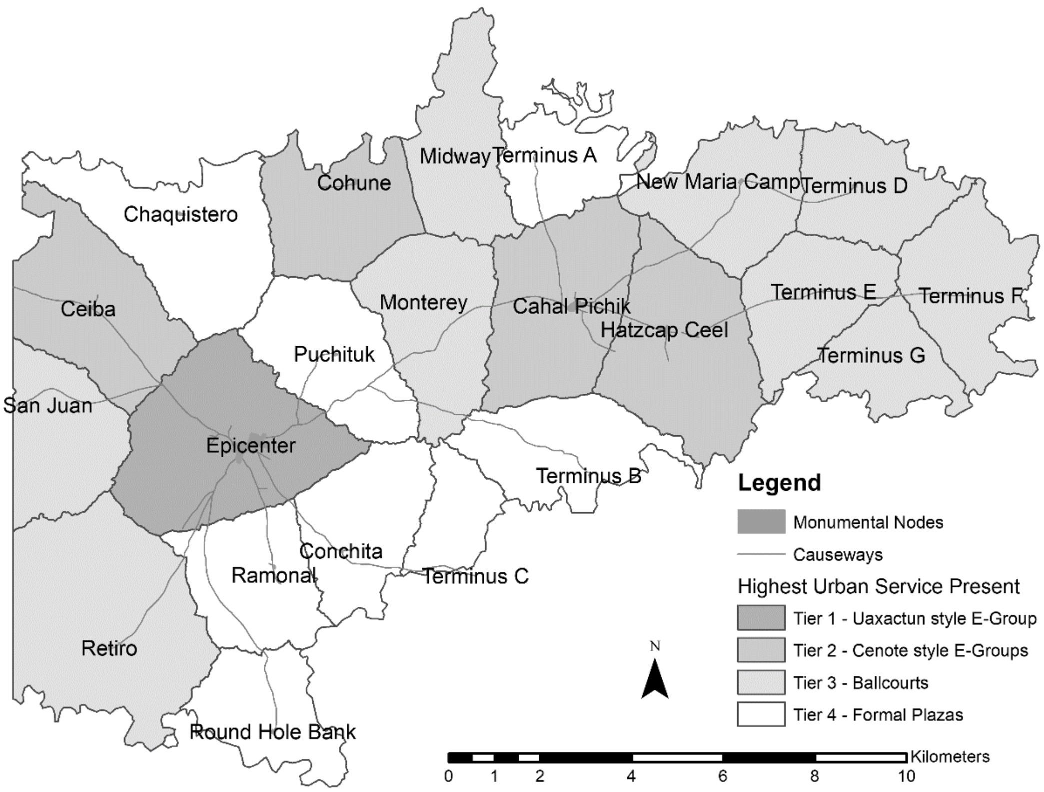


Figure 4.3: District shapefiles by service tier
Caracol's districts derived from least cost area allocation showing service tiers (explained in Chapter 5).

4.2 Domain II – Garden City Features: Household Architectural Autonomy

Data Domain II consists of the garden city aspects of Caracol associated with residential households. While the monumental architecture exists within specific nodes that are usually directly connected by the dendritic causeway network (AF Chase and Chase 2001), the garden city features comprise the rest of Caracol the city. This dataset includes the *plazuela* residential groups, the agricultural terraces, and the residential reservoirs. As a result, Caracol possesses a distinctive urban form and would qualify as a blue-green city (Barthel and Isendahl 2013), a green stone city (Graham 1999), or a garden city (AF Chase and Chase 1998b). Each of these terms refers to the inclusion of subsistence agriculture within an urban framework and, specifically, to the urban form of infield agriculture – agricultural fields within the city in addition to other green space features like kitchen gardens (AF Chase and Chase 1983, 2016b; Fisher 2014, 2020; Hutson, et al. 2007; Killion 1992). While urban agriculture exists in some modern cities (see Anh, et al. 2004; Arias Hernández 2004; Barthel, et al. 2015; Clouse 2014; De Bon, et al. 2010; Egziabher, et al. 1994); the full form of ancient Maya garden city urbanism described above – which was also prevalent in ancient tropical cities in Southeast Asia and Africa (see Coningham, et al. 2007; Evans and Fletcher 2015; RJ Fletcher, et al. 2003; Kusimba, et al. 2006) – no longer exists today.

The average residents of Caracol would have spent most of their time among these features of the built environment, their *plazuela* group with a local reservoir and their associated terrace fields for agricultural and sylvicultural use. Each *plazuela* unit also engaged in its own specialized household industry related to the production of chert, shell, bone, or other material goods (AF Chase and Chase 2014a, 2015). Items not produced by residents of these *plazuela* groups could be accessed in the various markets distributed widely across the landscape among the formal plazas at Caracol (AF Chase, et al. 2015; DZ Chase and Chase 2014b).

The standardization present among these garden city features, or lack thereof, as explored in Chapter 6, elucidates the degree of household architectural autonomy at Caracol. While standardization can result from top-down or bottom-up processes, the variation across the city, among neighborhoods, or within districts helps shed light on the spatial scale (if any) at which construction was organized. Standardization, measured using the coefficient of variation and relationships among feature areas, volumes, and perimeters within each spatial unit and plotted graphically, shows any existing degrees of regularity. If present, these differences in standardization may indicate the scale at which the associated feature(s) was(were) constructed and managed, highlighting the level of governance required and entailed; and, if absent, it provides an argument for higher household autonomy, perhaps with less bureaucratic oversight at the household level.

4.3 Domain III – Neighborhood Identities: Collective Action Potential

Data Domain III consists of neighborhood-based samples and their associated artifactual materials. This data derives from excavation of the eastern structures of *plazuela* groups. For at least 70% of households at Caracol, this structure served as a ritual building for the extended family group of the plazuela (AF Chase and Chase 2014a). The commonality of eastern ritual structures, caching practices, and tombs has been well established at Caracol as part of the "Caracol identity" (AF Chase and Chase 2009; DZ Chase and Chase 2004b). These aspects seem to relate to a citywide set of shared cultural practices; however, they might also contain information about more localized neighborhood practices.

The households excavated as a result of this research, in conjunction with prior excavations, help shed light on the degree of similarity in material remains associated with caches and burials within neighborhoods, and these similarities in material remains provide a proxy for collective action though shared categorical identity (e.g., Peeples

2018). Theoretically, these similarities in ritual practices should increase the degree of potential collective action among the population (Feinman and Carballo 2018:9-10). In addition, according to ME Smith and Novic (2012:8-11), neighborhoods should exhibit unique material assemblages as an extension of their unique neighborhood identities, if any such similarities were present. Given the interactions and relationships among individuals living in these communities, a unique shared identity should evolve – and its presence would facilitate future collective action by lowering the threshold for such collective behavior.

The analysis of artifactual material present at a sample of eight neighborhoods at Caracol focuses on the readily identifiable artifacts used in caching and burial practices. Based on the literature above, we would expect neighborhoods to exhibit more similar cultural practices that could be part of a neighborhood identity and lead to a higher degree of potential collective action through perceived similarities. To investigate this, I use material contained in the eastern structures of residential groups and deposited in tombs, burials, and caches (see AF Chase and Chase 2014a:4-6). Even without being displayed the contents would have been known to household members. This material, while intentionally deposited and sealed, were also occasionally disinterred. The ancient Maya at Caracol re-visited previous burials (DZ Chase and Chase 1996b, 2003b, 2011b) and show a pattern of cyclical caching and burial use and re-use (AF Chase and Chase 2013b; DZ Chase and Chase 2004c; 2017d:213). In addition, all *plazuelas* at Caracol appear to have had access to similar materials (likely procured from the market system) for these ritual deposits (DZ Chase and Chase 2017d:214-215). This "Caracol identity" of specific eastern shrine materials could (but does not) skew the data to show less variation between neighborhoods and standardization within the citywide or district levels instead. In any case, the collective action potential will be stronger with multiple overlapping categorical identities, and the neighborhood pattern investigated in Chapter 7 still relies on the citywide categorical identity manifested in these similar eastern shrine structures contained within residences across the city to procure a sample of materials from these neighborhoods.

4.3.1 Neighborhood Sample.

Data for testing the validity of the reconstructed neighborhoods (see Chapter 7) comes from both existing data and newly conducted excavations. This includes a sample of 60 residential plazuelas across 8 neighborhoods in 3 districts described below. Caracol's epicenter has been well tested over several decades of archaeological research; however, fewer *plazuelas* have been excavated from outlying districts in a comparable fashion except for those at Puchituk and Monterey. While the neighborhood sample used in this research could have simply used those residences in the district of Downtown Caracol, properly factoring out the effect of the district marketplace distributions on neighborhood material requires an equivalent sample of neighborhoods from other, non-epicentral districts. While neighborhoods did not necessarily use the most proximate markets, this neighborhood sample only includes only neighborhoods adjacent to these district nodes to reduce influence of other markets on their material distributions.

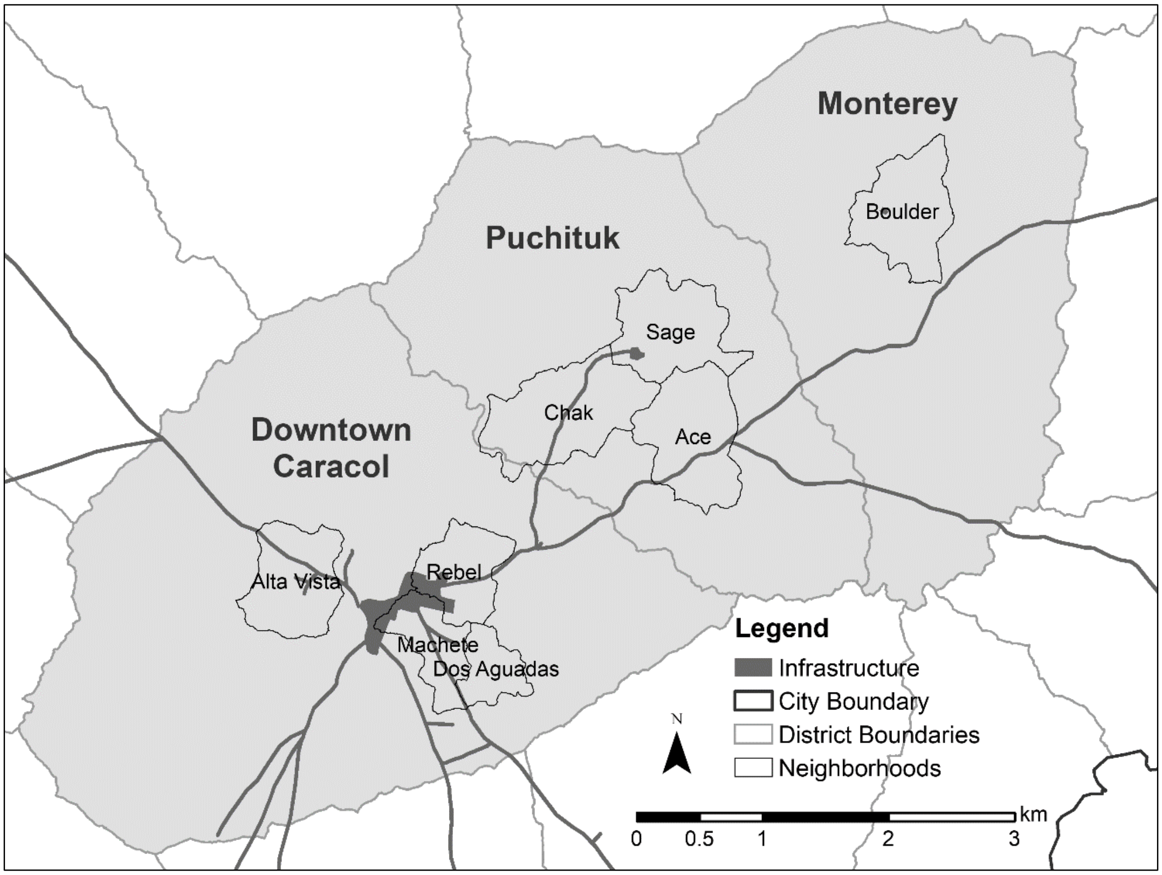


Figure 4.4: Sampled neighborhoods (also Figure 7.1)
The eight neighborhoods selected as a research sample for Data Domain III creating a sample of four neighborhoods in downtown Caracol and four neighborhoods in outlying districts.

In order to create a balanced sample of four neighborhoods near downtown Caracol and four neighborhoods near other districts, excavations immediately east-southeast of the Puchituk terminus were conducted as part of this dissertation research. Near the epicentral district of downtown Caracol the neighborhoods of Alta Vista, Dos Aguadas, Machete, and Rebel have been selected due to both their adjacency to downtown Caracol and high sampling of residential *plazuelas*. In addition, both Machete and Dos Aguadas represent nearly complete neighborhood samples. In other words, all of these epicentral neighborhoods have been tested extensively in prior field seasons, allowing for a use of archaeological data that can be derived from the catalogue cards, lot cards, and season reports. Alta Vista lies immediately west of the site core beyond a palace and raised plaza linked to the epicenter by causeways. Rebel is situated immediately north of the epicentral C Group. Both Machete and Dos Aguadas are adjacently located to the southeast of the epicenter (AF Chase and Chase 1987). Residents of these neighborhoods likely used the same marketplaces in the downtown Caracol due to their proximity, although they do sit along differing causeway routes into and out of the downtown that may indicate the preferred secondary markets they likely preferred.

Four additional neighborhoods from two additional districts expand this sample. The Puchituk and Monterey districts lie to the northeast of downtown Caracol. Puchituk acts as a causeway terminus, but the causeway system bypasses Monterey's public architecture entirely. Both districts have neighborhoods which received excavation in the 2017, 2018, 2019, and 2020 field seasons of the Caracol Archaeological Project. Testing was also conducted in this portion of the city northeast of the epicenter during the 1994-1996 field seasons. The collected data provide three neighborhoods affiliated with Puchituk, one on each major hill in the vicinity and all adjacent to Puchituk's monumental architecture: Sage appended to Puchituk plaza and to its east incorporating another hill; Ace to the southeast on its own ridge; and Chak to the immediate west of this terminus. The final neighborhood in this analysis is almost six kilometers distant from the epicenter and encompasses the excavated residential groups associated with the Monterey district – the Boulder neighborhood. This neighborhood circumscribes Monterey's formal plaza and ballcourt spanning the area between the two nearby hillsides. Taken as a whole, these four neighborhoods would have utilized two separate, but proximate, marketplaces and would have required a very long walk to get to the city center.

4.3.2 Material Indicators.

As a whole, the distribution of artifactual materials and contexts in these eight neighborhood samples helps factor out the potential effects of market distribution from their respective district nodes (four downtown and four in other districts). As a result, the material within the neighborhoods can elucidate the collective action potential through shared neighborhood identity, as measured by similarity in common materials from tomb, burial, and cache contexts associated with each *plazuelas'* eastern structure (e.g., ceramics and dental modification). These contexts, their contents, and the practices associated with them are related to residential level ritual, and the same types of deposits occur from the largest residence of Caana to the smallest sampled *plazuela* group. This widespread nature and the fact that, "… mortuary practices are often conservative and slower to change …" (Tarlow 2015:9) support the use of this material to test the categorical nature of ritual in these neighborhoods.

These mortuary contexts provide a unique method of looking at similar practices that go beyond shared relational identity (i.e., from group participation in individual rituals). Mortuary artifacts and offerings provide actions and means for communicating with the ancestors (McAnany 1995), for connecting with the supernatural forces that assure the well-being (López Luján 1993) or permanence (Houston 2014) of the deceased and the living alike, or that have the power to bless buildings for the duration of their existence (Bourdieu 2003). While these actions involve relational identity in the shared interactions of the rituals, the cultural logic of the material expressions tends to be derived from deeply held and widely shared beliefs that resist change over time. In other words, the mortuary contexts of eastern residential shrines provide an insight into the unquestioned assumptions belonging to a wider collectivity than an individual's immediate relations, and going beyond those of everyday interactions among neighbors (Bourdieu 1994).

In addition, while excavations of Caracol's households have shown similarities in this type of material as a whole, this data has been selected to investigate local variation within this broader pattern. While other residential material from non-burial and cache context can provide information on market distributions and exchange systems and some data provide information on wealth or socio-economic status, this analysis attempts to avoid those larger issues. As described in Section 7.4.2, this analysis focuses on all 14 basic Late Classic ceramic forms and two kinds of dental modification (see also Tiesler 2020:114), all recovered from eastern building contexts. Lumping together specific ceramic types helps remove time as a factor in this analysis and aggregating the data by plazuela provides a household level perspective that avoids the issues of re-entry and deposit form. It also leaves room for future analysis to see how this data contrasts with other materials from these special deposit and other residential contexts. A variety of other artifacts made out of obsidian, chert, groundstone, soapstone, serpentine/greenstone, stucco, worked and unworked bone (human and faunal), worked limestone, speleothems, slate, river cobbles, jadeite, pyrite, hematite, malachite, quartzite, worked and unworked marine shell, river shell, and corals are not included in this analysis.

When materials and types of deposits are more similar within neighborhoods than between them, this bolsters the idea of unique neighborhood categorical identity (beyond the relational identity implicit to the definition of social neighborhoods). It will also indicate that the neighborhood reconstruction identified groups with internal coherence, at least for these contexts. Finally, and the presence of shared material culture based on these rituals provides one line of evidence for a high potential for collective action within these neighborhoods in conjunction with the widespread shared practices previously identified at the citywide level.

However, it is possible that a citywide or district level categorical identity could override local distinctions. Similarities within districts may be due to market distributions instead of any intentional district identity, or categorical identities at the citywide and district level may have overpowered any archaeological signature of neighborhood level identity. In addition, a lack of neighborhood infrastructure in the built environment may have been due to a lack of neighborhood cohesion and collective action potential due to either of the above. In other words, an absence of similarities between neighborhood groups would likely be indicative of a lower potential for collective action at this social level and would require future research to better understand the processes at work at this "neighborhood" level of analysis. Luckily, this dataset bears out patterns of neighborhood level similarities precluding the strong influence of these alternative hypothesis.

4.4 Summary

This dissertation research combines three separate data domains to answer specific questions about governance at ancient Caracol by using methods that could be replicated elsewhere for other archaeological cities. Urban service facilities and their distribution shed light on the level of physical infrastructural power, as explored in Chapter 5. The garden city features, and their standardization, showcase the degree of household architectural autonomy, as seen in Chapter 6. And the similarity in neighborhood caching and burial practices provides overall insight into the similarity in the potential for collective action through neighborhood categorical identity, as discussed in detail in Chapter 7. Each of these three aspects presents a new way for looking at and analyzing governance among the ancient Maya. Taken together, they provide a more holistic view of governance in the ancient city of Caracol, Belize.

5 DISTRICTS AND URBAN SERVICES

While Mayanists often focus on the despotic power invested in rulership (e.g., Fash 1994:183; Lucero 2006b:38-44), direct evidence of the extent and impact of a ruler's power can be difficult to directly extract from the archaeological record. While one might normally turn to history, only a limited number of bark-paper books survive and remaining books provide detailed insight into ritual and astronomical matters rather than social and political relationships (e.g., JES Thompson 1972). Stone monuments imply the power of rulership by focusing on the relationships and conquests of individual rulers. Stelae and altars at Caracol, like those at most lowland Maya sites, describe relationships among rulers but not the day-to-day lives of the ancient city and polity's inhabitants. Thus, while the texts emphasize the power of rulership (Martin and Grube 2000:100-115), the extent of that control on the population is difficult to ascertain without additional data and analysis.

As noted previously in Chapter 2 material indications of physical infrastructural power can fill that void and identify the extent to which ancient Caracol had a high or low degree of infrastructural power following (M Mann 2019:173), whether that infrastructure was centralized or dispersed, and what generative forces may have been responsible for the ultimate infrastructural form of this ancient city. Both M Mann (1984, 2008) and Blanton and Fargher (2011, 2012) highlight the importance of urban infrastructure for states. Evidence of physical infrastructural power manifests itself in the built environment through specialized architectural features (i.e., formal plazas, ballcourts, e-groups, causeways, etcetera) that both provided important services and, at the same time, potentially served to organize and shape ancient behavior. Thankfully, the ancient Maya constructed administrative architecture liberally at Caracol, providing an excellent dataset for analysis. Previous cross-cultural comparisons have highlighted the relatively collective nature of Caracol the city (Feinman and Carballo 2018:11-12). However, prior analysis has not had access to the full extent of the city's landscape to evaluate actual levels of physical infrastructural power.

In the time period under analysis, Caracol may have been the seventh largest city in the world (see Modelski 2003); thus identification of its urban infrastructure is important not only to Maya archaeology but also in terms of cross-cultural comparison to other cities and states. In the sections below, I operationalize physical infrastructural power and present four distinct lines of analysis (using data domain I from Chapter 4) that, when combined, build a strong argument for the existence of high levels of physical infrastructure power at Caracol during the Late Classic Period. These various analyses also support the interpretation of Caracol as a collectively governed city despite the presence of an autocratic ruler as documented in hieroglyphic texts.

5.1.1 Operationalizing Infrastructural Power.

Mann (2019:173) defines infrastructural power as, "the capacity of the state to actually penetrate civil society and so get its actions logistically implemented throughout its territories." He also distinguishes between physical and social infrastructure. As used in this dissertation, *physical infrastructural power* is the ability of the urban governance system to provision services at particular urban levels (e.g., citywide, district, neighborhood, or residential) within the built environment. Modern technology facilitates both service provisioning and record-keeping (i.e., social infrastructural power), so ancient cities should exhibit less infrastructural power than modern ones (i.e., very few ancient societies will contain civic services at the household level). In addition, while both written records and the built environment provide information on the level of infrastructural power present, Caracol's written records focus exclusively on the ruler. As such, the distribution of urban service facilities around the city serves as a proxy for the degree of physical infrastructural power at Caracol.

This chapter uses the district and citywide levels to investigate urban service facility features at Caracol. These urban service facility features (e.g., causeways, formal plazas, ballcourts, formal reservoirs, and E Groups) provided official venues for economic, ritual, or political activities. The number and distribution of these features gives a direct indication of the degree to which city's physical infrastructural power infiltrated daily life with the following expectations:

1.) Widespread urban service facilities within neighborhoods (and at larger scales) indicate high physical infrastructural power.

2.) District based urban service facilities indicate moderate physical infrastructural power.

3.) Centralized urban service facilities limited to the downtown or city centers indicate low physical infrastructural power.

These larger questions are broken up into four smaller analyses. The first two analyses investigate the patterns of these urban service facility features in the built environment while the second two test the efficacy of reconstructed districts at provisioning urban services. The first analysis investigates the urban service facility features themselves and their distribution at Caracol using size metrics to see their distribution on a per-feature basis. The second analysis looks at the relationship between local populations and formal plaza area based on initial research by both Inomata (2006) and Ossa, et al. (2017). This provides information about the use of formal plazas and how their size varies with increased population. The third analysis uses settlement scaling research (see Ortman, et al. 2014; Ortman, et al. 2020; ME Smith, et al. 2021b) to test intra-urban service provisioning of the reconstructed districts at Caracol. This pattern of settlement scaling within districts has also been observed within modern cities (Xu, et al. 2020), but its use here also provides a means to test the infrastructural implications based on social interaction within the areas of these reconstructed districts. Lastly, the fourth analysis investigates the accessibility of these features on the landscape through least cost analysis. All four analyses combine to provide a more detailed perspective on physical infrastructural power at ancient Caracol (expanding greatly on ASZ Chase 2016b) with the first and second investigating the services within district nodes and the third and fourth testing the veracity of these spatially reconstructed district areas.

First, I present a four-tier model of districts based on presence of five urban service facility features (see Stanley, et al. 2016): causeways, formal plazas, ballcourts, formal reservoirs, and E Groups. These various service features are associated with nodes of monumental architecture across Caracol's landscape. At the same time, not every district contains every feature. Instead, the distribution and sizes of these features provide input on how widespread and pervasive infrastructure was at the citywide and district levels.

Second, analysis of the relative populations and formal plaza sizes tests the potential uses of these formalized open spaces along with implications about district versus citywide physical infrastructural power. This section makes use of prior work by both Inomata (2006) and Ossa, et al. (2017). The first set of results tests the ability of people to fit in formal plazas for ceremonies; the second examines the resulting scaling relationship of formal plaza size and population. This builds on the logic of formal plazas and their ability to serve as loci of energized crowding (see ME Smith 2019). In terms of people per plaza (e.g., Inomata 2006), these formal plazas can be too small for their local populations, satisfactory to their needs, or larger than required. The larger the plaza, the more infrastructure is present, but the scaling analysis provides additional information. In terms of scaling (e.g., Ossa, et al. 2017), values near one indicate equivalent infrastructure regardless of population (extra people equals extra space), values below one indicate more dispersed physical infrastructural power in districts (because larger districts cannot contain as many of their people), and values above one indicate more centralized physical infrastructural power at the citywide level (because larger districts have not only more space but more space per person).

Third, moving from district nodes to district areas, the district reconstruction at Caracol is tested. This analysis expands on the scaling relationship above (formal plazas and people) into the general realm of urban/settlement scaling theory (e.g. Bettencourt, et al. 2007; Lobo, et al. 2020; Ortman, et al. 2014). To put it simply, this theory posits that systems of cities see nonlinear, exponential, changes in other factors as population increases. In one example, bigger settlements do not simply have more civic architectural volume, but more civic architectural volume per person (ME Smith, et al. 2021b:11-13).

While a fractal pattern of intra-urban scaling (i.e., districts scaling within cities) remains undertested, this analysis provides a second example to augment recent research demonstrating intra-urban scaling exists in some modern cities (Xu, et al. 2020). If these reconstructed districts provisioned urban services in the past, then this scaling analysis will test if these services acted as more infrastructural (closer to 5/6ths scaling) or social (closer to 2/3rds) spaces (following the values from Ortman, et al. 2014:3); however, other values (below 2/3rds or above 5/6ths) could be obtained indicating that these district reconstructions may not have been used as such in the past.

Finally, this fourth analysis builds directly on the analysis above. Here I evaluate the accessibility of these features through least cost analysis of walking time for formal plazas, ballcourts, and E groups. Formal reservoirs were excluded from this analysis based on the results of analysis three above and discussed later in this chapter. The fundamental assumption (from settlement scaling theory) is that urban services with scaling factors closer to 2/3rds from above should exhibit greater accessibility and shorter walking times than those reconstructed districts for services closer to 5/6ths. While recent scaling work by ME Smith, et al. (2021b) suggests that Maya cities had a "slower temporal rhythm" of social interaction, this analysis provides a means of investigating how easy or difficult it would be for an ancient resident to go to one of these district nodes to interact.

Taken together, these four analyses test the physical infrastructural power of the ancient city of Caracol (and its districts). However, context is important. The results of investigating infrastructural power would be higher at a more modern settlement that has more advanced technology, additional urban services, or more elaborate communication and recording abilities. Nevertheless, the results of these analyses provide additional information on the urban services present at Caracol and a more detailed perspective on prior interpretations for its more collective governance (see also Feinman and Carballo 2018:11-12).

5.2 Urban Service Facility Features and Districts

At Caracol, the causeways, formal plazas, ballcourts, larger reservoirs, monumental reservoirs, and E Groups formed the primary set of urban service facility features – the features that provided official venues for economic, ritual, or political activities. Each of these built features would have provisioned services to urbanites in the past (following Stanley, et al. 2016). The co-location of these features into distinct nodes of monumental architecture allows for the identification of up to 25 districts at ancient Caracol (Table 5.1). Three of these districts are located in modern Guatemala and outside the scope of this dissertation; they would require additional lidar or on-ground survey to analyze, However, the 22 districts in modern Belize can be sub-divided hierarchically into four distinct tiers (see ASZ Chase 2016b) based on the presence of formal plazas, ballcourts, and E Groups (both Uaxactun and Cenote style, see AF Chase and Chase 2017b:33-34). In addition, least cost area allocation permits the recreation of district boundaries while incorporating Caracol's rugged landscape. Other urban service facility features may exist (e.g., range or gallery structures as meeting rooms or gateway groups as tollbooths), however, this set of urban services already provides a good dataset for investigating physical infrastructural power.

Table 5.1 provides metric data about the urban service facility features in 22 (of 25) urban districts in the city of Caracol. These measurements for districts within modern Belize derive from survey maps of the site (AF Chase and Chase 1987, 2001) and from datasets derived from lidar (AF Chase, et al. 2014b; AF Chase, et al. 2011a). In addition presence/absence information derives from Escobedo, et al. (2008:264-265,305-306,309-310) for one confirmed district and two potential districts within modern Guatemala. In addition to Table 5.1, the map in Figure 5.1 shows a visual representation of this data using a sky-view factor visualization as a background image for the various urban service feature shapefiles.

District Name	Causeway	Formal Plaza	Ballcourt structures	Ballcourt court	Ballcourt court	Monumental Reservoir	Large Reservoir	E Group structures	E Group W-length
	Description	Area m^2	Area m^2	Area m^2	Length m	Area m^2	Area m^2	Area m^2	Length m
Service Feature Tier 1: Uaxactun E Group, Cenote E Group, Ballcourts, Formal Plaza									
Epicenter	Primary Hub	71,730	A Group: 850	140	23	1,970	290	7,000	112
			B Group: 660	140	22				
Service Feature Tier 2: Cenote E Groups, Ballcourts, Formal Plazas									
Cahal Pichik	Secondary Hub	23,500	690	30 *	17	3,550	-	5,440	88
Hatzcap Ceel	Medial	23,450	720	120 *	20	1,490	-	4,420	97
Ceiba	Medial	5,820	430	90 *	22	-	750	3,010	73
Cohune	Local	6,390	350	50 *	19	-	-	1,650	59
Service Feature Tier 3: Ballcourts, Formal Plazas									
Retiro	Terminal	8,840	970	140 *	22	-	470	-	-
Terminus D	Terminal	4,830	430	120 *	20	-	120	-	-
Terminus E	Medial	2,590	420	130 *	19	-	-	-	-
San Juan	Medial	2,780	400	90 *	17	-	-	-	-
New Maria Camp	Medial	5,060	450	120 *	17	-	-	-	-
Terminus F	Terminal	2,800	340	100 *	17	-	-	-	-
Midway	Local	4,190	300	80 *	16	-	-	-	-
Monterey	-	2,080	280	65 *	17	-	-	-	-
Terminus G	-	2,300	350	130 *	19	-	-	-	-

District Name	Causeway	Formal Plaza	Ballcourt structures	Ballcourt court	Ballcourt court	Monumental Reservoir	Large Reservoir	E Group structures	E Group W-length
	Description	Area m^2	Area m^2	Area m^2	Length m	Area m^2	Area m^2	Area m^2	Length m
Service Feature Tier 4: Formal Plazas									
Chaquistero	-	8,040	-	-		-	-	-	-
Conchita	Medial	4,270	-	-		-	-	-	-
Puchituk	Terminal	4,200	-	-		-	160	-	-
Ramonal	Terminal	3,240	-	-		-	-	-	-
Round Hole Bank	Terminal	2,240	-	-		-	310	-	-
Terminus B	Terminal	1,640	-	-		-	-	-	-
Terminus A	Terminal	960	-	-		-	-	-	-
Terminus C	Terminal	1,220	-	-		-	-	-	-
Confirmed district node in Guatemala (Escobedo, et al. 2008:264-265)									
La Rejolla	Terminal	Present	-	-		-	-	Present	Present
Unconfirmed/potential district nodes in Guatemala (Escobedo, et al. 2008:305-306,309-310)									
Las Flores Chiquibul	Local / ???	Present	-	-		-	Present	Present	Present
San Jose	Local / ???	Present	-	-		-	-	Present	Present

Area values rounded to the nearest 10 meters-squared, and length values to nearest meter. *indicates issues with reported values

Table 5.1: District tiers and urban service facility feature measurements
This table contains measurements of urban service facility features within the monumental nodes of Caracol's districts (and updating ASZ Chase 2016b:Table 2). Services occur in a strict hierarchical scale of Uaxactun style E Groups (tier 1), Cenote style E Groups (tier 2), Ballcourts (tier 3), and Formal Plazas (tier 4). Each higher tier includes all features in the lower tiers. All districts with E Groups have ballcourts and all districts with ballcourts have formal plazas.

Both the Table (5.1) and the maps of monumental nodes (Figure 5.1) evince the strict hierarchical difference in service features present in each district tier within Caracol. While the specific sizes of features overlap between them, these tier designations are based on presence/absence of specific features, including E Groups (both Uaxactun and Cenote style, see AF Chase and Chase 2017b:33-34), ballcourts, and formal plazas. These three features exist in a strict hierarchy where E Groups always co-occur with ballcourts and ballcourts always co-occur with formal plazas; however, the inverse of both statements is false (ASZ Chase 2016b:25-26). Another way to consider this relationship is that residents of this city travelled further to use E Groups than to watch games in ballcourts, and the ubiquity of formal plazas indicates that ancient residents used them more frequently than all other services.

While it was initially hoped that large reservoirs not co-located with residential households or agricultural terraces would be useful in establishing districts, they do not exhibit any clear hierarchical relationship with other service features. Formal reservoirs have been the subject of substantial research; however, their primary purpose continues to be discussed and debated. They may have provided services for the distribution of water to the population at-large or buttressed royal ritual and authority (Lucero 2006a, b), but alternatively they also may have served more mundane purposes such as for the plastering, construction, and maintenance of monumental architecture. Their function may also have changed over time. The ancient Maya constructed both monumental reservoirs and E Groups during earlier time periods (e.g., Preclassic through Early Classic 1) and this probably affects their resulting distribution. Other large reservoirs are in areas that have not seen extensive excavation but may be similarly early in date. For the E Groups within Caracol, initial construction used the Cenote-style form in the Late Preclassic, but eventually only remodeled the downtown Caracol E Group into the only Uaxactun-style E Group at Caracol in the Early Classic (AF Chase and Chase 2017b:49-56), thus reinforcing the epicenter as the unique primary tier 1 city center.

Additional monumental architecture can be seen in the map shown in Figure 5.1. While the ancient Maya may have provided services at other structures situated in their formal plazas, potential uses of those features remain more ambiguous. Some of the monumental architecture represents elite residences called acropoleis (acropolis when discussing one feature); other architecture represents range or gallery structures that could have served as meeting rooms and gateway groups along the causeways could have acted as tollbooths for those entering the formal plazas.

While formal plazas provided the fundamental unit in a district node, the Maya built additional monumental architecture in and around those plazas (Figure 5.1). The concentration of this architecture, especially service features, suggests that these nodes served as district centers (following administrative districts from ME Smith 2010:140). As discussed in Chapter 4, to reconstruct potential service areas for these districts, I combined the digital elevation model, least cost area allocation method, and presence/absence of various urban services to produce the map in Figure 5.2 (see also ASZ Chase 2016b). The city boundary used for Caracol represents both a falloff in population density and a reduction in agricultural terracing. I used this process of least cost area allocation within the city boundary to produce formal plaza service districts, ballcourt service districts, formal reservoir service districts, and E Group service districts.

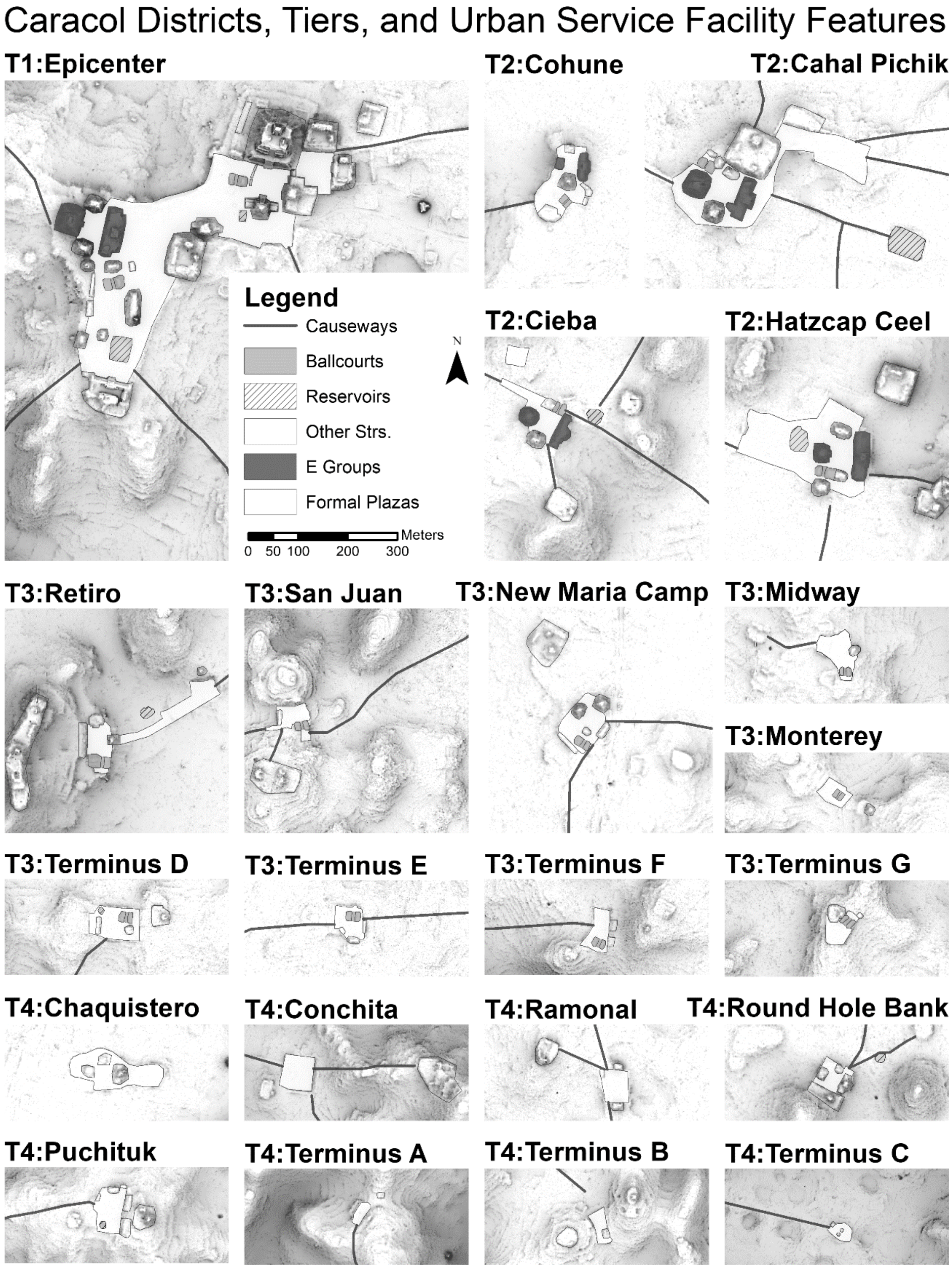


Figure 5.1: Maps of the monumental nodes in 22 of Caracol's districts.
Each district is labeled with its tier from Table 5.1 where T4 has formal plazas, T3 also has ballcourts, T2 also has Cenote style E Groups, and T1 has a Uaxactun style E Group.

The reconstructed service areas demonstrate that higher tier services have greater provisioning areas and less overall distribution, suggesting that the ancient Maya used these services more infrequently. The E Groups of Tiers 1 & 2 have the most restricted distribution, followed by ballcourts in Tier 3, and formal plazas within Tier 4. Importantly, all of the infrastructure at Caracol rested on the use of causeways to interconnect the city (Figure 5.2). Each of these service features is described in greater detail below.

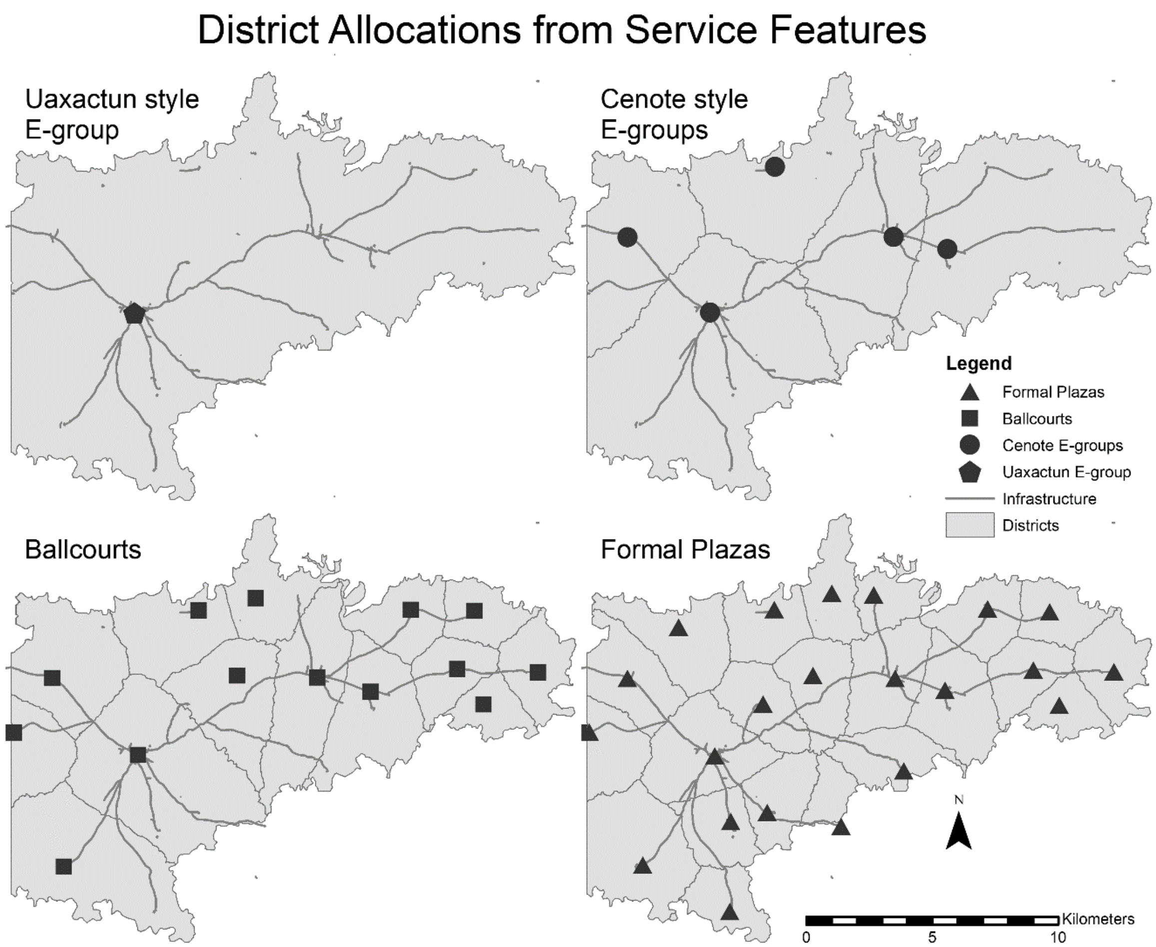


Figure 5.2: Reconstructed service areas for districts at Caracol
Each district area is based on least cost area allocation using the lidar derived DEM. The formal plazas provide the fundamental districting unit and service areas increase with each tier above the formal plaza.

5.2.1 Causeways.

The city's causeways define the urban form of Caracol (AF Chase and Chase 2001) and provide a communication and transportation backbone integrating the landscape. Additionally, considering the hubs and routes helps identify the relationships among Caracol's districts. Table 5.1 shows the causeways from the perspective of each district at Caracol based on the number of routes that pass through that district node. Downtown Caracol serves as the "primary hub" (at 9, it has the most direct connections with other district nodes) with the most causeway connections and centrality along the central route through the city. Cahal Pichik serves as a "secondary hub" (it has 4 direct connections, the 2nd highest); it possesses neither the number of interconnected routes as the epicenter nor the epicenter's centrality, but it comes closest and serves as a nexus for routes to and from the eastern edge of the city. Six district nodes serve as "medial" routes (2 direct connections) along a longer stint of the causeway. Ten district nodes serve as "termini" (1 direct connection) to the causeway system. Initially all district nodes other than the epicenter had been referred to as termini by the Caracol Archaeological Project in publications; it was subsequently discovered that some of these nodes were not in fact ends, but rather intermediate connectors. Cohune and Midway show small "local" causeway spurs that may have continued and been integrated into the larger causeway system; however, those routes cannot be seen in the current lidar dataset with confidence. Finally, Chaquistero, Monterey, and Terminus G all appear to lack any causeway to connect them to the larger network; although, the density of settlement and population shows that these nodes were integrated into the city as a whole. This distributed network of roads helps to define Caracol's causeways as a dendritic system spreading out from downtown Caracol, or, put another way, all roads here lead to downtown Caracol (AF Chase and Chase 2001). Conversely, these causeways also connect people with services and resources throughout the city.

The causeway system at large focuses on interconnecting the district nodes and routing movement through downtown Caracol; however, there are also “local” and what appear to be incomplete causeways. An old Royal Air Force map shows a logging road over Cohune’s causeway; however, ground survey has demonstrated that this unfinished ancient causeway can be observed on the ground (Murtha 2002). Other centers like Chaquistero appear to have no direct causeway link, but demonstrate their affiliation through the presence of an *ahau* altar – emblematic of Caracol – dated to just after the Caracol-Tikal war in 562 CE (Murtha 2015:88). Monterey sits with easy access just off the causeway running from downtown Caracol to Cahal Pichik, and recent investigations in the 2018 field season demonstrate urban renewal (see AF Chase and Chase 2014a:8), which may indicate a future intention to integrate this node into the causeway system that was cut short by the depopulation of Caracol. Finally, additional causeways may emerge through additional research; the initial Caracol lidar survey identified 11 new causeways (DZ Chase, et al. 2011b:64).

Demonstrating the centrality of downtown Caracol, Figure 5.3 shows the least cost paths (LCPs) between districts overlaid onto the causeway system that exists for both “optimal” connections that more closely match the known causeways (Figure 5.3 top), downtown Caracol’s LCPs to all other districts (Figure 5.3 middle), and LCPs from every district to every other district (Figure 5.3 bottom). While the overall LCP network does not entirely match the epicentral LCP routes, only specific connections appear to facilitate intra-district over downtown-to-district routes. This may be a result of the temporal order of causeway construction whereby some routes may begin along an existing causeway instead of running straight from district to district; for example, the route from downtown Caracol to San Juan splits off the route running from downtown Caracol to Ceiba in a way that suggests the route to Ceiba preceded the route to San Juan. In any case, the final map of all district LCP connections with the dendritic causeway network overlaid onto it (Figure 5.3 bottom) shows that this causeway system does not facilitate optimal intra-district travel routes.

As an aside, a few causeway "spurs" exist that connect specific plazuelas or acropoleis around the city into the larger causeway network. These spurs often connect larger than average residences and cover only short distances (see Figure 5.1 routes for Ceiba, San Juan, or Ramonal for a few acropoleis connected to monumental nodes via causeway spurs). These spurs neither occur in every district nor occur frequently enough among residences along causeways to represent neighborhood centers. Additionally, other than size, no other unique architectural feature of residences connected by these spurs indicates any sort of community center aspect to them. In general, these spurs look like more bottom-up connections by wealthier residences to the centralized, top-down causeway system at large.

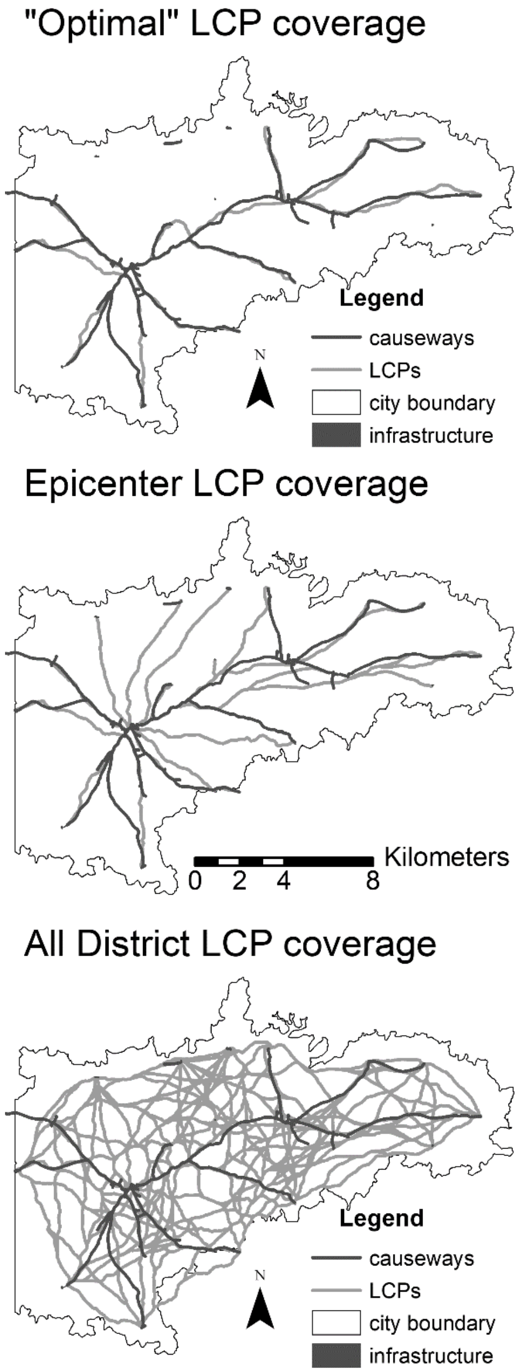


Figure 5.3: Least cost paths and known causeway connections at Caracol.
The top map shows "optimal" LCPs those LCP routes closest to the known causeways, the middle map shows all of the epicenter to district LCPs, and the bottom map shows all overlapping LCPs.

These spurs indicate, in part, that the causeways provided a fundamentally different service from the other feature types discussed here. Causeways served as routes connecting nodes of monumental architecture together thereby spanning and inter-connecting districts. All other features discussed below exist only in those monumental nodes, not between nodes. Researchers have proposed multiple uses for causeways including overlapping roles for ritual processions, social avenues, trade routes, or military roads (AF Chase and Chase 2001:277-280; Hassig 1991:18; Hutson, et al. 2012:307; Landa 1978:74; JM Shaw 2008:106-124). Fundamentally, like formal plazas, causeways - once built - supported a variety of uses, and the initial impetus for construction may be impossible to determine with archaeological data alone.

The road system as a whole highlights the very centralized, top-down nature of transportation infrastructure at Caracol for a variety of reasons. Downtown Caracol has more direct connections to adjacent district nodes than any other district and serves as the primary hub. Downtown Caracol has 9 direct connections while Cahal Pichik has the second highest (secondary hub) at 4 direct connections and all other routes are either medial with 2 direct connections or terminal with 1 direct connection. This pattern matches that expected for more dendritic road networks (see AF Chase and Chase 2001; Chevallier 1975:205; Earle 1991:14; Hassig 1991:19-20; CA Smith 1976; Stantley 1991:198-199). In addition, that secondary hub at Cahal Pichik branches off directly from downtown Caracol; all other routes facilitate movement to or from Caracol along medial routes. Finally, at the citywide level, all existing routes are better situated for movement from and to downtown Caracol than any other district node (see Figure 6.3).

As such, the causeway network at Caracol exhibits a top-down, centralized design in its dendritic form that is augmented by bottom-up processes leading to residential causeway spurs. Even with the additional routes identified through the lidar data (ASZ Chase 2016b; DZ Chase, et al. 2011b:64), there is no change to the focus of the causeway system on focusing movement into and through the city center. However, the presence of causeway spurs and their uneven distribution citywide suggests additional bottom-up process of wealthier household integration to the overall top-down network of dendritic roads. Finally, while not all district nodes have identified causeways, future survey may identify additional causeways interconnecting the city. Either way, the dataset on hand highlights the centrality of the system and points toward physical infrastructural power and administrative decisions primarily at the citywide level.

5.2.2 Formal Plazas.

From Table 5.1, the sizes of formal plazas, ranging from over 71,000 m^2 to just under 1000 m^2, roughly line up with that district's tier or relative "importance," but also manifest the temporal history of construction. Downtown Caracol (71,730 m^2) contains the largest formal plaza followed by Cahal Pichik (23,500 m^2) and Hatzcap Ceel (23,450 m^2). This makes sense. All three nodes conurbated (the process of one city merging out of multiple, previously separate urban areas) to from the city of Caracol, forming its original three districts. This longer time horizon and their primacy in the resulting urban system help explain their much larger formal plazas than those of later districts. Downtown Caracol's formal plaza size remains disproportionate, however, and an outlier in the dataset. This may be related to the role of this district node as a polity capital in addition to its role as this city's capital, the location of Caana (the primary administrative and palatial structure), and the presence of the ruler. The presence of the ruler's residence on Caana is inferred from the remnants of a throne, mat design on the northwestern architecture, repetition of restricted access, hieroglyphic texts within tombs, etcetera (AF Chase and Chase 2017a).

Retiro (8840 m^2) and Chaquistero (8040 m^2), as two lower tier nodes, have much larger formal plazas than expected. One likely explanation is that both nodes may also have conurbated into the city of Caracol at a later date, having formerly possessed independence. Retiro also uniquely possesses a very large acropolis that is the second largest residence after Caana in downtown Caracol (see Figure 5.1). Caana served as the ruler's residence and several other functions (see AF Chase and Chase 2017a), and this larger residence at Retiro along with this larger than expected architecture suggests some degree of former independence.

While the average plaza sizes in each tier are generally similar, tier 4 also shows two other nodes with larger than expected plazas at both Conchita (4,270 m^2) and Puchituk (4,200 m^2); Ramonal has the next largest size in this category at (3,240 m^2). The ancient Maya of Caracol built each of these three district nodes in the early part of the Late Classic Period. The location of these district nodes adjacent to downtown Caracol may explain this. Their proximity to the downtown also results in higher populations (see population discussion in Chapter 7).

Using a wilcox test (wilcox.test in R version 3.6.3, see also R Core Team 2020)on the distributions of tier 3 an tier 4 plaza sizes does not produce a statistically significant difference between both distributions. However, after the "outliers" indicated above are removed (i.e., removing district nodes with higher population resulting from proximity to the epicenter as well as both formerly independent nodes), the average size of tier 4 (median of ~1,400 m^2 and mean of~1,500 m^2) tends to be lower than the average size of districts in tier 3 (median of ~2,800 m^2 and mean of ~3,300 m^2), and these reduced datasets do produce a statistically significant difference (again using a wilcox test in R). As a whole, this indicates that the presence of a ballcourt in tier 3 districts and no ballcourts in tier 4 districts provides at least one important difference in potential residential use of those monumental nodes, but that the presence of a ballcourt does not mean that formal plazas will be larger.

Essentially, other factors complicate this relationship of district tiers and formal plaza sizes. Additional information on formal plazas follows below in Section 5.3 along with a discussion of their populations. In conjunction with the data in Table 5.1 and discussion above, the variability in formal plaza sizes roughly relates to factors including district age, the number of additional service facility features present, and proximity to other districts.

5.2.3 Ballcourts.

Accuracy of ballcourt sizes in Table 5.1 is impacted by a variety of factors. Excavated ballcourt measurements are most precise. As such, the 6A and B Group ballcourts from downtown Caracol represent the most accurate size data; they were excavated and recorded by the Caracol Archaeological Project (AF Chase and Chase 1987:9) and reconstructed by the Tourism Development Project based on excavated CAP and TDP data (AF Chase, et al. 2020c:447; Hoggarth, et al. 2020:706). These two ballcourts show a very standardized size for the ballcourt area (140 m^2 rounded to nearest 10 m^2) and length (22-23 m rounded to the nearest m). More difficult to measure are unexcavated ballcourts where differential erosion can impact determination of ballcourt playing area. Unexcavated ballcourts are easier to measure when two freestanding structures delineate the playing field and more complicated when the side of another building is used as one of the two structures (see Figure 5.1).

For these reasons, the ballcourt lengths instead remain more representative of the field size overall for courts without excavation, and the coefficient of variation among reported field lengths is only 12%; the coefficient of variation for field areas, as reported, is higher at 33%. In other words, the ballcourt lengths at Caracol show relatively little variation, and the issues impacting area all act to increase that coefficient of variation. While ground survey and excavation would be required to confirm this, it seems that the "ideal" ballcourt playing field at Caracol is likely close to 140 m^2.

The presence of ballcourts in district nodes tends to concentrate towards the northern and eastern districts and those districts further from the city boundary. This may be correlated to the time of construction or district but may also relate to the ideal distance between ballcourts as will be seen later in this chapter. Importantly, only the downtown Caracol district had two ballcourts, highlighting the primacy of the epicenter over other districts within the city of Caracol. Additionally, the first "ring" of districts located about three kilometers from the epicenter and constructed in the early part of the Late Classic era all lack ballcourts, again, presumably emphasizing the importance of downtown Caracol's ballcourts.

5.2.4 *Formal Reservoirs.*

The formal reservoirs at Caracol, located in proximity to monumental architecture and formal plazas, include both the monumental reservoirs with over 1,000 m^2 surface area and the smaller, but relatively speaking still large reservoirs that range from 750 to 120 m^2. These two feature types complement the much smaller residential reservoirs at Caracol - although there is some overlap between the largest residential reservoirs and the smallest large reservoirs. Aside from size, the monumental reservoirs have one other unique trait; they only occur at the three oldest districts at Caracol. Thus, while theories of elite water management have played a role in discussions of ancient Maya governance (e.g. Lucero 2006a, b; Scarborough and Gallopin 1991), from the data at Caracol this theory could only possibly apply to these monumental reservoirs during the earliest period of site occupation (ASZ Chase 2019) due to the prevalence of a plethora of residential reservoirs in the Late Classic Period (ASZ Chase 2016a). Also, of note for the elite control hypothesis, the largest "monumental" reservoir in downtown Caracol sits quite a distance away from the ruler's palace of Caana, being located next to the South Acropolis residence and southern causeway entrances to downtown Caracol. Instead, a "large reservoir" (which is currently dry) is associated with Caana's own B Group architectural unit (Figure 5.1). As for the large formal reservoirs, there are currently not enough in the sample to discern a pattern in their distribution among the districts, but they are almost certainly not as early as the formal monumental reservoirs.

All formal reservoirs could have provisioned water for various uses, including potable drinking water, water for mixing lime plaster, loci of water rituals, or displays of wealth and power. Reservoirs, whether formal or residential, were built and positioned to capture direct rainfall and run-off from plastered plaza surfaces. The A Group reservoir provides perhaps the clearest example of this, with still-visible channel (running north from its northwest corner) that drains water from the A Plaza and surrounding areas. As such, these reservoirs were hydrologic instead of hydraulic features; they focused on the storage of rainwater (hydrologic) instead of uses for water pressure (hydraulic). (However, see French and Duffy 2010; French, et al. 2013 for hydraulic uses at Palenque). Thus, formal reservoirs not only provided a water source, but alleviated standing water and flooding during the rainy season.

Formal reservoirs provide a different set of potential functions and services from other defined urban service facility features but may have worked in concert with them. Any performative practices near these formal reservoirs would have used the adjacent plazas in each district, as one of the many uses of that plaza (e.g. Tsukamoto and Inomata 2014). Only in the case of water provisioning (Lucero 2006a, b) would these features act as urban service facilities directly, but if that were the case in practice, then they should be ubiquitous among all district nodes and they should scale with population. They do not. Downtown Caracol (estimated at 10,062 people) possessed roughly twice the population of Cahal Pichik (estimated at 6,321 people); however, the monumental and large reservoir area combined covers only 2,260 m^2, far less than the monumental reservoir in Cahal Pichik at 4,550 m^2. While this does not include depth, that is nearly twice the surface area.

As noted above, monumental reservoirs co-occur with other monumental architecture. Those that co-occur with the largest formal plazas, those with greater than 23,000 m^2 surface area, also possess E Groups. Earlier district construction times (in the

Late Preclassic Period, as supported by the relevant archaeological data) permit the easiest explanation for these co-occurrences, instead of attributing cause and effect among these three feature types. The presence of large reservoirs at districts lacking ballcourts also provides interesting evidence for the lack of a clear hierarchical order of large reservoirs as features among district nodes (see Table 5.1).

Downtown Caracol, yet again, possesses a unique pattern of formal reservoirs. As with the ballcourts, it contains two features where other districts contain only a single feature. In addition, the two reservoirs fall into one each of the monumental and large categories. In terms of size, the monumental reservoir at downtown Caracol (1,970 m^2) has less surface area than the largest one at Cahal Pichik (3,550 m^2). No other reported feature type has another district with a larger feature than the one present in downtown Caracol (Table 5.1). As mentioned above, this also does not correlate with the expectations for the monumental reservoirs functioning as centralized water provisioning features for the population at large – at least during the Late Classic Period. The population of the downtown Caracol (estimated at 10,062 people) was almost double the size of the population around Cahal Pichik (estimated at 6,321 people). The data here suggests that the different spatial distribution and feature size expectations from other feature classes may rely on the dates of construction.

5.2.5 E Groups.

Finally, E Groups provide a unique feature class. The Maya built these features primarily in the Preclassic Period (AF Chase, et al. 2017b:49-56). The E Group at downtown Caracol saw initial construction in 360 BCE with subsequent construction and modification at various times through minimally 640 CE (AF Chase and Chase 1995:95-99). However, the Maya used this E Group until the end of occupation at Caracol around 900 CE (see AF Chase and Chase 2004a; DZ Chase and Chase 2000). In all cases E Groups represent relatively early initial construction efforts and their widespread distribution highlights a regional Maya tradition centered in the Peten of modern Guatemala (AF Chase, et al. 2017b:Figure 1.4).

Among these districts, the three conurbated nodes of downtown Caracol, Hatzcap Ceel, and Cahal Pichik contain the largest E Groups. Other confirmed E Groups within the lidar data occur at Ceiba and Cohune (both mapped) - and La Rejolla (just outside the lidar data coverage in Guatemala, but a part of Caracol) also has an E Group (Escobedo, et al. 2008:264-265). While both Las Flores Chiquibul and San Jose have E Groups (Escobedo, et al. 2008:305-306,309-310), it is not entirely clear if they were independent sites or districts integrated into Caracol. The causeway at San Juan extends beyond the lidar dataset and may lead to either one or both of these nodes integrating them into the causeway system. Also, while survey reports suggest Late Classic dates for both Las Flores Chiquibul and San Jose (Escobedo, et al. 2008:305-306,309-310), the presence of E Groups may indicate earlier, as well as later, occupation.

From E Groups present in the lidar dataset, size variations exist. They have an area coefficient of variation of 43% and the western structure N-S length coefficient of variation at 21%; however, these variations seem quite large for a sample size of five (Table 5.1). There may be regional or temporal patterns to the resulting sizes of E Groups, but the relative lack of standardization among so few features may relate to their earlier time of construction (and possibly to the original independence of these centers pre-conurbation). The presence of the largest feature at downtown Caracol makes sense, especially given that this E Group alone was the only one that the ancient Maya remodeled into a Uaxactun-style complex from an earlier Cenote-style E Group (Figure 5.2); the others within the site all maintained their earlier Cenote-style form (AF Chase and Chase 2017b:49-56). This continued occupation, use, and re-modification of only the downtown E Group reflects the centralized functions of this feature over time in epicentral Caracol.

5.2.6 Services Summarized.

Fundamentally, all features included in Table 5.1 highlight the size and primacy of downtown Caracol as both the city center but also hint at its role as the center of a substantially larger polity during part of its history (see AF Chase and Chase 1998a). The epicenter of this city acted as the primary hub of the causeway network; it has the largest formal plaza, two ballcourts, both a monumental and a large reservoir, and the only Uaxactun style E Group. Each of these aspects remain unique among all 22 districts within this lidar dataset. However, the distribution of services among other centers shows a hierarchical system whereby every district node with an E Group co-occurs with a ballcourt and every node with a ballcourt co-occurs with a formal plaza - while the inverse is not true - forming four distinct, hierarchical district tiers (Table 5.1).

Three early independent centers (downtown Caracol, Hatzcap Ceel, and Cahal Pichik) that became the backbone of Caracol the city possess the only monumental reservoirs. While the distribution of monumental reservoirs identifies early occupation and conjoined monumental construction, formal reservoirs as a whole do not easily fit into the hierarchical system (Uaxactun-style E Group, Cenote-style E Groups, Ballcourts, and Formal Plazas), likely because the need for these urban service facility features had been blunted by the presence of reservoirs within most households by the Late Classic Period; thus, they clearly had an early construction focus that waned over time.

The presence of these urban service facility features among widespread district nodes also highlights the dispersed nature of services at ancient Caracol (see Figure 5.2). For an ancient state, this represents a strong infrastructural presence with widespread services, and these distributed districts provided a plethora of urban service facility features. In contrast, Tikal's urban form exhibits clustered services in the city center and lacks a dendritic causeway system to link monumental nodes beyond the city center (see ASZ Chase and Cesaretti 2019). Taken together this represents a more collective form of service distribution than expected for an autocratic state where services would either not exist or exist in a more centralized fashion (Blanton 2009; Blanton and Fargher 2012), and this distribution also represents strong infrastructural power within the city through the presence of a high number of service features which could reach more residents (M Mann 1984, 2008). At first, these two ideas appear to be at odds with each other; however, the distribution of district nodes and elites across the city likely acted to blunt or check the centralized authority of the ruler. While the causeway system and the plethora of services in downtown Caracol showcase citywide centralization, the dispersed nature of the other districts and services indicates a more bottom-up district approach to day-to-day administration at the district-level. Analyses on how people could access and use these services, provided in the sections below, sheds additional light on the nature of widespread infrastructure and collective governance among these districts.

5.3 *Formal Plazas and Population*

As mentioned above, formal plazas are open spaces that serve a variety of potential uses. While identification of specific plaza functions is not always possible, it has been suggested that plazas were used in economic, ritual, political, and social activities in the past (Kowalewski 2019; Tsukamoto and Inomata 2014). While social science and archaeological research on plazas has focused on all of these potential uses, there have been specific investigations of the ability of these formal plazas to serve as spaces of energized crowding (ME Smith 2019), as loci of social interaction (Ossa, et al. 2017), or as areas for widespread participation in public events (Inomata 2006). Each of these ideas focuses on the use of formal open space in urban environments as attractive loci of social interaction.

Considerations of plaza space available for various uses depends not only on population but also on its construction timeframe. While fewer people in a district likely resulted in a smaller plaza to accommodate that smaller population and more people in a district likely resulted in a larger plaza for them to use, the correlation is not absolute. There may be a time-lag between population growth or decline and formal plaza construction. Furthermore, built-up construction areas likely limited the possibilities of plaza expansion, and plazas were not necessarily decreased in size if and when population declined. Even so, as will be seen below, the pattern of plaza area to population at Caracol suggests that the ancient residents built very large formal plazas that could accommodate the entire district at once. While these plazas were sufficiently large for local gatherings, they also exhibit a super-linear scaling relationship. Larger districts not only have larger formal plazas but more formal plaza area per person in that district.

5.3.1 Relative Population.

In order to assess the relationship between plaza size and population, the relative population of each district is compared to Caracol's minimum-estimated Late Classic Period of population of 100,000. In conjunction with formal plaza areas in Table 5.1, the graph in Figure 5.4 shows the relative populations of all 22 districts covered by lidar data within Caracol in modern Belize (i.e., ignoring the Guatemalan settlement and districts that are beyond the lidar dataset). Figure 5.4 shows percentage of population using the average of 4,545 as the baseline 100%. The populations vary from district to district, but the overall pattern highlights a very high (outlier) population at downtown Caracol with more than double the average population among all districts. The outlier status of downtown Caracol can also be seen in the histogram of population among districts (Figure 5.5) which otherwise shows a relatively normal-looking distribution (but with too few points to check). The population of the city center was not just larger, but substantially larger than the population within other districts.

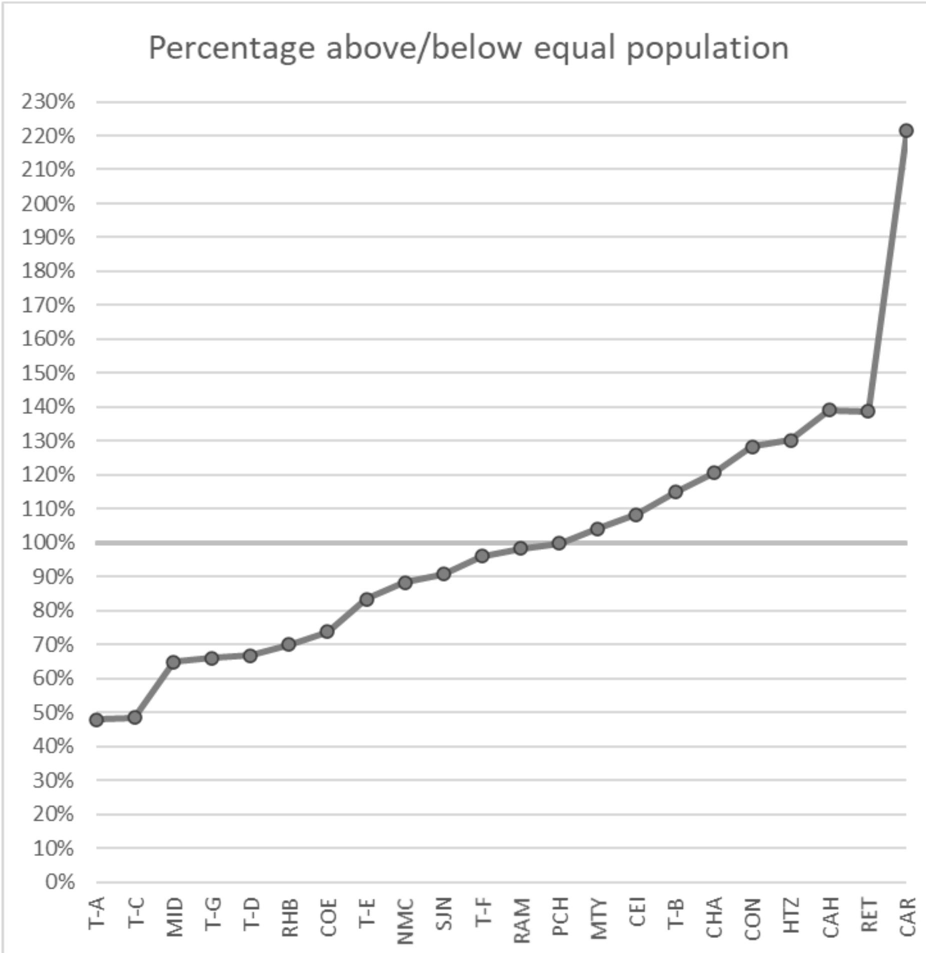


Figure 5.4: District population line graph from least to most population
Each district (using a three-character ID code) is shown along with the relative proportion of population identified from ground and lidar survey. 100% represents the expected for equal distribution of population among districts at 4,545 people. In addition, this graph highlights in particular the outlier nature of downtown Caracol (CAR) as the epicentral city district and the nature of urban sprawl evident through low populations at Termini A (T-A) and C (T-C).

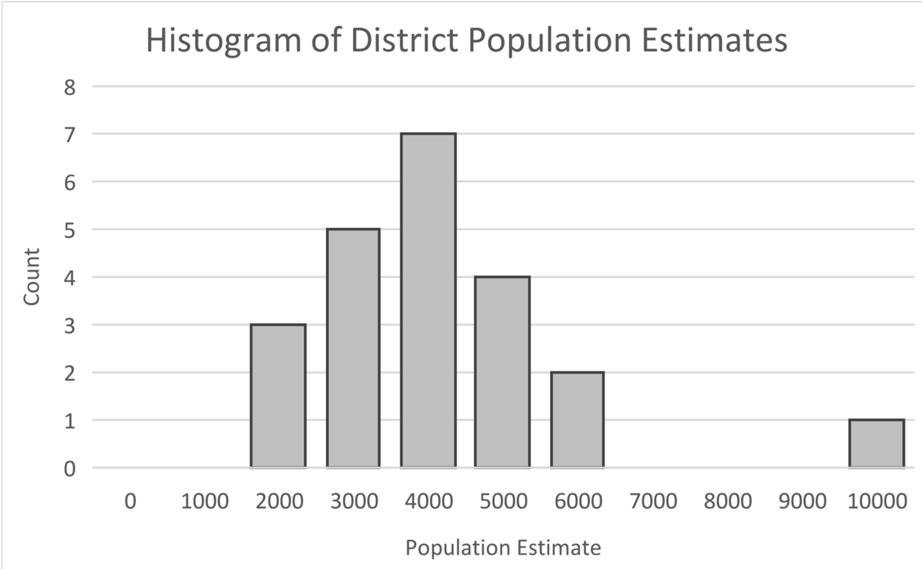


Figure 5.5: District population as a histogram
A histogram of 1000 population bins to highlight the outlier nature of downtown Caracol with a district population of over 10,000 residents.

Additionally, Terminus A and Terminus C – the final two monumental nodes constructed – possessed less than 50% of the expected population (Figure 5.4). Neither of these points represent outliers in a mathematical sense (see also Figure 5.5), but they do appear to form a distinct pattern of lower-than-expected settlement. Termini A and C were built in the Late Classic 2 period close to the depopulation of Caracol, and their construction appears to exist without a prior surrounding population. This reinforces the notion that the ancient Maya had built both district nodes near the city boundary to encourage additional settlement and facilitate urban sprawl.

In general, higher population appears to be correlated with to the rough age of each district, proximity to the original east-west causeway corridor, or adjacency to downtown Caracol with potential population spillover from the city center. The higher-than-average populations occur primarily at formerly independent settlements that conurbated into the city of Caracol. This includes both the original three settlements of downtown Caracol, Cahal Pichik, and Hatzcap Ceel as well as temporally later Retiro to the south and Chaquistero to the north. Alternatively, the high population around Conchita relates to its proximity to downtown Caracol. No clear falloff boundaries exist among the *plazuela* distributions within the city, even across the reconstructed district boundaries. The impact of distance from (and access to) the east-west causeways can also be seen in examples such as Cohune; it represents an early district with an E group but exhibits a lower-than-expected population. The factors of time, trade, and proximity all may have played a part in the pattern of population exhibited during Caracol's apogee.

District	dID	Pop. Est.	Plaza Size m^2	0.46 m^2/person Capacity	0.46 m^2/person % Pop.	1.0 m^2/person Capacity	1.0 m^2/person % Pop.	3.6 m^2/person Capacity	3.6 m^2/person % Pop.
Terminus A	T-A	2174	960	2,087	96%	960	44%	267	12%
Terminus C	T-C	2208	1,220	2,652	120%	1,220	55%	339	15%
Midway	MID	2950	4,190	9,109	309%	4,190	142%	1,164	39%
Terminus G	T-G	3000	2,300	5,000	167%	2,300	77%	639	21%
Terminus D	T-D	3034	4,830	10,500	346%	4,830	159%	1,342	44%
Round Hole Bank	RHB	3186	2,240	4,870	153%	2,240	70%	622	20%
Cohune	COE	3354	6,390	13,891	414%	6,390	191%	1,775	53%
Terminus E	T-E	3792	2,590	5,630	148%	2,590	68%	719	19%
New Maria Camp	NMC	4011	5,060	11,000	274%	5,060	126%	1,406	35%
San Juan	SJN	4129	2,780	6,043	146%	2,780	67%	772	19%
Terminus F	T-F	4365	2,800	6,087	139%	2,800	64%	778	18%
Ramonal	RAM	4467	3,240	7,043	158%	3,240	73%	900	20%
Puchituk	PCH	4534	4,200	9,130	201%	4,200	93%	1,167	26%
Monterey	MTY	4736	2,080	4,522	95%	2,080	44%	578	12%
Ceiba	CEI	4922	5,820	12,652	257%	5,820	118%	1,617	33%
Terminus B	T-B	5225	1,640	3,565	68%	1,640	31%	456	9%
Chaquistero	CHA	5478	8,040	17,478	319%	8,040	147%	2,233	41%
Cohune	CON	5832	4,270	9,283	159%	4,270	73%	1,186	20%
Hatzcap Ceel	HTZ	5916	23,450	50,978	862%	23,450	396%	6,514	110%
Cahal Pichik	CAH	6321	23,500	51,087	808%	23,500	372%	6,528	103%
Retiro	RET	6304	8,840	19,217	305%	8,840	140%	2,456	39%
Downtown Caracol	CAR	10062	71,730	155,935	1550%	71,730	713%	19,925	198%
				19 of 22 above		10 of 22 above		3 of 22 above	

Table 5.2: District population estimates and formal plaza areas in m^2
Data are arranged from lowest to highest population (see also Figures 5.4, 5.5 above). Capacity analysis follows Inomata (2006). Depending on the space per person, the three primary districts in Caracol could all accommodate local populations and downtown Caracol's formal plaza could accommodate many more people than those within its district indicating wider use. However, no single plaza could accommodate the full city population, except for downtown Caracol at 0.46 m^2 per person spacing.

5.3.2 People per Plaza.

The use of plazas for performances, ritual, and political power provide one way to understand the use of this formalized open space in the past (see Inomata 2006; Tsukamoto and Inomata 2014). Based on Andean ethnographic data, (Inomata 2006:811-812) proposed using three potential spatial units in order to estimate the number of people who could use a plaza, depending on how crowded it was; these numbers are 0.46 m^2 per person, 1.00 m^2 per person, and 3.60 m^2 per person. Replicating this analysis at Caracol using lidar-derived data for both the plaza areas and the relative populations yields interesting results that highlight the size of three district plazas at downtown Caracol, Cahal Pichik, and Hatzcab Ceel. The different levels of plaza occupation – from 2,087 to 155,935 people at 0.46 m^2 per person, 960 to 71,730 people at 1.0 m^2 per person, or 267 to 19,925 people at 3.6 m^2 per person in Table 5.2 – shows that most formal plazas could host 100% of their local populations in the Late Classic Period.

At 0.46 m^2 per person (Table 5.2), which would be very densely packed, all but three districts could fit their entire local district populations into their own formal plazas - and two of the three that cannot fit 100% can fit over 95% of the district population within the plaza. The remaining district node of Terminus B (T-B) exhibits the smallest plaza space per population and even at this dense spacing it can only hold 68% of its local population. This likely relates to its time of construction, which like Termini A and C (T-A and T-C) occurred toward the end of Caracol's occupation, and to its location on a southern causeway departing the primary downtown Caracol (CAR) to Cahal Pichik (CAH) route that contains a band of higher population density. In essence, some of the people assigned by the least cost area analysis to Terminus B could have traveled to other adjacent formal plazas with additional space - especially Cahal Pichik and Hatzcap Ceel (HTZ) – to the north without substantial additional travel time. Finally, one interesting result is that at this very tightly packed plaza density, the plazas in downtown Caracol could have fit the entire population of the city as a whole with room to spare, especially if the structures themselves were used (structure areas are not included in Table 5.2's calculations); however, not everyone would have had an equivalent view of events and activities.

At 1.0 m^2 per person (Table 5.2), roughly half (10 of 22) of the formal plazas could have accommodated their district populations at maximum capacity. In addition, the over 70,000 people that could have filled downtown Caracol would have been a substantial part of the population to pack into the city center for any large-scale ceremony. It would have proved sufficient for just over two-thirds of the members of all *plazuela* groups citywide to participate in such an event in the city's downtown.

At 3.6 m^2 per person (Table 5.2), only three groups could have accommodated the entirety of their local populations. They represent the three districts with both the largest formal plazas and the largest populations: downtown Caracol, Hatzcap Ceel, and Cahal Pichik. However, while downtown Caracol could have accommodated twice the local population in its formal plaza, at this density of people it would have required almost exactly the entire plaza space to facilitate the communities living in the other two.

These metrics show a sizeable population at downtown Caracol and demonstrate that this local population could fit within the formal plazas in the city center at each density. This again reinforces the uniqueness and scale of the city center, and this larger size almost certainly indicates that central gatherings saw the inclusion of individuals from other districts, if not visitors from other cities. It should also be said that at full capacity downtown Caracol would include locations with poor sightlines to any event, meaning that any single ceremony would have required either a procession, a parade, or the movement of crowds through a smaller space to ensure everyone could properly see, hear, or participate in any specific event or activity. However, the space in the downtown could have served a variety of other purposes beyond ritual and political ceremonial performances. It could have provided ample space for multiple market stalls (AF Chase, et al. 2015), acted as a meeting ground for warriors (sensu AF Chase and Chase 1989; Hassig 1991), or provided space as necessary for any other social, political, or economic activities.

5.3.3 Plaza Scaling.

Combining Tables 5.1 and 5.2 to include both local populations and formal plaza area, the scaling factor of plaza space can be determined following Ossa, et al. (2017). Fundamentally, this analysis asks if the correlation between population and plaza area represents exponential growth and, if so, then what exponential growth factor exists? Mechanically, scaling analysis uses the regression between two attributes; however, this regression is conducted after logarithms are applied to both axes. By taking the logarithm, this analysis investigates the exponential relationship between these two attributes through the slope of that regression (e.g., *y* = *scaling_coefficient* * *x* +

intercept) with that slope providing the scaling factor of interest because it represents the exponential factor in the unlogged dataset (e.g., $y = x^{scaling\_coefficient}$). A scaling coefficient of or near 1.00 represents a constant ratio of formal plaza size to population suggesting that local populations of settlements exclusively frequented these plazas. A scaling coefficient greater than 1.00 represents formal plaza area growing faster than the rate of population whereby each additional resident represents an even greater increase in plaza size. Finally, a scaling coefficient less than 1.00 represents a reduction in formal plaza area with additional population and the saving of labor by investing less energy in plaza construction with additional population.

When Ossa, et al. (2017) tested the Inomata (2006) model of plaza use for ceremonies by looking at how plaza area scales with settlement populations, they found a low scaling coefficient of 0.40 for a dataset of Maya settlements around Palenque (Ossa and Smith 2017; Stuardo 2002, 2011; Stuardo, et al. 2014). As discussed in the next section below, scaling of infrastructure often varies from 2/3rds (0.67) and 5/6ths (0.83); 0.40 is substantially lower. This low scaling factor indicates less investment in plaza space for the larger the population of the settlement in question, and does not support the proposition that ancient ceremonies involved all urban residents (e.g. Inomata 2006; Tsukamoto and Inomata 2014). However, this type of analysis has not yet been replicated with other datasets. In addition, it is an open question as to whether or not this pattern would hold within Caracol as an intra-settlement analysis. The analysis that follows provides interesting intra- and inter-site comparisons that provide new insight to such a use of scaling and formal plazas in the Maya world.

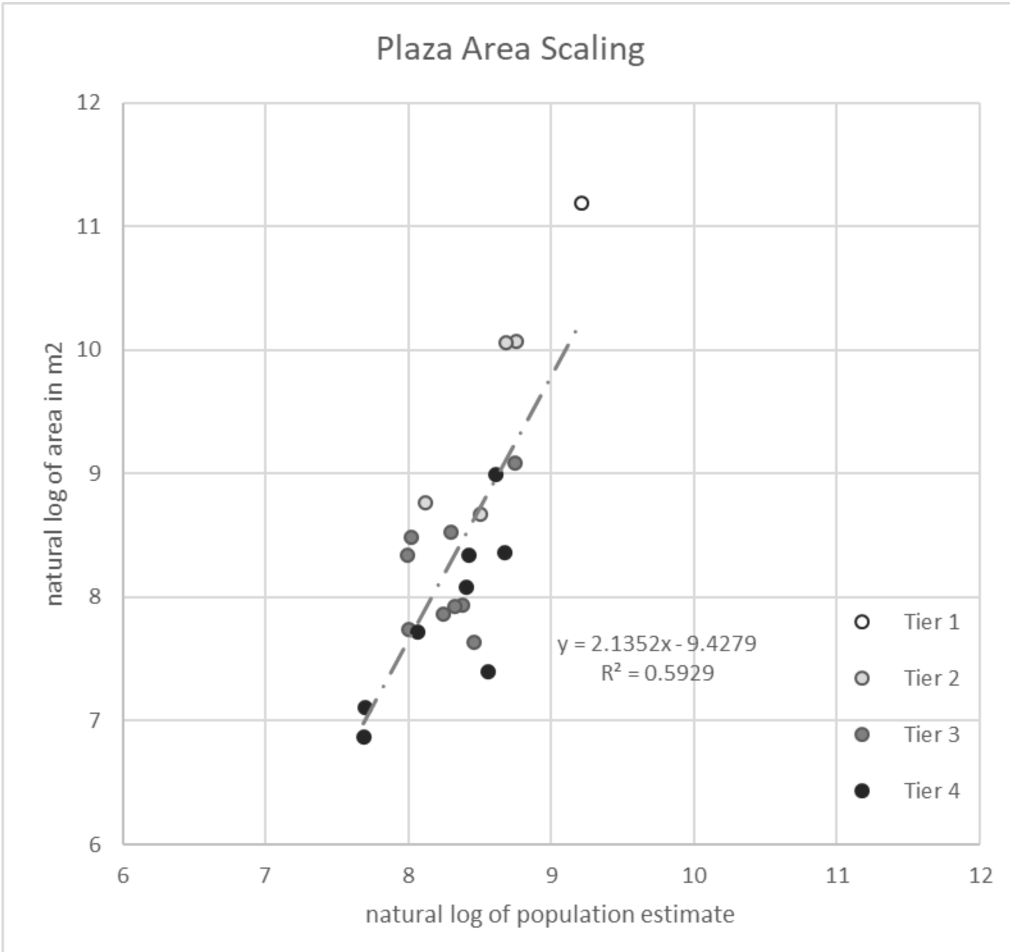


Figure 5.6: Scaling analysis of formal plaza areas vs. population
Shows scaling of districts plaza areas (Table 5.1) against their populations (Table 5.2). The results show a weak but significant overall r-squared value of 0.6 for the relationship for a scaling coefficient of 2.1 indicating that as district population increased plaza size increased substantially more. This graph also color codes the data points by district Tier (Table 5.1) to highlight that higher-level tiers tend to have higher values with only a few exceptions.

At Caracol, the graph (Figure 5.6) of people per plaza shows a superliner relationship. This 2.1 scaling coefficient represents a very high scaling value quite distinctive from most coefficients measured for modern cities (Bettencourt, et al.

2007:Table 1). This coefficient means that the higher population districts at Caracol not only had larger plazas but substantially larger plazas in terms of the spatial needs per person. This does not match the idea that older plazas were limited in size and grew slowly to support the needs of their growing populations, and it may suggest proactive infrastructural investment in formal plaza construction. Even so, this represents the second analysis of this type at an ancient Maya city and additional investigations of district-level formal plazas and populations need to be conducted to better understand how anomalous or normal this pattern is.

The graph in Figure 5.6 also shows the relationship of different district tiers – with higher tiers containing additional urban service facility features – against the population present in those districts – identified using the 100,000 population estimate for Caracol against the proportion of residences identified in each district. This analysis demonstrates that the average values of plaza area and population increase from tier to tier. However, a few data points provide exceptions. For example, Retiro (tier 3) and Chaquistero (tier 4) appear in line with other Tier 1 and 2 districts that contain an E Group (although neither Retiro nor Chaquistero contain one). While it will take additional excavation to provide dating, this supports interpretations that both districts were largely built in the Classic Period after E Group construction had ceased. While Chaquistero may have been the result of city expansion, Retiro was a pre-existing center that was incorporated into Caracol in the Late Classic. Another interesting aspect of this data is the relative overlap between Tier 3 and Tier 4 districts, suggesting that the inclusion of a ballcourt, while important, did not simply result from the same process that led to additional population or plaza area. This pattern may indicate the less frequent need to use ballcourt facilities as compared to formal plazas.

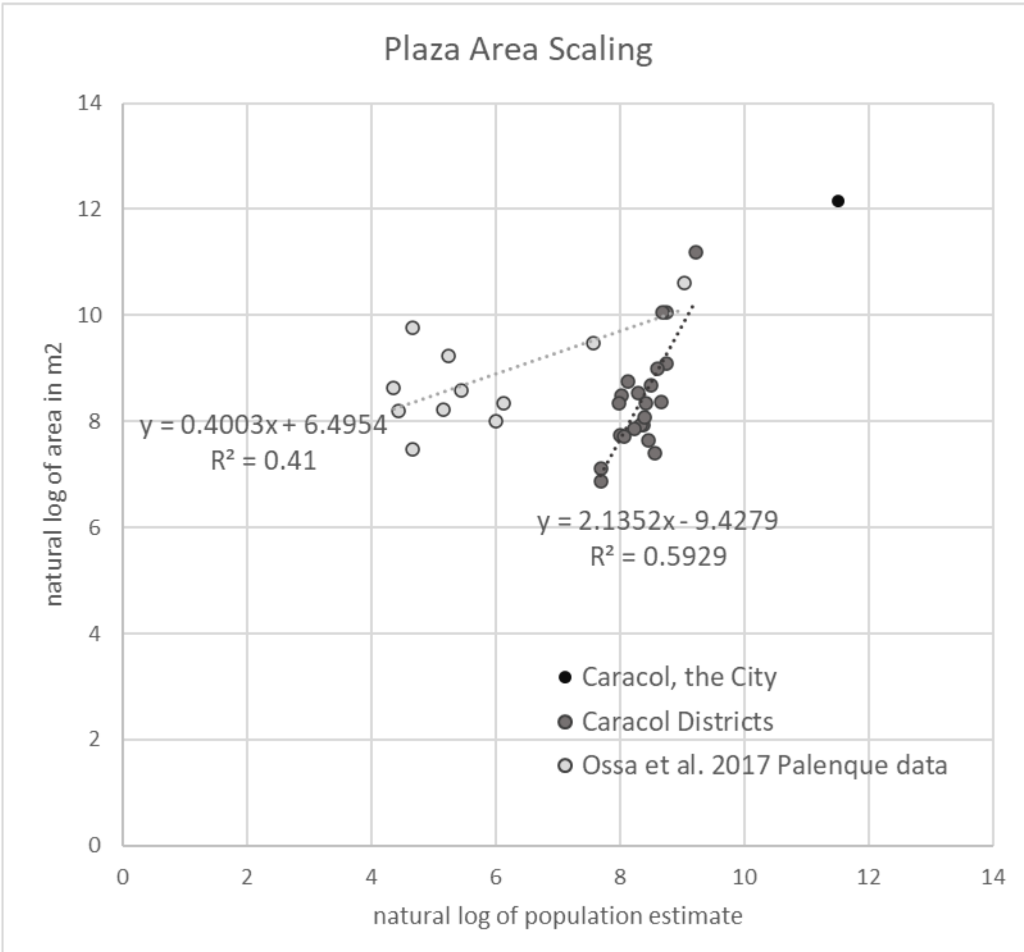


Figure 5.7: Comparative plaza area scaling showing Caracol and Palenque Incorporation of the intra-urban Caracol district data from Figure 5.6 in dark grey with the Palenque settlement data (Ossa and Smith 2017) including the combined district data as the “Caracol, the City” in the top right corner.

Incorporating the Palenque dataset (Ossa and Smith 2017; Stuardo 2002, 2011; Stuardo, et al. 2014) from Ossa, et al. (2017) with both the city of Caracol and the individual district data on the same graph provides an interesting contrast between these datasets (Figure 5.7). The district level data from Caracol scales are very different from the Palenque settlement data. In addition, each has different r-squared values with 0.41 for Palenque and 0.59 for Caracol indicating that the Caracol data has a tighter linear relationship. However, while both of these r-squared values are relatively low (but still reasonable for this type of social-science data), another issue may be present. The Palenque data has a number of settlements with much smaller population sizes. Nine of the 11 settlements at Palenque have fewer than 500 people (with the smallest representing only 78 people); as such, any changes in demographic estimates will drastically modify these results, and scaling relationships are more sensitive to shifts or changes at the smaller end of the scale than the larger end (Clauset, et al. 2009:9-13). In contrast, each of Caracol's districts has over 2000 people in it (see Table 5.2). In other words, teasing apart the relationship between plaza size and population at ancient Maya settlements (the Palenque sample) and districts (the Caracol sample) will require additional datasets from other settlements and districts of intermediate population sizes.

At the same time, this analysis provides new insight into ancient civic life at Caracol. Despite the widespread distribution of formal plazas across the landscape, these formalized open features exhibit hierarchical size differences. The tier 1 district has the largest formal plaza size followed by tier 2 districts with tiers 3 and 4 districts exhibiting more mixed trends of plaza sizes. However, even the smallest plazas were sufficiently large to accommodate their local populations (see Section 5.3.2). This suggests that the super-linear scaling of plaza size relates to specific attributes of tier 1 and 2 districts that required them to facilitate additional populations from other districts. Since these tiers are defined by the presence of E Groups, that architectural feature may have provided the impetus for larger centralized events for residents at Caracol in line with the communal and social uses of E Groups suggested elsewhere (see chapters in DA Freidel, et al. 2017).

5.4 Intra-urban Scaling of Districts

Most urban scaling analysis has focused on sets of contemporaneous settlements within various world regions (Bettencourt, et al. 2007; Cesaretti, et al. 2016; Ortman, et al. 2014; Ortman and Coffey 2017; Ortman, et al. 2016). However, at least one recent analysis demonstrates urban scaling patterns embedded in modern city districts (Xu, et al. 2020). Another has looked at *sian otots* (e.g., neighborhood-like groups) at Copan, Honduras (Codd 2020). These studies provide two comparative cases suggesting that district-level analysis should yield results.

Fundamentally, if the principles of settlement scaling theory (SST) are correct (ME Smith, et al. 2021b:122-125), then the areas of these reconstructed districts – which provided urban service provisioning areas in the past – should exhibit scaling relationships between 2/3rds (i.e., more "social" via the "amorphous settlement model" of SST) and 5/6ths (i.e., more "infrastructural" via the "networked settlement model" of SST). These two models represent different forms of social interaction in settlements altered by the form of that settlement; the amorphous model represents idealized social interaction within a circular settlement zone, and the infrastructural model represents social interaction bounded by specific transit features (Ortman, et al. 2014:2-3). As such, values nearer to the 2/3rds suggest more social uses of district areas, while values closer to the 5/6ths suggest more infrastructural uses of district areas. In addition, values significantly below 2/3rds or above 5/6ths suggest that the features did not serve this purpose or other issues. This could also indicate an issue in contemporaneity of features, but excavation data at Caracol have shown complete residential occupation around 700 CE, so contemporaneity of use should not complicate this relationship.

As such, this analysis provides a test of these reconstructed districts as administrative units by evaluating their scaling factors. While the nature of these districts and the types of urban service facility services they possess have already been described above, this analysis provides a means of testing for the types of interactions present at these district nodes (as the centers of the district areas). In other words, this analysis uses the implications of SST for interpretation of archaeological data to assess the efficacy of calling these reconstructed service areas “districts” (similar to the analysis of plazas by Ossa, et al. 2017 described in the previous section).

As a whole, scaling theory acknowledges that variation exists among cultures, but it focuses on basic universal statements about human behavior that can (i.e., should) apply to any culture or society (ME Smith, et al. 2021b:122). In essence, this theory has been built from an empirical evidence of general trends observed and described mathematically (Bettencourt, et al. 2007:7301-7302). This scaling research suggests that contemporary cities are remarkably similar and that interesting variations from the expectations should be explored to better understand these properties in settlements. This mathematical patterning suggests economies of scale through increasing returns in infrastructural development that occur when cities grow in size (Bettencourt, et al. 2007:7303). However, the cities of the ancient Maya remain understudied in this form of analysis and seem to provide variations from the observed patterns so far observed that will be discussed in the next section.

5.4.1 Maya Cities and Scaling.

While scaling analysis has been successfully used for a variety of systems world-wide, it has only been analyzed in two ancient Maya contexts thus far. These include a recent publication of predominantly smaller, peripheral settlements (ME Smith, et al. 2021b) and a recent MA thesis investigating the internal dynamics of Copan (Codd 2020). Both analyses suggest variation among the ancient Maya and suggest differences from scaling patterns observed elsewhere (see below). As such, the ancient Maya provide an interesting example to test this empirically based model of settlement and interaction to see how their urban systems can enhance our understanding of settlements and the implications of urban scaling theory more broadly.

One issue that should be addressed for the ancient Maya is that infield and outfield agricultural settlements (see discussion in Chapter 2) should be scaled separately due to the different density patterns observed (see AF Chase and Chase 2016a). These two types of urban agricultural systems greatly affect the reconstructed area estimates for ancient cities - with infield cities reporting all urban and agricultural area, while outfield cities report only urban areas. Maya cities exhibit both types of urbanism, and mixing the two types of cities will exhibit odd and divergent scaling results due to the differences in area and density.

Ancient Maya settlements exhibit smaller, denser outfield cities and larger, less-dense infield cities (AF Chase and Chase 2016a). As noted above, scaling analysis is more sensitive to changes at the smaller end of the scale (Clauset, et al. 2009:9-13). Following this tenet, mixing both types of settlement in the same analysis will lead to inaccurate results due to these two distinct urban patterns with their unique density measurements. Analyses like these require that the fundamental units studied are defined in the same manner; the area estimates for infield and outfield settlements represent two distinct datasets for population and area scaling analyses.

A recent ME Smith, et al. (2021b) publication on Maya scaling shows a bifurcation in reported scaling analyses around settlements with 40 structures (single mounds and not multi-structure *plazuelas* as used in this analysis). The settlement sample focuses on smaller settlements of 2 to 3,482 people (ME Smith, et al. 2021b:Appendix 2) and excludes all larger Maya cities from analysis (i.e., any from 5,000 to 100,000). Only 10 of the 91 sites included in Appendix 2 have a population over 500 people (an important limit for human cognition discussed in Section 7.2.3) and the Appendix 1 dataset shows only 12 of the 605 sites possess more than 100 dwellings (ME Smith, et al. 2021b:Appendices 1 and 2). It also includes 63 "settlements" of a single dwelling where social interaction would involve a single-family unit (ME Smith, et al. 2021b:Appendix 1); in other words, these datasets tend to represent very small settlements. In addition, the infield or outfield nature of these cities has not been distinguished in this analysis; ergo, this bifurcation observed in settlements of 40 structures in the urban scaling line of best fit could represent a transition from outfield agriculture at smaller settlements to infield agriculture at larger settlements (see both AF Chase and Chase 2016a; Fisher 2014).

In a recent intra-urban analysis of the Maya city of Copan, Codd (2020) demonstrates the lack of a clear pattern that is consistent with settlement scaling theory. The intra-urban dataset utilized includes the *sian otots* or water groups of Copan (Codd 2020:Figure 3.4; Fash 1983; Freter 2004). These *sian otots* represent settlement clusters of 200 to 300 people and 60-80 households (Freter 2004:96). In other words, they likely acted as neighborhood units (see discussion in Section 7.2 and its subsections). Scaling of these neighborhoods results in a coefficient of 0.16 or about ~1/6th (Codd 2020:57). Based on scaling theory, these neighborhoods (as social units of frequent and repeated face-to-face interaction) should exhibit a scaling factor near 2/3rds (~0.66) representative of social interaction in an area (Ortman, et al. 2014:2). As such, this provides an excellent case study for understanding different scaling patterns within a city. This remains the first analysis of scaling theory among neighborhoods in an ancient or modern society; as such, future comparative results are required to see how unique the results from Copan are. However, the sample from Caracol reported here focuses on the district level instead of the neighborhood level, meaning that these results are not directly comparable with Codd's results at Copan.

Another important consideration is that scaling analysis may be fractal, in other words neighborhoods and districts may exhibit intra-urban scaling patterns. Other scaling research has shown a fractal relationship among modern urban districts in Chinese cities

(Xu, et al. 2020). The interpretation of these scaling coefficient results relies on the idea of urban services concentrated in nodes that served as loci of interaction (something demonstrated at Caracol in ASZ Chase 2016b), which fits the current model proposed within scaling theory as energized crowding (ME Smith 2019). These factors suggest that intra-urban scaling exists in modern cities and should exist in ancient ones as well.

5.4.2 District Area Scaling Data.

This dataset for scaling district area provides a statistical universe instead of a statistical sample. Most of the city of Caracol is contained within this lidar dataset, and only 5% to 17% of the city exists outside it in Guatemala (1 to 3 districts and 10 to 40 square kilometers in total). In other words, 83% to 95% of the city is contained within the lidar dataset with 22 districts in Belize occupying about 200 square kilometers. However, the western-most boundary, the border between Belize and Guatemala, is an artificial break in the dataset in terms of ancient settlement. The hard cutoff (and lack of equivalent lidar data) means that the density and area measurements of those districts that intersect it may not be completely accurate.

The areas used for these four analyses follow the district shapefiles shown in Figure 5.2. However, the analyses below will include the whole dataset within Belize and a subset with those districts adjacent to the modern border removed for the larger samples of formal plaza districts and ballcourt districts. This presents both the data as measured and a perhaps more accurate analysis with the subset of districts completely contained within Belize. To account for this, the following graphs will show which points within the district analyses have been affected by this boundary, and then, include graphs and analysis that excludes these points so as not to introduce potentially erroneous data.

In addition, the population estimates used for each district represents a rough allocation of 100,000 (AF Chase and Chase 1994:5) people among the districts proportional to the residences identified in the lidar dataset (see discussion in Chapter 7). While future research may slightly change this population estimate, the proportional allocation of population among districts and the application of a logarithm to that population should limit the effect of future changes on these coefficients. These changes may act to shift the line of best fit upward for an increased estimate or downward for a reduced population estimate but should be similar.

Finally, in association with each Scaling graph there are two sets of tables. The first table presents stem-and-leaf plots (Shennan 1997:27-29) of scaling factors. Each number there represents the hundredths digit of the co-efficient with the tenths digit represented in the row header. These numbers provide a simple sensitivity analysis by showing the results from removing individual districts within the datasets to see how robust the scaling factors are to change. In addition to these stem-and-leaf plots, each analysis also includes a table of regression statistics. These values were calculated using lm (of area to population) and confint (at 95%) in R version 3.6.3 (R Core Team 2020), and they provide a basic level of information for reporting a regression. However, given the nature of this data as closer to a population than to a sample, this regression information does not provide any interpretive value to the accuracy of the coefficients. In a population, the coefficient is the coefficient while in a sample, the confidence interval (CI) provides a 95% range of potential coefficients for the population.

5.4.3 Formal Plaza District vs. Population Scaling.

While the above section demonstrates that formal plaza area exhibits a very high coefficient when scaled with population, this analysis shows that the districts formed by least cost area allocation and their associated populations exhibit an expected scaling relationship. The coefficient of 0.73 (Figure 5.8 bottom, Table 5.3 bottom, and Table 5.4 bottom) represents an intermediate scaling factor between the social and infrastructural scaling factors identified in other settlement scaling analyses. This result supports the interpretation of formal plazas possessing both social and infrastructural aspects based on the intermediate scaling coefficient.

Three nodes lie on the boundary between modern Belize and Guatemala and those are shown with darker circles in this analysis (Figure 5.8 top, Table 5.3 top, and Table 5.4 top). These districts likely had different population and areas in this landscape beyond the lidar than could be identified and included for analysis. However, even including these points yields a scaling coefficient result of 0.80 (Figure 5.8 top, Table 5.3 top, and Table 5.4 top) that lines up pretty closely with 5/6ths, representing the more infrastructural end of settlement scaling expectations.

These results strongly suggest that the city of Caracol managed to exhibit a fractal scaling pattern at the intra-urban, district level. In essence, the concentration of public architecture into district nodes created local attractors with embedded social processes that may have seen daily use (following ME Smith, et al. 2021b). Although this analysis does not identify the exact nature of these processes or frequency of interaction, the more intermediate scaling factor of 0.73 (Figure 5.8 bottom) indicates a mixture of both social and infrastructural scaling coefficient mechanisms (Ortman, et al. 2014:3; ME Smith, et al. 2021b:122-125).

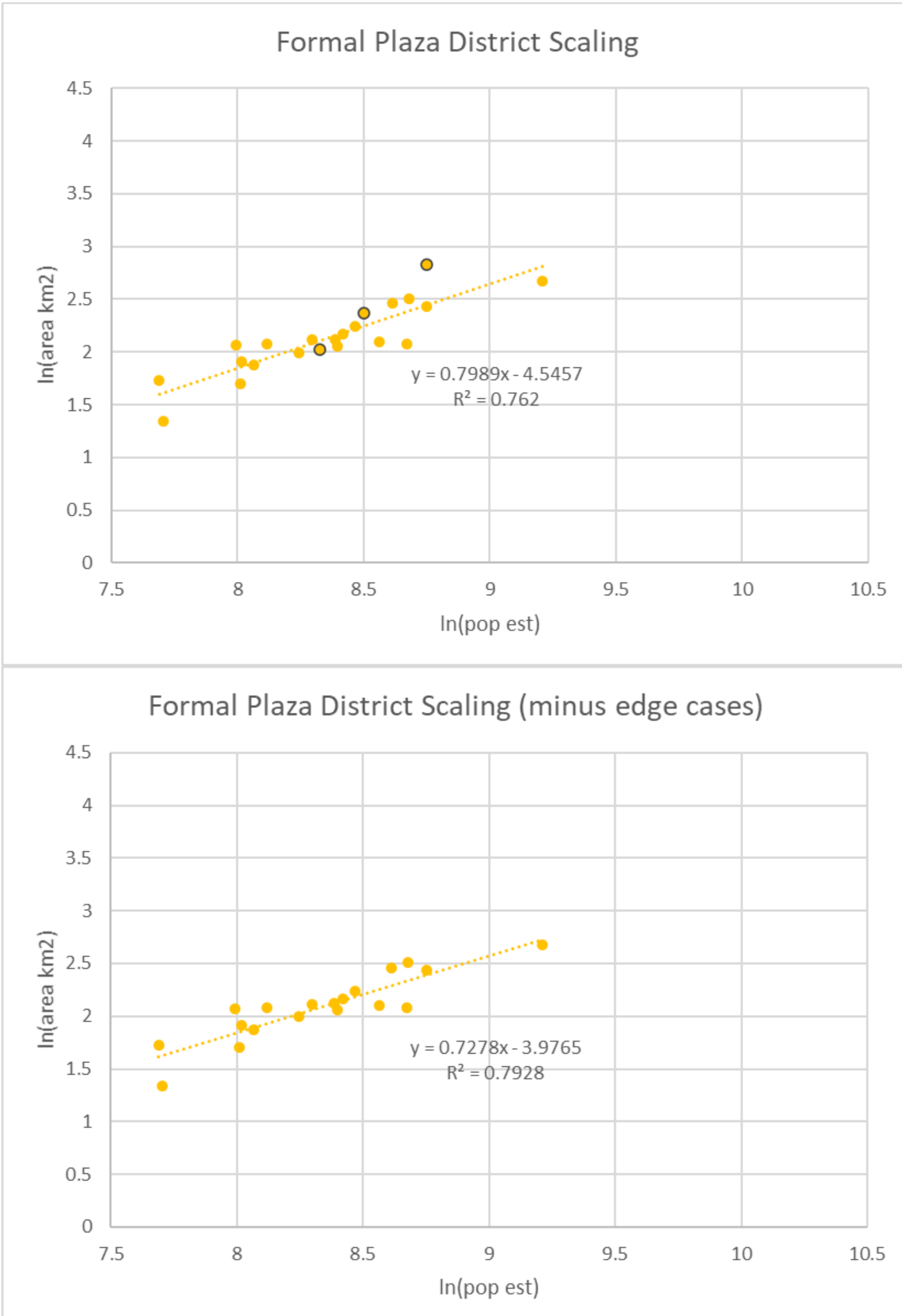


Figure 5.8: Formal plaza district scaling with and without edge cases.
The upper version includes three districts (with dark edges) that included area and population in Guatemala outside the lidar dataset. The coefficient of 0.73 shows higher densities in smaller districts and sits between "social" and "infrastructural" SST values.

Plaza Stem-&-Leaf Plot	
1.0	
0.9	
0.8	0, 0, 0, 0, 0, 0, 0, 0, 0, 1, 1, 1, 3, 4, 6
0.7	2, 4, 8, 8, 9, 9
0.6	
0.5	
0.4	
0.3	
0.2	
0.1	
0.0	

(minus edge cases)	
1.0	
0.9	
0.8	
0.7	0, 1, 1, 2, 3, 3, 3, 3, 3, 3, 3, 4, 4, 4, 6, 6, 6, 7
0.6	4
0.5	
0.4	
0.3	
0.2	
0.1	
0.0	

Table 5.3 Coefficients from formal plaza sensitivity analysis
Each leaf represents removal of a single points to test scaling coefficient sensitivity.

*Formal Plaza Regression

Predictor	*b*	95% CI	Std. Error	*t* value	*p*
Regression Data on all Formal Plaza Districts					
Intercept	-4.546	[-6.298, -2.804]	0.83510	-5.443	2.50E-05
ln(population)	0.799	[0.591, 1.007]	0.09983	8.002	1.16E-07
Multiple R-squared: 0.762, Adjusted R-squared: 0.7501					
Regression Data with edge cases removed					
Intercept	-3.977	[-5.564, -2.389]	0.75258	-5.284	6.08E-05
ln(population)	0.728	[0.537, 0.918]	0.09024	8.065	3.27E-07
Multiple R-squared: 0.7928, Adjusted R-squared: 0.7806					

Table 5.4 Formal plaza regression information
*Dataset is close to a population and not a sample. Thus, the values in Figure 5.8 provide the information necessary for this analysis; however, a sample would require interpretation of these values to determine if the scaling relationship holds.

5.4.4 Ballcourt District vs. Population Scaling.

Like the formal plaza districts, the ballcourt districts also exhibit a sublinear scaling relationship with their populations. For both graphs (Figure 5.9) the r-squared values are very high at 0.93 (top) and 0.95 (bottom). The scaling factor of 0.84 (Figure 5.9 bottom, Table 5.5, and Table 5.6) lines up well with, but slightly above, the 5/6ths (~0.83) value expected for an infrastructural (over a more social) scaling coefficient. This suggests an infrastructural role to these reconstructed ballcourt district areas or to one of the other structures that co-occur with ballcourts within the district nodes.

Additional research on visibility and potential participation is required to understand if ballcourt features exhibit scaling relationships that match expectations of viewership for the ballgame itself (see Stark and Stoner 2017). This represents a potential future avenue of scaling research, but even when focusing on district areas these results suggest that ballcourts are tied into social processes extending beyond simply the elite individuals in each district through the scaling coefficient present. Importantly, this scaling relationship may represent a correlation with other features or processes co-occurring in these districts - with the ballcourt only serving as a proxy indicator.

The scaling factor incorporating the three districts on the border with Guatemala generate a factor of 0.9 (Figure 5.9 top). This result, again, suggests a return on investing in ballcourts as infrastructural features, but the 0.84 value remains closer to expectations for infrastructural area scaling (Ortman, et al. 2014:3; ME Smith, et al. 2021b:122-125). This means that, while ballcourts may have served as social venues for watching the ballgame (or use of another feature), scaling analysis bears out the infrastructural function of interactions in these ballcourt districts.

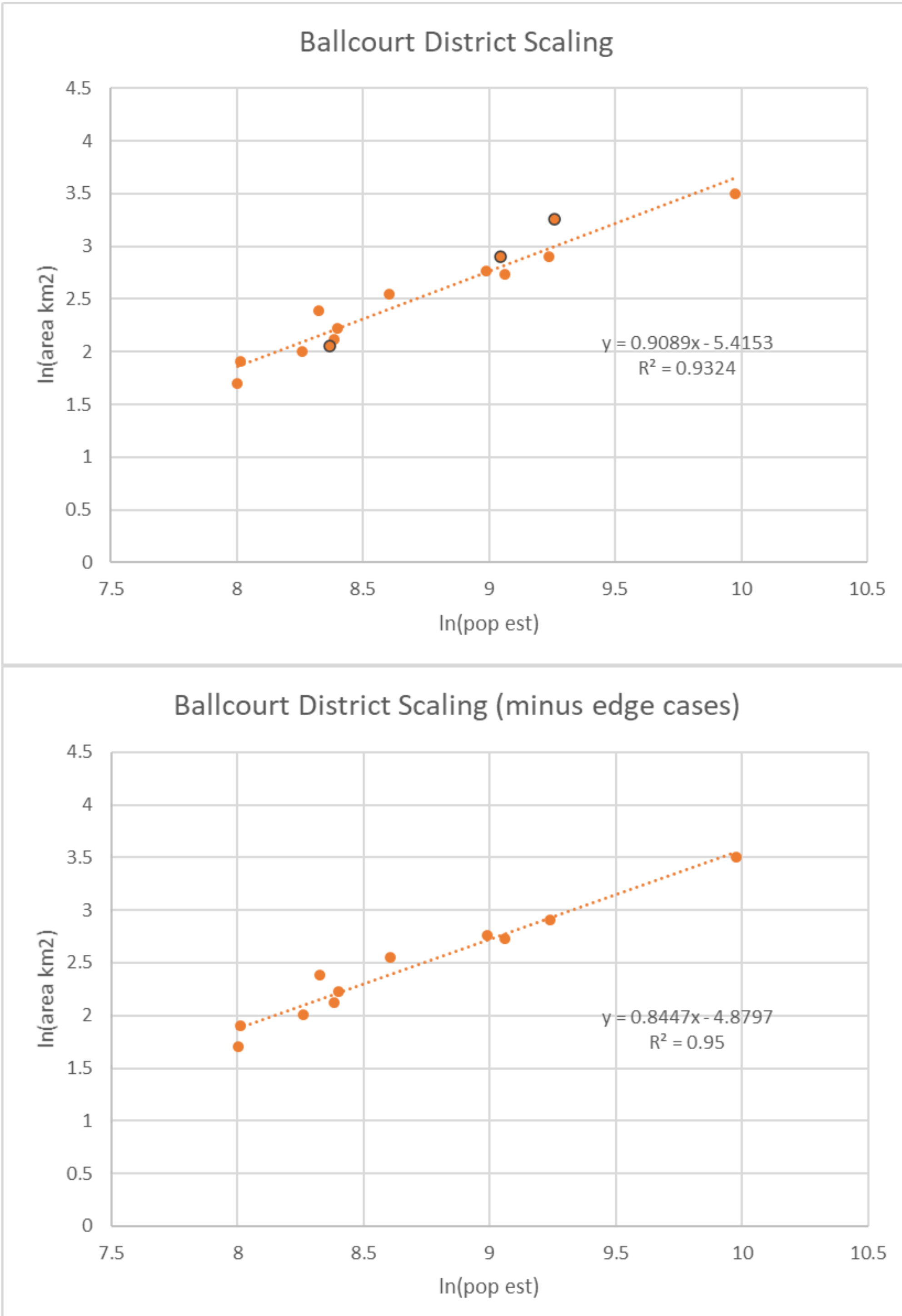


Figure 5.9: Ballcourt district scaling with and without edge cases.
The upper version includes three districts (with dark edges) that included area and population outside the lidar dataset in Guatemala. The coefficient of 0.84 remains close but just barely above the 5/6ths (0.83) expected "infrastructural" SST value.

Ballcourt Stem-&-Leaf Plot		(minus edge cases)	
1.0	0	1.0	
0.9	0, 0, 0, 0, 1, 1, 1, 2, 2, 2, 3	0.9	
0.8	7,8	0.8	0, 3, 4, 4, 5, 5, 5, 5, 5, 7, 9
0.7		0.7	
0.6		0.6	
0.5		0.5	
0.4		0.4	
0.3		0.3	
0.2		0.2	
0.1		0.1	
0.0		0.0	

Table 5.5 Coefficients from ballcourt sensitivity analysis
Each leaf represents removal of a single points to test scaling coefficient sensitivity.

*Ballcourt Regression

Predictor	*b*	95% CI	Std. Error	*t* value	*p*
Regression Data on all Ballcourt Districts					
Intercept	-5.415	[-6.758, -4.072]	0.61636	-8.786	1.42E-06
ln(population)	0.909	[0.755, 1.063]	0.07063	12.868	2.21E-08
Multiple R-squared: 0.9324, Adjusted R-squared: 0.9268					
Regression Data with edge cases removed					
Intercept	-4.880	[-6.148, -3.612]	0.56057	-8.705	1.12E-05
ln(population)	0.845	[0.699, 0.991]	0.06459	13.078	3.69E-07
Multiple R-squared: 0.95, Adjusted R-squared: 0.9445					

Table 5.6 Ballcourt regression information
*Dataset is close to a population and not a sample. Thus, the values in Figure 5.9 provide the information necessary for this analysis; however, a sample would require interpretation of these values to determine if the scaling relationship holds.

5.4.5 Formal Reservoir District vs. Population Scaling.

Formal reservoirs represent a different type of urban service from plazas and ballcourts; as noted in previous discussion above, they may have provisioned water in the past (Lucero 2006a, b; Scarborough and Gallopin 1991) or more residential features may have served that function (ASZ Chase 2016a; Johnston 2004; Weiss-Krejci and Sabbas 2002). The implications for a scaling relationship near 5/6ths would support the water provisioning hypothesis, while the lack of such a relationship would support the idea of residential features providing more of a water provisioning role. However, the results are slightly muddled based on a sensitivity analysis.

The reservoir district coefficient of 0.85 (Figure 5.10 top) suggests an infrastructural (instead of social) area scaling result highlighting the role of reservoirs supporting a water provisioning hypothesis for these reconstructed districts within the city, and the r-squared of 0.86 provides a relatively tight relationship within the dataset. Yet, the lower graph (Figure 5.10 bottom, Table 5.7, Table 5.8) shows that the scaling coefficient drops to 0.49 with the removal of a single district. For each scaling analysis in this section, I removed individual points to test the sensitivity of the resulting coefficients (Table 5.7); a clear outlier exists only within this dataset. The exclusion of a single district south of the city center, Round Hole Bank, reduces the entire scaling coefficient by 0.37, a very significant decrease. This presents a conundrum where the removal of one district changes the results from indicative of infrastructural scaling in reconstructed reservoir district areas to one showing a very low slope more similar to the metric for plaza area and population identified by adding Caracol the city to the Palenque dataset from Ossa, et al. (2017).

These data, with the sensitivity analysis, shed doubt on the interpretation of these features as urban services. However, with the inclusion of a temporal element, an alternative interpretation can be offered. What if formal reservoirs once provisioned water in the Late Preclassic era (and perhaps Early Classic), but ceased in that role by the Late Classic? The use of these monumental reservoirs would change, but the features themselves would remain present in the districts. Historically at Caracol, the monumental reservoirs occur at the three initial settlements that conurbated into the city of Caracol alone, and by the end of occupation at Caracol residential reservoirs ubiquitously covered the landscape (ASZ Chase 2019). Assuming the change in formal reservoir use over time, it would make sense that the potential scaling relationship exists as part of a historical process of reservoir use. While formal reservoir district scaling provides more ambiguous evidence than the other reconstructed district area scaling analyses due to its sensitivity to one data point, these features provide evidence both for the provisioning of services among these districts in the past and also show that this service may be fundamentally different in that provisioning from the others included here due to historical processes.

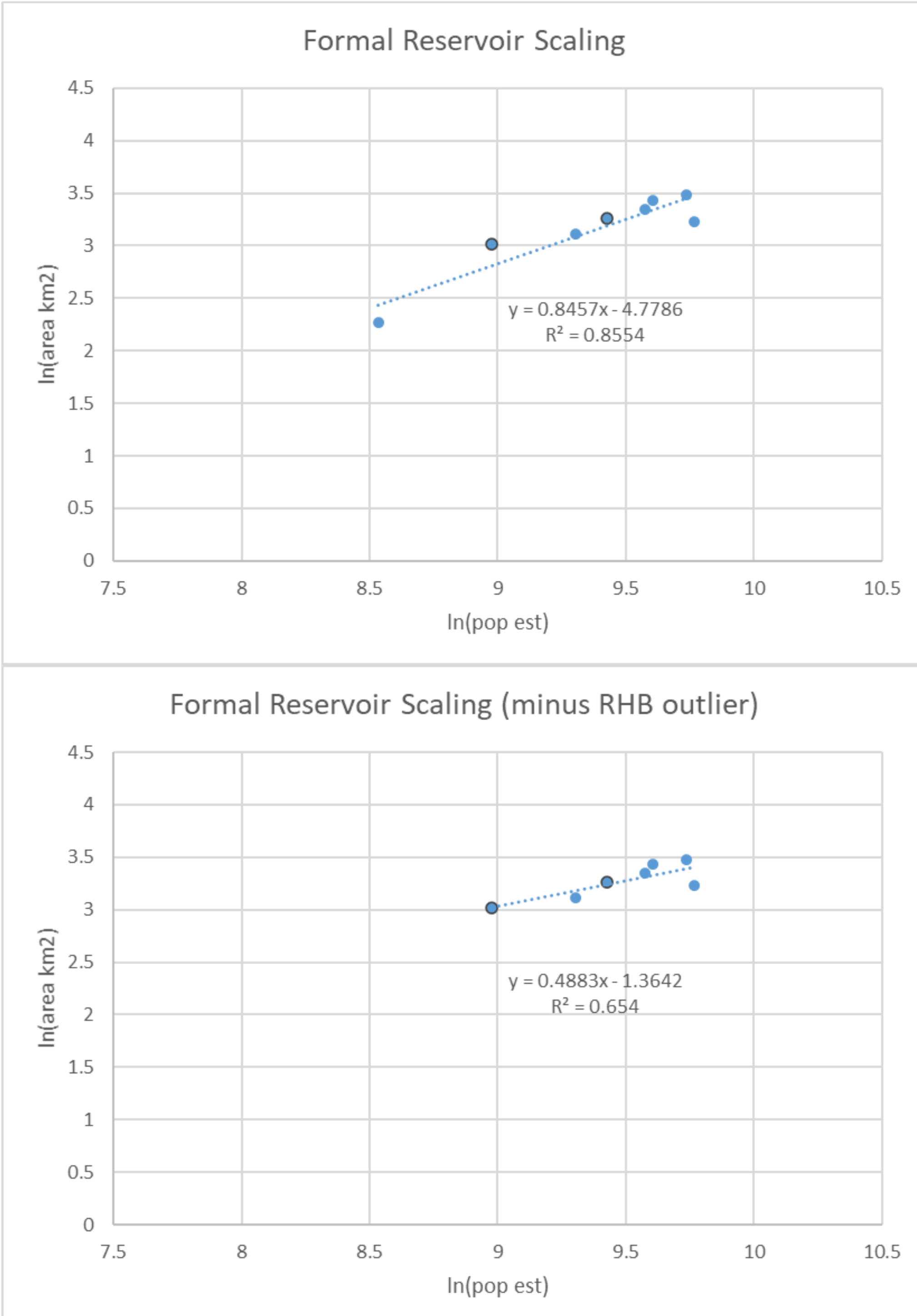


Figure 5.10: Formal reservoir district scaling with and without Ramonal.
The upper version includes all districts while the lower excludes Ramonal – an outlier.
This causes the scaling coefficient to change drastically from 0.85 to 0.49.

Formal Reservoir Stem-&-Leaf Plot		(with RNB removed)	
1.0		1.0	
0.9	3, 6	0.9	
0.8	3, 4, 4, 4, 5	0.8	
0.7		0.7	
0.6		0.6	5
0.5		0.5	
0.4	9	0.4	2, 5, 6, 8, 8, 9
0.3		0.3	
0.2		0.2	
0.1		0.1	
0.0		0.0	

Table 5.7 Coefficients from formal reservoir sensitivity analysis
Each leaf represents removal of a single points to test scaling coefficient sensitivity.

*Formal Reservoir Regressions

Predictor	*b*	95% CI	Std. Error	*t* value	*p*
Regression Data on all Formal Reservoir Districts					
Intercept	-4.779	[-8.035, -1.522]	1.3307	-3.591	0.0115
ln(population)	0.846	[0.498, 1.193]	0.1420	5.957	0.0010
Multiple R-squared: 0.8554, Adjusted R-squared: 0.8313					
Regression Data with RHB removed					
Intercept	-1.364	[-5.238, 2.509]	1.5069	-0.905	0.4068
ln(population)	0.488	[0.080, 0.897]	0.1588	3.074	0.0276
Multiple R-squared: 0.654, Adjusted R-squared: 0.5848					

Table 5.8 Formal reservoir regression information
*Dataset is close to a population and not a sample. Thus, the values in Figure 5.10 provide the information necessary for this analysis; however, a sample would require interpretation of these values to determine if the scaling relationship holds.

5.4.6 E Group District vs. Population Scaling.

Finally, E Group districts also appear to exhibit a scaling relationship similar to that of the ballcourt and reservoir districts with a coefficient of 0.89 (Figure 5.11, Table

5.9, and Table 5.10). Unlike the prior analyses, only five points make up this dataset and it provides too few data points for a concrete analysis. With the fewer points, the higher r-squared of 0.98 would be expected. In addition, excluding the two potentially problematic districts reduces this dataset even farther, but results in the same scaling coefficient.

Fundamentally, more data is required to discuss and interpret this scaling relationship. However, that data will need to come from inter-urban comparative analysis of intra-urban E group district service area scaling patterns. Of all the service feature areas scaled in these sections, E groups exhibit the most restrictive distribution. The history of their construction limits them spatially to the southeastern Maya lowlands as well (AF Chase and Chase 2017b:Figure 2.9). Akin to the reservoir districts above, the temporal constraints on when the ancient Maya constructed, and modified, E Groups might affect the scaling relationship. For example, the inhabitants of Caracol built no new E Groups in the Late Classic Period, although they continued to use existing E Groups. These features could exhibit a temporal aspect to scaling due to their early construction, but also remained in use until the end of occupation at Caracol (AF Chase and Chase 2007).

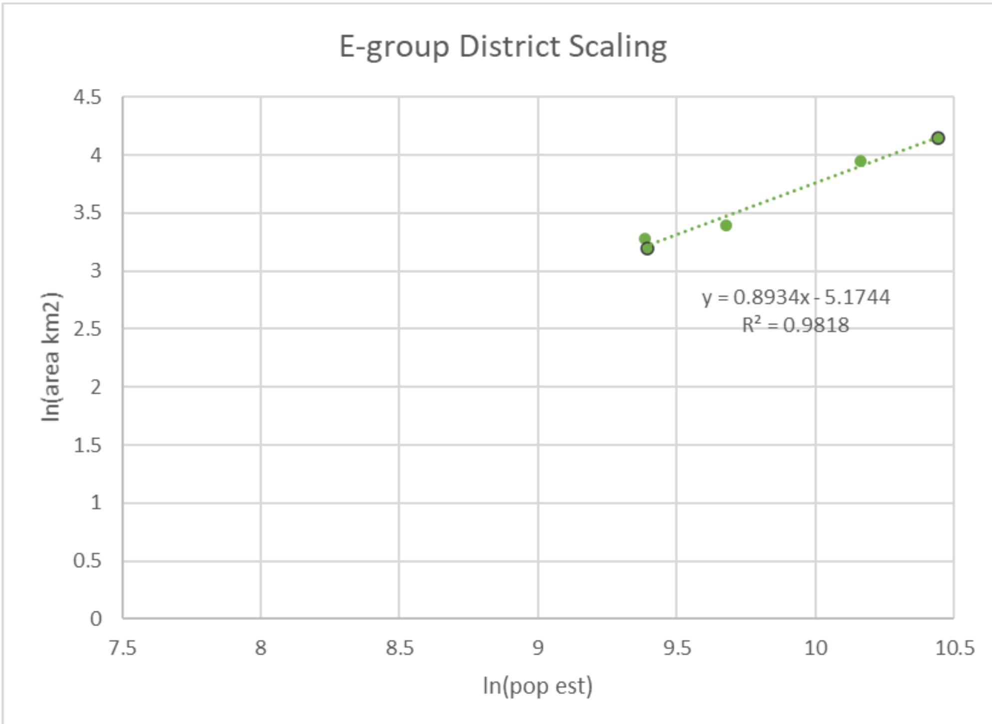


Figure 5.11: E Group district scaling.
With only five points in this result the analysis needs comparative data. While the coefficient of 0.89 is near but above the expected value for infrastructure scaling, the two darker edged points likely had additional area and population outside the lidar dataset in modern Guatemala that could affect their position on this graph.

E Group Stem-and-leaf Plot

1.0	
0.9	1, 5
0.8	7, 8, 8
0.7	
0.6	
0.5	
0.4	
0.3	
0.2	
0.1	
0.0	

Table 5.9 Coefficients from E Group sensitivity analysis
Each leaf represents removal of a single points to test scaling coefficient sensitivity.

Predictor	*b*	95% CI	Std. Error	*t* value	*p*
Regression Data on all E Group Districts					
Intercept	-5.174	[-7.369, -2.980]	0.68960	-7.503	0.00490
ln(population)	0.893	[0.670, 1.117]	0.07022	12.722	0.00105
Multiple R-squared: 0.9818, Adjusted R-squared: 0.9757					

*E Group Regression

Table 5.10 E group regression information
*Dataset is close to a population and not a sample. Thus, the values in Figure 5.11 provide the information necessary for this analysis; however, a sample would require interpretation of these values to determine if the scaling relationship holds.

5.4.7 Reconstructed District Service Area Scaling.

The data presented above for Tier 4 formal plaza districts (Figure 5.8), Tier 3 ballcourt districts (Figure 5.9), formal reservoir districts (Figure 5.10), and Tier 1 & 2 E Group districts (Figure 5.11) suggests that these administrative units' service areas exhibited scaling coefficients that match those expected for urban/settlement scaling theory. The formal plaza districts exhibit an intermediate result of 0.73 suggesting both social (2/3rds) and infrastructural (5/6ths) interactions with and uses of these districts. In contrast, ballcourt districts at 0.84 and E Group districts at 0.89 (caveat, sample size of four) both exhibit relationships near, but slightly above, the 0.83 expected value more infrastructural uses. This suggests that these features may not have been used as frequently for events, but that they still exhibit expected infrastructural area scaling patterns closer to 0.83 than 0.67 (Ortman, et al. 2014:3; ME Smith, et al. 2021b:122-125). While formal reservoir districts at 0.85 appear to match this pattern as well, a sensitivity analysis finds that excluding a single district changes this relationship to 0.48 instead. This suggests that these reconstructed reservoir districts may not match expectations for infrastructural uses as well as others or expose a remnant of the historical construction of these features. Intra-urban scaling, in general, remains a new topic for scaling research (see also Codd 2020; Xu, et al. 2020). The study presented here constitutes the first application of intra-urban scaling theory at the district level of an ancient city, and these results will require comparison with results from additional cities to determine how unique or commonplace they truly are.

This research resulted in one interesting conclusion: each of these district boundaries subdivides the same dataset of residential plazuelas and city area into four distinctive sets of boundaries based on service areas. I had not expected all four district types to exhibit scaling relationships between 2/3rds and 5/6ths. In contrast, Codd (2020) identified very different scaling factors subdividing the city of Copan by its *sian otots*. This suggests that the 2/3rds to 5/6ths results at Caracol should indicate a meaningful pattern. Either way, more comparative data will help determine how common or anomalous these results from Caracol are.

Taken together, these patterns may mean that all of these urban service facility features (or feature sets that co-occurred with them) provisioned urban services in the past and structured interactions within these reconstructed district areas thereby exhibiting the patterns expected of urban/settlement scaling theory. Or it may mean that the most common scaling unit of formal plaza districts forms the basis for scaling relationships among ballcourt, formal reservoir, and E Group districts. Each feature provided unique services in the past, but the scaling patterns visible in this dataset may result from the pattern of formal plazas and their effects on the city contained within the larger districts for other service features. Intra-urban scaling remains sufficiently new, so that the potential relationship between these multiple, overlapping boundaries cannot currently be understood without comparison to other settlements – although the data from Copan suggests that scaling patterns similar to those for modern cities should not be taken for granted in ancient intra-urban contexts (Codd 2020).

In any case, because this dataset represents a near universe of districts and all of Caracol located within modern Belize, these urban scaling analyses provide additional evidence suggesting that these urban service facility features acted as infrastructure in the past. Each district type exhibited scaling coefficients according to the expectations of intra-urban scaling. Formal plaza districts exhibited the lowest coefficient (at 0.73) between the two expected values of social area scaling at 2/3rds and infrastructural area scaling at 5/6ths (Ortman, et al. 2014:3; ME Smith, et al. 2021b:122-125), while ballcourt, formal reservoir, and E group districts all exhibited higher scaling coefficients slightly above but very close to the expected 5/6ths value.

5.5 1-hour Service Accessibility

The various analyses in the above sections tested reconstructed districts for urban service facility features in the past and supports the interpretation of these features as social or infrastructural divisions of the city. However, the next analysis shows how accessible these features are on the landscape and provides a complementary perspective on district use. Using least cost analysis (see White 2015; White and Surface-Evans 2012) and plotting the resulting travel times from every meter-by-meter raster cell, these analyses focus on formal plazas, ballcourts, and E Groups. The exclusion of formal reservoirs relates to their potential data sensitivity issue with the scaling coefficient above (Figure 5.10), and reservoir features do not occur in the same hierarchical fashion as the other three feature types (Table 5.1). Finally, this analysis does not currently use the causeways or other landscape features to either help or hinder movement.

These maps and graphs highlight a hyper-connected landscape of urban service facility features. Each Figure (5.12, 5.13, and 5.14) shows the landscape within Caracol and how many minutes it took to walk to the formal plazas, ballcourts, or E groups from any part of the landscape within the city. Additionally, each Figure uses the same scales and the same color gradients to allow for direct visual comparisons. While future analysis may incorporate landscape classifications to facilitate movement like causeways or to hinder movement like agricultural terraces, the results should roughly match those presented here. Both formal plazas and ballcourts exhibit average commuting times in line with daily use in modern contexts (Marchetti 1994). In fact, these results strongly suggest that a daily trek to and from these district nodes did not require a great investment in time for most residents, especially if all residents of a *plazuela* did not need to visit these features every day.

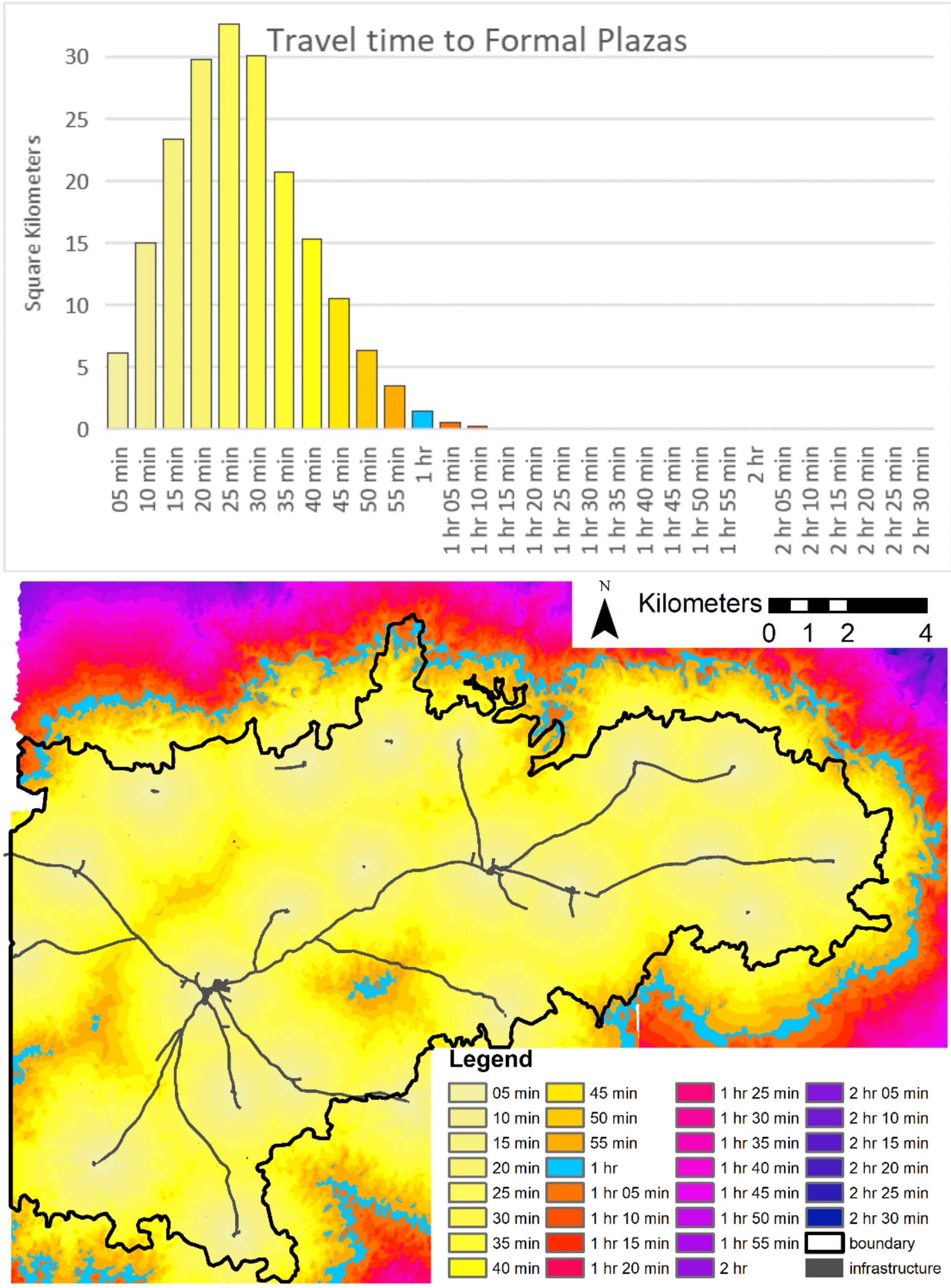


Figure 5.12: Travel times to formal plazas across the landscape of Caracol.
Most of the landscape within the city has under a 25-minute walk to a formal plaza.

5.5.1 25-minutes to Formal Plazas.

The distribution of formal plazas across the landscape demonstrates a commitment to accessibility (Figure 5.12). Formal plazas remain accessible throughout the entire city, and most of the landscape within Caracol requires less than a 25-minute walk to or from one of these formal plazas. The short travel time to formal plazas would have facilitated regular social interactions in these spaces.

While the exact frequency of people going to and from these services cannot be determined, the dispersed nature of the formal plazas provided reasonable walking distances for the average resident, reinforcing previous analyses in this chapter suggesting that these were likely the most commonly used urban service features. For the ancient Maya of Caracol, infield urbanism meant that their agricultural terraces remained proximal and adjacent to their residences for an easy daily commute to their corps, and facilitated the addition of nightsoil (AF Chase and Chase 2015:17). In contrast, urban residents with outfield urbanism need to commute to their fields located beyond the city's boundary. This has some implications for daily commutes and the frequency of using formal plazas. In other words, the infield nature of Caracol reduced the average commuting time for agriculture and the dispersed nature of the formal plazas provided proximal spaces for interaction; it is possible that infield agriculture reduced overall commuting times for urban residents in ancient Maya cities versus traditional, outfield cities.

One final interesting thing to note, the placement of formal plazas along the city boundary would have permitted peripheral populations in "greater" Caracol (e.g., the population beyond the city boundary demarcated in Figure 5.12 to access the market system, socialize in plazas, or participate in special events. This helps to explain the sprawl-like nature of Termini A and C (Figure 5.4), especially if they facilitated the entry of additional people from beyond the city boundary. In addition, this means that the population estimate of Caracol at 100,000 people (AF Chase and Chase 1994:5) does not include the total number of individuals who might have frequented the formal plazas (a potential reason for the plaza scaling results above).

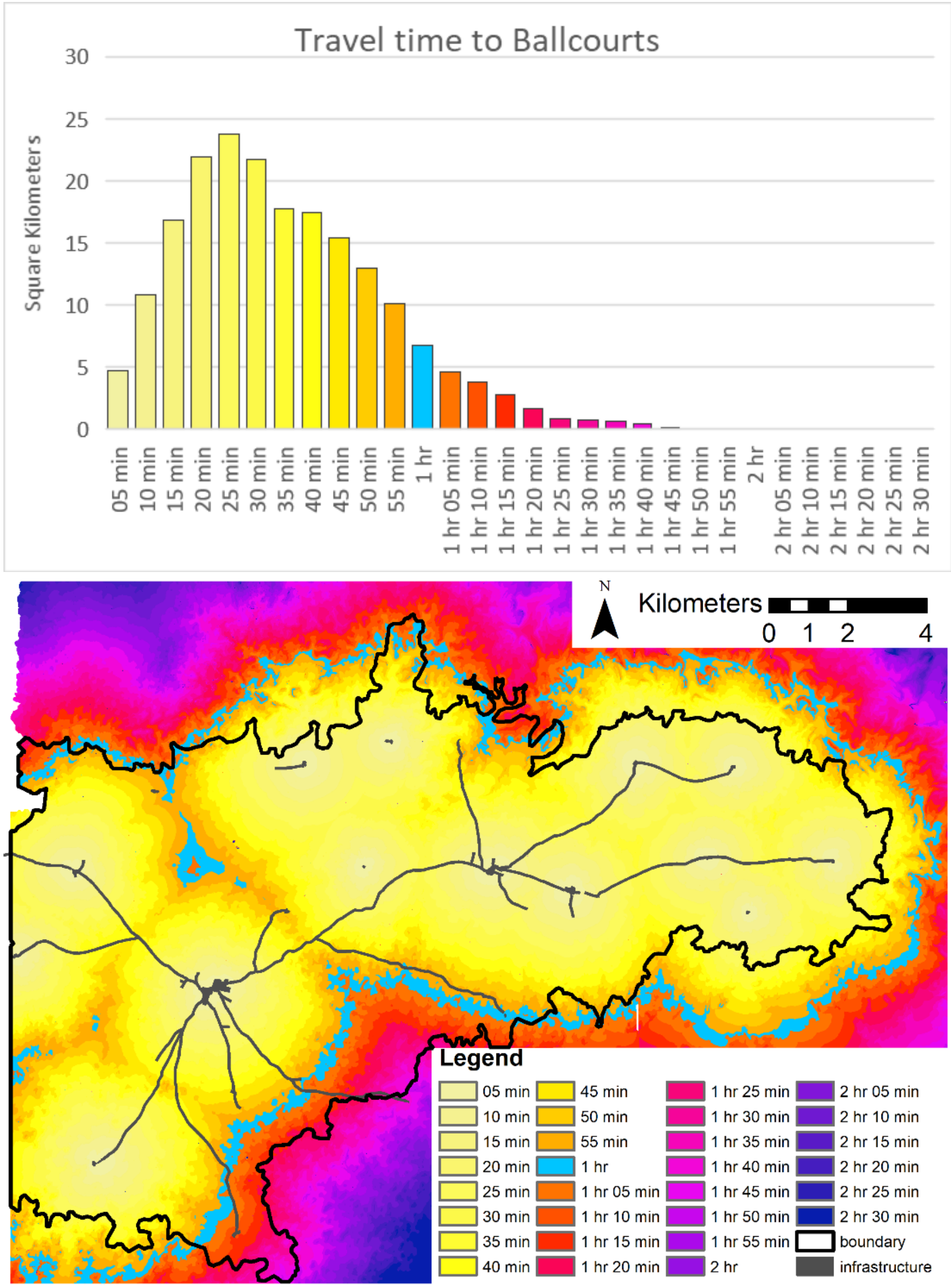


Figure 5.13: Travel times to ballcourts across the landscape of Caracol.
Most of the landscape within the city has under a 30-minute walk to a ballcourt.

5.5.2 30-minutes to Ballcourts.

The distribution of ballcourts lines up relatively well with the boundary of Caracol. This facilitates an average travel time to a the closest ballcourt of under 30-minutes (Figure 5.13). In general, this distribution appears similar to the formal plazas (Figure 5.12), only 5-minutes more. The ballcourts occur at more central, interior district nodes, and this distribution may be related to history, population growth, or other mechanisms pertaining to past integration.

While the extra five minutes added to the average travel time seem at first glance to be quite similar, the ballcourts do not appear to serve the "greater" Caracol population nearly as well as the formal plazas. Ballcourts appear to act as services within the urban boundary but not beyond it. This may suggest that ballcourts remained more important in internal city affairs, required the relatively "higher" density population in the center of the city to function properly, or that ballcourts were not used as frequently and that populations external to the city would travel into it to participate in ballcourt events.

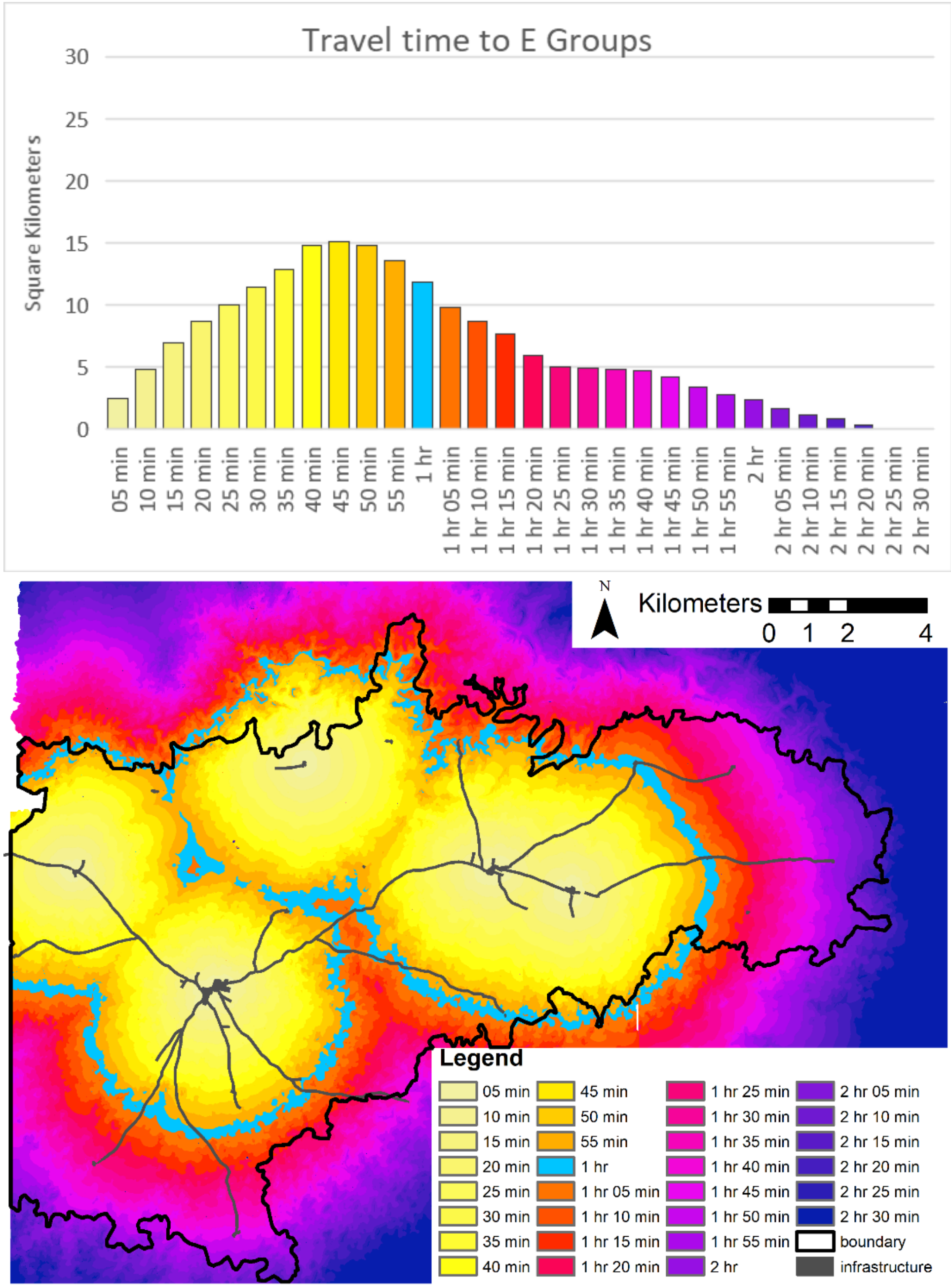


Figure 5.14: Travel times to E Groups across the landscape of Caracol.
Most of the landscape within the city has under a 45-minute walk to an E Group.

5.5.3 45-minutes to E Groups.

E Groups represent the least well distributed features and the 45-minute average travel distance to them corresponds to that distribution (Figure 5.14). These features handle only the core areas of settlement as well as most of the densest (low-density) occupation. Yet, the E Group at Cohune north of downtown Caracol facilitated a much lower population density than the others (Table 5.2).

The longer tail on E Group accessibility falloff (Figure 5.14) suggests (but does not prove) that this feature class saw relatively infrequent use by the population at large at least in contrast to the formal plazas and ballcourts. This becomes especially apparent in the contrast to the histograms of formal plaza (Figure 5.12) and ballcourt (Figure 5.13) accessibility. However, this pattern may be a result of the early time period for E Group construction followed by settlement growth skewed to the south and east.

Including aspects of the first analysis in this chapter (Table 5.1), the ancient residents of this city only converted the E Group in downtown Caracol to a Uaxactun-style complex from a Cenote-style group (AF Chase and Chase 2017b:49-56). In contrast, this analysis looks at the accessibility of Cenote-style E Groups and this Uaxactun-style one. While E Groups as a whole appear to have infrequent access and use from a citywide perspective, this singular Uaxactun-style one in downtown Caracol had even more restricted access. At the same time, the size of the formal plaza in downtown Caracol could accommodate the entire site population at $0.46 m^2$ spacing and 3/4ths of the population at $1.0\ m^2$ spacing (see Table 5.2). Taken together, these facts suggests that the downtown E Group may have been one of the exclusive service provisioning structures correlated with the downtown's larger formal plaza size.

5.5.4 Overall Accessibility.

Residents of Caracol the city did not need to travel very far to reach the urban services distributed throughout various district nodes. While there may have been seasonal cycles to use of these services, the formal plazas remained very accessible to the population at large. As food for thought, these ancient travel times do not differ much from modern travel times to and from work in the modern world, ranging from an ideal of 15-minutes to actual averages over 40-minutes, one-way (Páez and Whalen 2010; Redmond and Mokhtarian 2001; O Smith 2017c). Other analyses have found that modern city settlement depends on commuters being able to reach urban infrastructure in an average of 30-minutes with zoning and new transportation technologies increasing city size by reducing travel times (Marchetti 1994). In contrast, the daily travel of most ancient Maya at Caracol focused on walking to and from their agricultural terraced fields that sat adjacent to their *plazuelas*. As such, travel to urban services at Caracol would have represented less frequent travel and, even when they needed to travel, commuting times remained very light.

The results presented here bolster the initial argument about the hierarchy of urban service tiers where E Groups take about 45-minutes to reach, ballcourts take about 30-minutes to reach, and formal plazas required about 25-minutes to reach. The overall accessibility of features indicates that the ancient residents of Caracol likely used formal plazas more frequently than ballcourts and likely used ballcourts more frequently than E Groups. However, the infrastructure of urban services remained highly accessible regardless of the feature in question.

5.6 *Infrastructure at Caracol*

Taken together, all four of these datasets and analyses indicate a relatively high degree of physical infrastructural power present at ancient Caracol at the district and citywide levels; although, similar analyses at its contemporaries are still necessary. Importantly, this research provides additional context on the nature of that infrastructural power at the citywide and district levels. The various monumental nodes maintained strong interconnections and accessibility through their widespread distribution across the landscape, and each of these features could be accessed by the population at large at the district level. At the same time, multiple lines of evidence reinforce the idea of a strict hierarchy in the urban service facility features types of E Groups, ballcourts, and formal plazas, and the dominance of downtown Caracol in size and connectivity at the citywide level.

First, the distribution of urban service features at nodes of monumental architecture provides a clear spatial pattern. Four tiers of districts are established based on the increasing number of urban services present within them in a strict scale of E Groups, ballcourts, and formal plazas wherein every district of a higher tier (lower number) also possesses each feature of tiers below it. However, every district contains a formal plaza and additional monumental architecture. The relatively widespread distribution of these features suggests that they provided infrastructural uses at different temporal rhythms, but the tiered nature of these features and of the sizes highlights the primacy of downtown Caracol. In particular, the dendritic nature of the causeway network suggests centralization of physical infrastructural power into that specific node. These results suggest that physical infrastructural power may have varied on a feature-by-feature basis and highlight the dual nature of centralization in feature sizes along with widespread distribution at multiple district nodes.

Second, analysis of the relative populations and formal plaza sizes showcases evidence for the superscalar nature of these formalized open spaces along with implications about the centralization of citywide physical infrastructural power. The three districts that initially conurbated to form the city of Caracol (downtown Caracol, Hatzcap Ceel, and Cahal Pichik) all contain much more plaza space than their local populace required. The first set of results (following Inomata 2006), demonstrates the ability of the local population to fit in their district's formal plazas for ceremonies and other activities. However, the second set of results (following Ossa, et al. 2017), showcases a super scaling relationship of formal plaza size and population. In other words, larger districts had formal plazas that were larger per person than the smaller districts, but those smaller districts could still hold their full populations. This suggests that larger districts hosted events for additional populations living in outlying districts or perhaps form other settlements (especially in the case of the 155,935 occupancy-limit of downtown Caracol at $0.46m^2$ spacing shown in Table 5.2).

Third, the reconstructed districts areas – based on service provisioning areas and least cost area analysis – exhibit scaling results that align with settlement scaling theory. Based on the ideas of urban scaling (Ortman, et al. 2014:2-3; ME Smith, et al. 2021b:122-125) this suggests that the coefficient of the relationship between area and population at a logarithmic scale should vary from 2/3rds (i.e., more "social" via the "amorphous settlement model") and 5/6ths (i.e., more "infrastructural" via the "networked settlement model"). Both represent models of social interaction in less and more infrastructural settlements, respectively. With this context, formal plaza districts scale intermediately at 0.73 between social (~0.67) and infrastructural (~0.83) expectations indicating both more social and more infrastructural modeled interactions within these district areas. In contrast, ballcourt, formal reservoir, and E group districts demonstrate more infrastructural scaling with coefficients near 5/6ths supporting infrastructural interpretations of interactions within these district areas. Overall, these analyses suggest that ancient Caracol conforms to intra-urban scaling patterns in non-Maya, modern cities (Xu, et al. 2020) and differs from other Maya settlements (Codd 2020; ME Smith, et al. 2021b).

Fourth, the prior analyses provide data bolstering the identification of these features as urban services with social and infrastructural uses and this analysis demonstrates their accessibility by residents. Most of Caracol's inhabitants were within a 25-minute walk to a formal plaza, a 30-minute walk to a ballcourt, or a 45-minute walk to an E Group. Based on Marchetti (1994:Figure 2), the "daily radius" of a city exhibits roughly thirty minutes of travel time suggesting that Caracol's infrastructure was highly accessible for daily interaction (unlike the results from ME Smith, et al. 2021b). In other words, ancient Caracol benefitted from both its nature as a garden city through infield urbanism and through energized crowding at its many district nodes.

As the above four analyses show, the dispersed nature of urban service facility features indicates physical infrastructural power at the district level. At the same time citywide patterns of concentrated power suggest that understanding the inherent balance between district and city level infrastructure requires additional research. These results suggest a more collective governance system at large through the distribution of urban services, yet this decentralized (or heterarchical) arrangement of civic governance still demonstrates the primacy of downtown Caracol. The downtown district clearly exhibits not only larger but more features in addition to its central placement along the causeway system. Both the centralization of the citywide level and the decentralization of the district level suggests a complex mixture of both hierarchy and heterarchy in governance processes.

As an ancient Maya city, Caracol already has a reputation both for strong, centralized governance at the city level (AF Chase and Chase 1998a, b) as well as for distributed services at the district level (ASZ Chase 2016b, and here in text). Looking at each urban level separately helps to piece together a larger picture of ancient governance. The city possessed a series of powerful rulers (Martin and Grube 2000), but it also possessed a high degree of services and collective features (see also Feinman and Carballo 2018). Importantly, a single analysis, dataset, or metric cannot explain the governance of this city alone without potentially misrepresenting the whole.

The findings from this investigation of physical infrastructural power at Caracol support the existence of strong and pervasive district-level infrastructure across this ancient city. Nodes of monumental architecture distributed widely across the city's landscape provided urban services to its residents. At the same time, these district nodes exhibited a tiered system of service features (based on E Groups, ballcourts, and formal plazas). This combination of centralized and distributed services corresponds with not only physical infrastructural power, but also more collective governance (vis-à-vis their services). Importantly the archaeological remains from the city of Caracol indicate the existence of distributed infrastructure and collective governance while also possessing the series of strong rulers documented in hieroglyphic texts.

6 INEQUALITY, STANDARDIZATION, AND THE GARDEN CITY

While written hieroglyphic records focus on the lives of elites (e.g. Martin 2020; Martin and Grube 2000), Mayanists have tried for decades to use archaeology to better understand the lives of the rest of society (see Ashmore and Wilk 1988; DZ Chase and Chase 1992c; Lohse and Valdez 2004). However, the interaction between the rulers and their citizens remains a difficult problem to address. Cross-cultural analysis of historical societies by Blanton and Fargher (2008) documents a worldwide pattern whereby autocratic rulers exhibit relatively limited influence on their subjects while more collective governing systems were more likely to affect the daily affairs of their citizens. The degree of standardization in the settlement landscape and the level at which it occurs (e.g., neighborhood, district, city or polity-wide) provides one dimension to understand the influence of governance through both top-down and bottom-up processes on daily life.

Household architectural autonomy is the ability of residential groups – in this specific case extended family units living in residential plazuela groups – to maintain their independence from larger urban governing systems in their residential built environment (e.g., processes located in neighborhoods, districts, or the city itself). At Caracol, this represents the relative independence of family groups living in *plazuelas* and acropoleis from centralized administrative oversight at the residential/*plazuela* level. One way to assess this aspect of governance is through a consideration of standardization where high household architectural autonomy would correlate with little residential standardization, while low household architectural autonomy would correspond with high degrees of standardization. However, standardization can result from both bottom-up and top-down processes and occur separately at the neighborhood, district, or citywide scales. These scales and processes hold different implications for the nature of that standardization.

As described in Chapter 3, this chapter utilizes a dataset of 7709 residential groups identified at Caracol using the lidar dataset. While this provides a large settlement sample, this dataset does not include residences that were part of ancient Caracol but that are located outside the Belize datapoints in Guatemala. In addition, while the boundary for Caracol is identified by a drop-off in both agricultural terracing and residential density (ASZ Chase 2016b:Figure 6.1); residential groups beyond that boundary still lie closer to Caracol than to any known, competing cities. Even though this analysis covers a large spatial area, future work will be required to include settlement between Caracol and its contemporaries on the landscape of the Vaca Plateau.

This research focuses on residential feature measurements derived from lidar data for length, width, area, orientation, and distance to investigate household architectural autonomy. It provides an alternative perspective to both collective action (bottom-up standardization) and infrastructural power (top-down standardization). This parallels recent research at Tlaxcallan using standardization to investigate collective action (Marino, et al. n.d.). It can also demonstrate the role of infrastructural power in causing standardization through building codes as demonstrated in historic records of the Song dynasty (Guo 1998) or standardized worker housing (Basri and Lawrence 2020:700-701). However, archaeologists have also investigated and identified standardization through other forms of investigation. For example, at Teotihuacan exhibits standardization in construction practices of stone selection and lime plaster composition (e.g., Murakami 2010, 2016, 2019a, b) as well as in specific units of measure (e.g., Sugiyama 1993). In addition, common repeated residential features or sets of features can indicate standardization. This includes the roughly seventy percent of residences at Caracol practicing ritual caching, burials, and tombs in the eastern mortuary structures of their *plazuelas* (AF Chase and Chase 1996a; AF Chase, et al. 2020b:355). Each of these provides a future avenue for enhancing this analysis of household architectural autonomy.

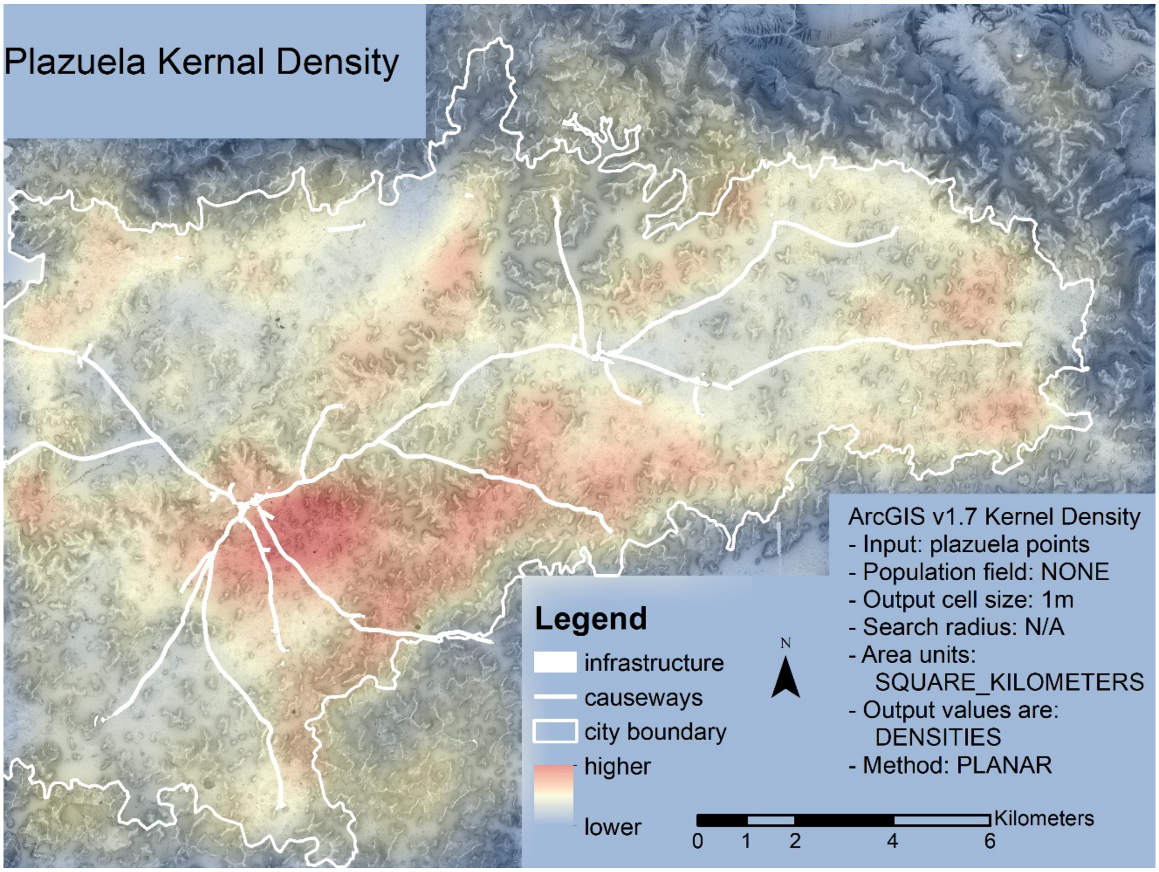


Figure 6.1: This map shows a kernel density analysis on 7709 residences. Kernel density smooths out the point-based location data to show the relative population density across the Caracol landscape at the city level and highlights the higher densities within previously identified city boundaries. Note however that no part of this landscape exhibits zero population density.

6.1.1 Operationalizing Household Architectural Autonomy.

This chapter uses the plazuela level to assess the degree to which ancient households maintained and exhibited agency separate from the larger governing apparatus through their built environment. The degree of standardization of the garden city features (agricultural terraces, residential reservoirs, and plazuela housemound groups) serves as a proxy for household architectural autonomy. The presence or absence of standardization of these garden city features is considered at different scales of analysis (citywide, district, residential).

1.) Citywide standardization of any feature type would indicate very low autonomy and likely indicates top-down imposition on feature form.

2.) District-level standardization would indicate low autonomy and likely indicates top-down imposition from district administrators but could also represent bottom-up forces (such as collective action) within these districts.

3.) And no standardization would indicate very high autonomy and indicate bottom-up processes of construction that do not lead to standardization.

*. Note that a lack of standardization does not automatically imply household architectural autonomy in all areas, only in those being measured.

Assessments of standardization are made by using coefficients of variation and investigated through measures of inequality. This follows Peterson and Drennan (2018:39-40), who discuss the Gini, a traditional metric of inequality, as a measure of the "unevenness" in distributions. However, as hinted at above, standardization, when present, can be due to both top-down and bottom-up process, and determination of causal processes may be difficult due to equifinality. Either way, the degree and nature of residential forms provides key insight into the ability of ancient residents to construct and maintain their households without larger oversight, and tests assumptions of residential autonomy from household archaeology that are rarely tested.

A consideration of household architectural autonomy requires consideration of both collective action theory (Blanton and Fargher 2008, 2016) and infrastructural power (M Mann 1984, 2008). The previous chapter on infrastructural power demonstrates district-level physical infrastructural power in the widespread distribution of urban service facility features at Caracol. Through the level of collective action theory, this would indicate a more collective state where the implementation of these services by the state have been argued to be a result of bottom-up collective action (Blanton and Fargher 2008, 2016). Taking this one step further, collective states should have less household architectural autonomy due to collective action while autocratic states should possess higher levels of autonomy due to inattention of despotic rulers who focus elsewhere for state revenue (Blanton and Fargher 2008:12-22; Levi 1988). However, infrastructurally powerful states regardless of autocratic or collective nature can exhibit that infrastructural power through standardization even at the local level (M Mann 1984:192-194).

This type of top-down, infrastructural standardization can be seen in historic building manuals from the Song dynasty (see Guo 1998) or worker housing in England and the Near East (see Basri and Lawrence 2020:700-701), and may also be present in the gridded residential patterns seen at Tenochtitlan (Calnek 1972:109-111) and Teotihuacan (ME Smith 2017b). Given the level of physical infrastructural power among districts identified in the previous chapter, it might be expected that there also would be some standardization at the local, residential level; however, as will be shown in this chapter, the situation is more nuanced with standardization only in some aspects of the built environment.

Standardization of residences occurs through two distinct types of processes. From the top-down, citywide or district-level, administration can enforce widespread standardization in disparate locations throughout the city. This would indicate a strong governing presence to be able to enforce any standardized building codes or centralized construction projects. It could also indicate a less centralized system of construction focused on standardized weights and units of measure that then lead to local standardization of urban form. From the bottom-up, collective labor can lead to standardization when various residents band together to build these features (e.g., Carballo 2013) or share a common cultural perspective on the built environment regarding residential form (e.g., Hall 1966; Rapoport 1988).

Fundamentally, the mere presence of standardization does not provide the impetus or process behind that standardization (e.g., whether it is top-down as opposed to bottom-up). Yet, the level and scale of standardization (e.g., the urban level at which it exists), especially when combined with other archaeological information, provides evidence to help discern more top-down versus more bottom-up processes.

After examining the standardization in multiple measurements of residential *plazuelas* in this chapter, I also explore the distance between residential groups, the degree to which there is overlap in size between *plazuelas* and acropoleis, the standardization among residential reservoirs (see also ASZ Chase 2016a, 2019), and to a limited extent, the standardization among agricultural terraces (see also ASZ Chase and Weishampel 2016). Each of these different types of data provides another feature type in which to measure standardization. While there are many other ways to consider standardization, including plazuela structure layouts and construction techniques, those analyses would require additional excavation and laboratory work.

The distances between residences help provide information about agricultural fields, houselot space, and land tenure systems. 1) Standardized distances (i.e., a uniform distribution) between residences would suggest uniform areas of residential land tenure. This does not need to be an exact value but should indicate a highly clustered point for fully equidistant residential lots. 2) A bell curve of distances (i.e., a normal distribution) between residences would indicate less overall standardization in residential area or effects of the landscape, but still suggest an overall standardization of land per residence. 3) And a long-tailed normal distribution (i.e., a heavy tailed skewed distribution) would indicate low standardization by showcasing multiple differences in household distribution on the landscape. These three broad categories help establish how standardized residential lots are based on distance between those residences and provide a unique metric for comparing ancient urban built environments.

Both *plazuelas* (also called "patio groups" by Ashmore 1981b:48-49) and acropoleis (see also Andrews 1975:67-71) provide two distinctive labels for the residential forms at Caracol. Acropoleis exhibit additional construction value through increased use of cut stone, raised platforms, and (generally) larger sizes. In text, these two residential forms appear quite distinct from each other; however, these two residential types may be either: 1) internally standardized and distinctive from each other with no overlap indicating a clear status difference based on residential type (like the intermediate and high status residences at Teotihuacan described in ME Smith, et al. 2019) and suggesting low household architectural autonomy in the ability of plazuela residents to build into acropoleis; 2) exhibit some overlap in size and form suggesting an evolution from one residential type into the other over time and indicating higher household architectural autonomy; or 3) exhibit complete overlap in size with unclear implications for household architectural autonomy. This last is unlikely given the larger sizes attributed to acropoleis but would indicate that some other social process would be at work in residents building one form or the other. Investigating the difference in standardization between both residential forms will help shed light on both household architectural autonomy and status divisions at Caracol.

Finally, both residential reservoirs and agricultural terraces comprise most of the garden city landscape – the built environment of Caracol apart from the district nodes covered in Chapter 5. These two features may also exhibit standardization in a similar fashion to the residences as outlined above. At the same time, neither feature exhibits a clear one-to-one relationship with the residences on the landscape, so allocating their ownership to specific *plazuela* groups would be difficult and requires additional consideration. Instead, I analyze these features by themselves at this *plazuela* level, yet the ownership and management systems in relation to the residents warrants future research.

Each of these features represents part of the pattern underlying the infield urbanism (see AF Chase and Chase 2016a; AF Chase and Chase 2016b; Fisher 2014) exhibited by this garden city landscape. While the prior chapter focused on the district nodes, these other features on the landscape provide a different dataset for viewing governance. Standardization or the lack thereof as outlined in the text above provides information about the potential autonomy of these residences from urban levels situated above the residential/*plazuela* level.

6.1.2 Multiple Measures of Inequality.

Another indirect way to investigate household architectural autonomy exists through identification of inequality as expressed through five univariate analyses of residential groups. This includes the use of Lorenz curves and Gini indices as diversity metrics (Peterson and Drennan 2018:39-40). Perhaps unintuitively, this focuses on the use of the Gini index as a metric of standardization among an assemblage. To explain, Gini values near the line of equality (e.g., values near 0.00) represent datasets where every data point has the same value, or full equality in the dataset. This “equality” means that complete standardization exists in the univariate metric studied within that dataset, and low values near zero indicate high levels of standardization. In addition, the closer the Gini value sits to 1.00, the more standardized most of the assemblage is, except for the single data point that owns nearly all of the wealth. Visually, flat parts of the Lorenz curve showcase standardization while the lack of flatter parts within the overall curve demonstrate a lack of standardization (see also examples from Wright 2014:26-27). In addition, the edges of those flat parts of the curve, if present, can also be identified as described later in this chapter using f” kinks.

As such, Gini values, their associated Lorenz curves, and univariate f” kinks provide additional information about the level of standardization present in the dataset, but in more of an exploratory way. The most widely accepted applications of Gini indices in archaeology are related to household size (following ME Smith 1992; ME Smith 1994). The Gini indices analyzed below use five different datasets to consider inequality including both metrics focused on house size as well as access to urban infrastructure (residential group area in square-meters, residential group height in meters, formal plaza access in minutes, ballcourt access in minutes, and E Group access in minutes) to generate Gini values both for the city of Caracol, residences within the boundary of intensive agricultural terracing, as a subset and for greater Caracol, those residences closer to Caracol than any other city, as a superset. While pairs of these values can be compared between the two samples above, the five different datasets cannot be directly compared with each other. Instead, they provide distinct "dimensions" for understanding different types of inequality and various metrics of standardization at ancient Caracol.

6.1.3 Standardization.

While there is evidence for standardization of certain ritual items and deposits associated with eastern mortuary shrines, the situation is different when considering items typically used for Gini values such as residential size. The datasets and metrics discussed in this chapter, taken together with the last chapter, demonstrate that the physical infrastructural power present at the city and district levels did not effectively penetrate into the neighborhood or *plazuela* levels of governance – at least in terms of construction metrics such as length, width, height, and orientation or access to urban services that can be compared without excavation (e.g., an eastern mortuary structure and associated materials require excavation data to evince similarities). Instead, the evidence points to an overall lack of residential standardization within the built environment indicating a local focus on *plazuela*-level construction efforts. In isolation, this might suggest a more autocratic system for the city; however, the relatively low inequality and the widespread district-level distribution of services do not appear to fit with that interpretation providing a potential mismatch between the aspects of governance explored in this chapter and the previous one.

When taken together, these analyses in this dissertation demonstrate that any given metric for understanding governance does not inherently reflect the reality of the system as a whole (see discussion in Chapter 8). As such, the relatively high physical infrastructural power of Caracol at the district and citywide level coexists with relatively high household architectural autonomy in the city, at least outside of the processes within the monumental, district nodes.

6.2 Garden City feature Standardization

Even though the causeways that cross-cut the urban areas integrate the city of Caracol (AF Chase and Chase 2001), *plazuelas*, residential reservoirs, and agricultural terraces comprise the basic architectural features of the Caracol garden city landscape (sensu AF Chase and Chase 1998b). Each feature represents a slightly different scale of organization. *Plazuelas* and reservoirs are associated with the plazuela-level of extended family households while the agricultural terraces – at least at Caracol – incorporate both local and neighborhood-level organization (ASZ Chase n.d.). Terrace systems exist on hilltops, hillslopes, and valley bottoms that drain into each other (ASZ Chase and Weishampel 2016; AF Chase and Chase 1998b; Murtha 2002). This interconnection of terrace systems entails cooperation or management at the supra-household level and probably served as a key factor in formal neighborhood-level relationships.

In contrast, residential reservoirs appear to be less frequent on the landscape of Caracol than either terraces or *plazuelas* but are still common in the landscape. Current data suggests that approximately one reservoir exists for at least every five plazuela groups, however, in some areas of settlement reservoirs are more common. Reservoirs, because of their likelihood to be at least partially infilled over time, are more difficult to identify in the lidar-derived DEMs and that ratio will likely increase with additional on-ground survey and lidar work. As such, while all investigated neighborhoods contain at least one reservoir, given their general location within or alongside plazuela groups, residential reservoirs are best associated with the *plazuela*-scale of residential analysis even though not every *plazuela* appears to have had a reservoir.

Standardization of features occurs through both bottom-up and top-down processes; however, as noted above, a lack of standardization indicates increased household architectural autonomy from a controlling force or the presence of a more autocratic system of governance (following the logic of Blanton and Fargher 2008:12-22). In this formulation collective governance engages in additional standardization. However, standardization can also represent a strong infrastructural presence of state power at the local level (e.g. M Mann 1984:192-194).

Archaeologists have used multiple methods to identified standardization in construction efforts at Teotihuacan, in central Mexico. Here studies were not focused on identifying the collective vs. autocratic nature of the city (although Murakami 2019a uses collective action), but to the existence of standardization itself. Analyses have included attempts to identify standardized units of measure (Sugiyama 1993), discuss the "anomaly" of its general structure orientation and grid plan (ME Smith 2017b), and the standardized nature of construction in both the lime plaster and andesite blocks used in apartment compounds (Murakami 2010, 2016; 2019a:750-752). These various analyses all suggest that standardization (at least for those features studied) exists at the citywide scale, and this indicates low household architectural autonomy.

In terms of formal measurements of residential groups: length, width, area, height, and orientation plotted against each other provide a visual means of investigating standardization of residential architecture that can be generated and replicated with other remote sensing data and compared with other archaeological datasets. While some studies might use residential volume instead, that metric for the ancient Maya – who buried older residences under newer remodeling – potentially relates more to residential longevity and inheritable wealth as a whole rending volume perhaps less well suited for measuring residential inequality at long-lived sites as noted by Hutson (2016:151-152; 2020:411-412). To complement the visual data, the coefficient of variation, the standard deviation divided by the mean of a distribution, represents a mathematical way of understanding similarity versus dissimilarity. However, both provide complementary comparative information. While they will shed light on the degree of standardization and the household architectural autonomy present at ancient Caracol, future research at other contemporaneous cities will bring better understanding for how normal or unusual the system at Caracol was.

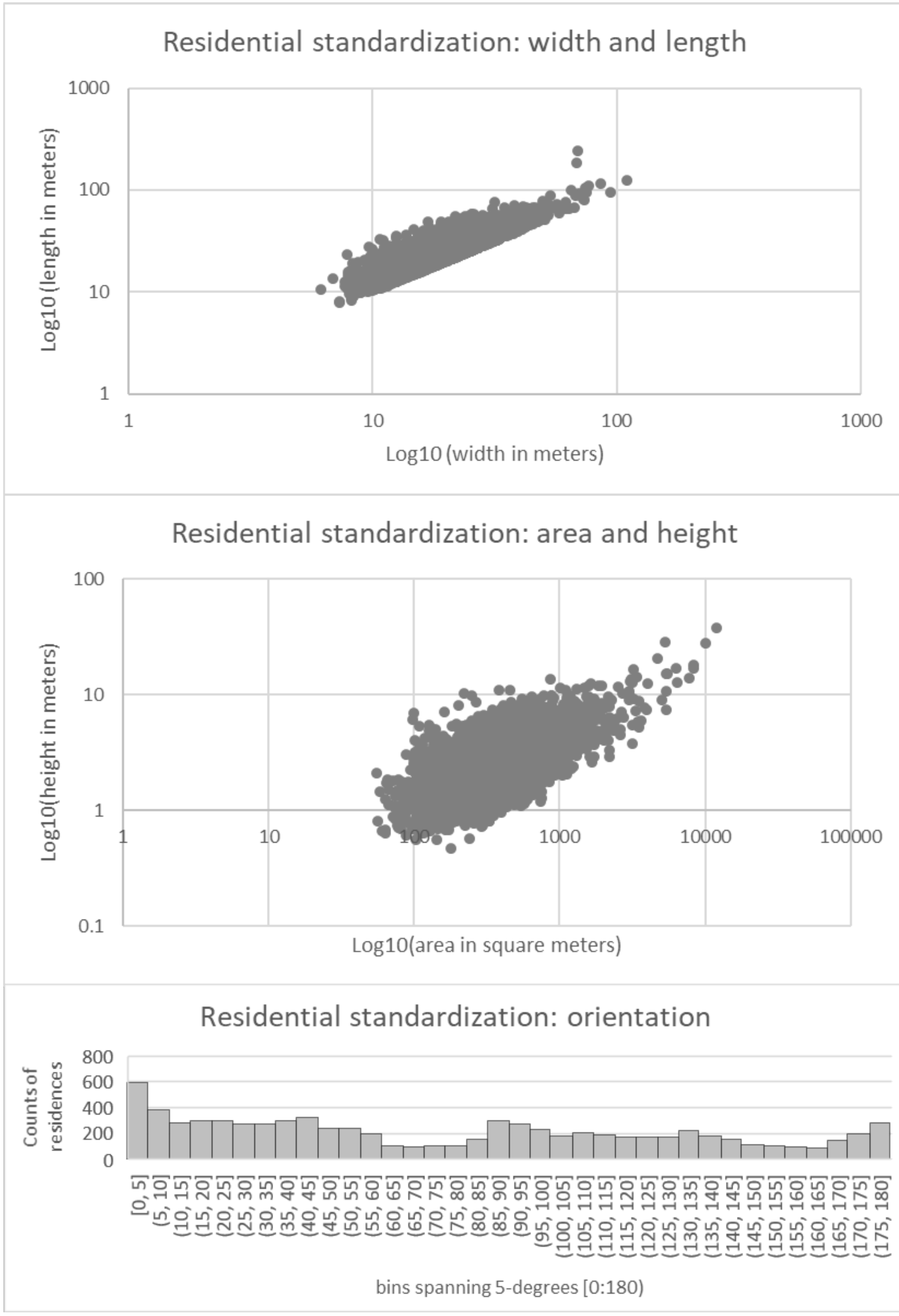


Figure 6.2: Residential architectural standardization
Residential architecture at Caracol shows a relative lack of standardization between length, width, area, height, and orientation at the citywide scale.

Citywide residential architecture

	Area		Height		Length		Width	
City	**CV**	**Mean**	**CV**	**Mean**	**CV**	**Mean**	**CV**	**Mean**
Caracol	0.914	469m	0.559	2.86m	0.341	20.5m	0.357	25.7m

Table 6.1: CVs for residential architecture at the city of Caracol.
These coefficients of variation represent a relative lack of standardization among residential feature classes in conjunction with the Figure 6.2 above.

6.2.1 Residential Plazuelas: Citywide.

Both Figure 6.2 and Table 6.1 provide a great deal of information on the residential groups within ancient Caracol. First, the log10 graphs visually show the variation in these metrics between households while accounting for the larger sizes of some residential architecture (especially the acropoleis). The ArcGIS (version 10.7) minimum bounding geometry tool in the data management toolbox provided the lengths, widths, and orientations of manually digitized plazuela shapefiles building on the sample from ASZ Chase (2017) and using the rectangle by area bounding box tool option. While both length and width appear to show lower coefficients of variation at 34% and 36% respectively (Table 6.1), these values will require similar analysis and comparison with other cities to fully understand. Future comparisons with other Maya cities may change this perception of low standardization if others exhibit higher values in the future. In any case, the combination of length and width into area provides the least standardized dataset with a very high coefficient of variation value of 91%, and even the value of height, representing the difference between the highest and lowest cell under the *plazuela* shapefile in meters, at 56% argues against size standardization among residences (Table 6.1).

Visually, the straight line of y = x under the points in the graph of width to length (Figure 6.2 top) represents the assumptions of the minimum bounding geometry tool's algorithm. It presents the larger value as length and the smaller value as width creating that hard y = x lower bound on the dataset. The wide line that appears on this logged graph indicates that a general idea of necessary residential area, or the specific requirements of household size existed, but that a specific ratio itself is not evident in the data. This is emphasized by the fact that taking the logarithm drastically reduces the visual variance introduced by larger plotted values.

In addition, the graph of area and height highlights this difference at the logarithmic scale (Figure 6.2 middle). Height here represents the maximum difference in elevation within a residential shapefile, not the full volume; however, this graph shows that residential heights varied widely. While these heights represent current and not ancient ones, but the expectation for similar taphonomic processes of decomposition exist.

Finally, the degree values show relative equality between different angles of orientation (Figure 6.2). The ArcGIS tool generated these orientations as the angle of the length across a shapefile, and there appear to be some very, very slight clustering of values along angles of 0, 45, 90, 135, and 180 degrees. These 45-degree measures do not likely represent ancient Maya preference for orientations from true north; instead, they likely reflect either a bias in the algorithm itself or the true north grid orientation of one-meter by one-meter DEM cells generated from lidar data and its effects on the manual feature digitization process. In addition, this orientation represents the entire plazuela and not the orientation of any structures or architecture within it.

These data do not provide a strong argument for standardization within the sizes of residential *plazuelas* at the citywide level. Following the expectations laid out earlier, this suggests higher household architectural autonomy based on these measurements from the lidar dataset. However, the next section explores these same variables at the district level using the same sample of three districts used in Chapter 7. This provides a check to see if the diversity of patterns seen citywide is replicated, or not, at this more localized intra-urban level.

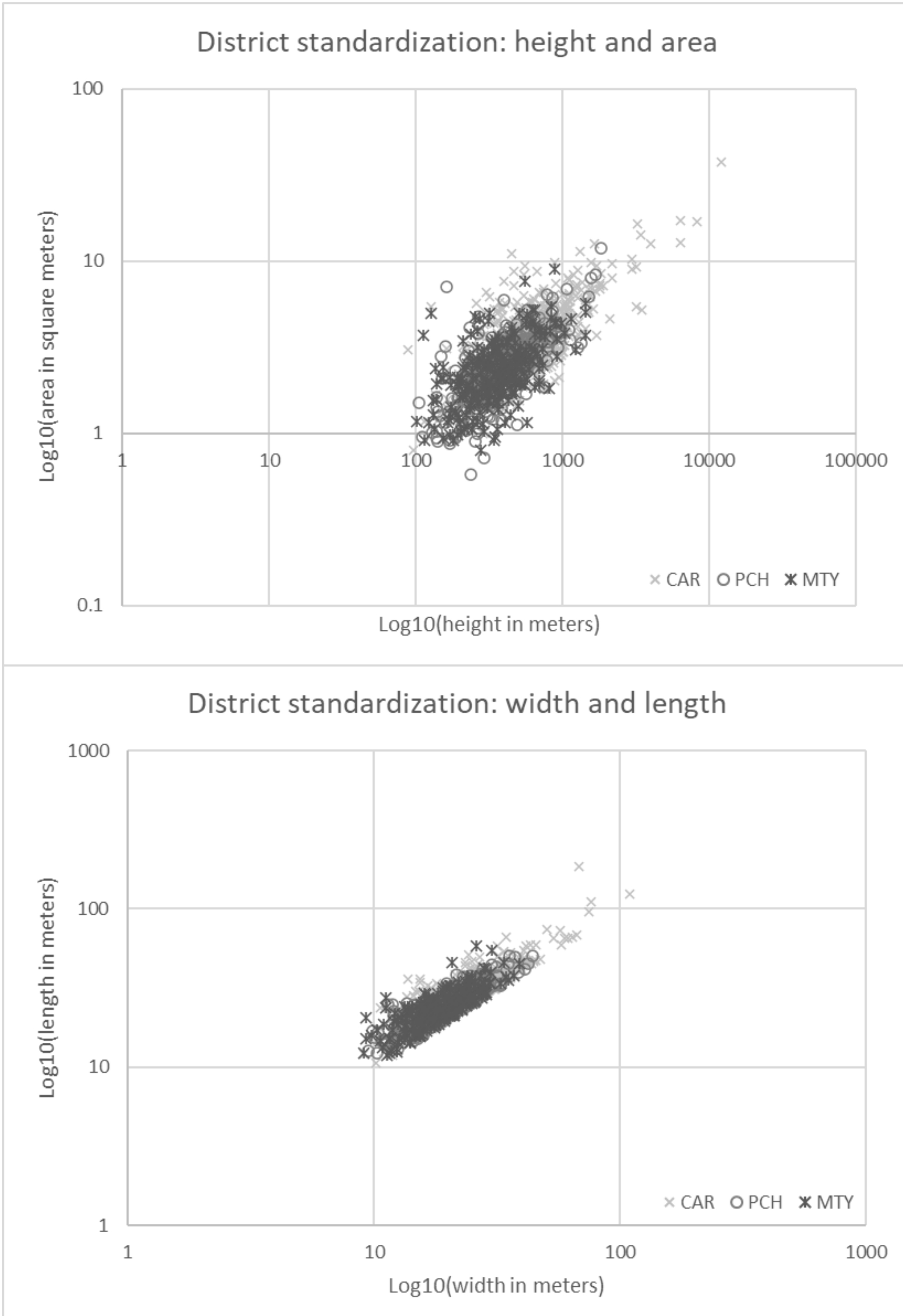


Figure 6.3: Residential standardization in three districts
This plot shows that all three districts (CAR = Downtown Caracol, PCH = Puchituk, and MTY = Monterey) overlap in physical measurements of their residences. The only difference is that Downtown Caracol has both more and larger residences.

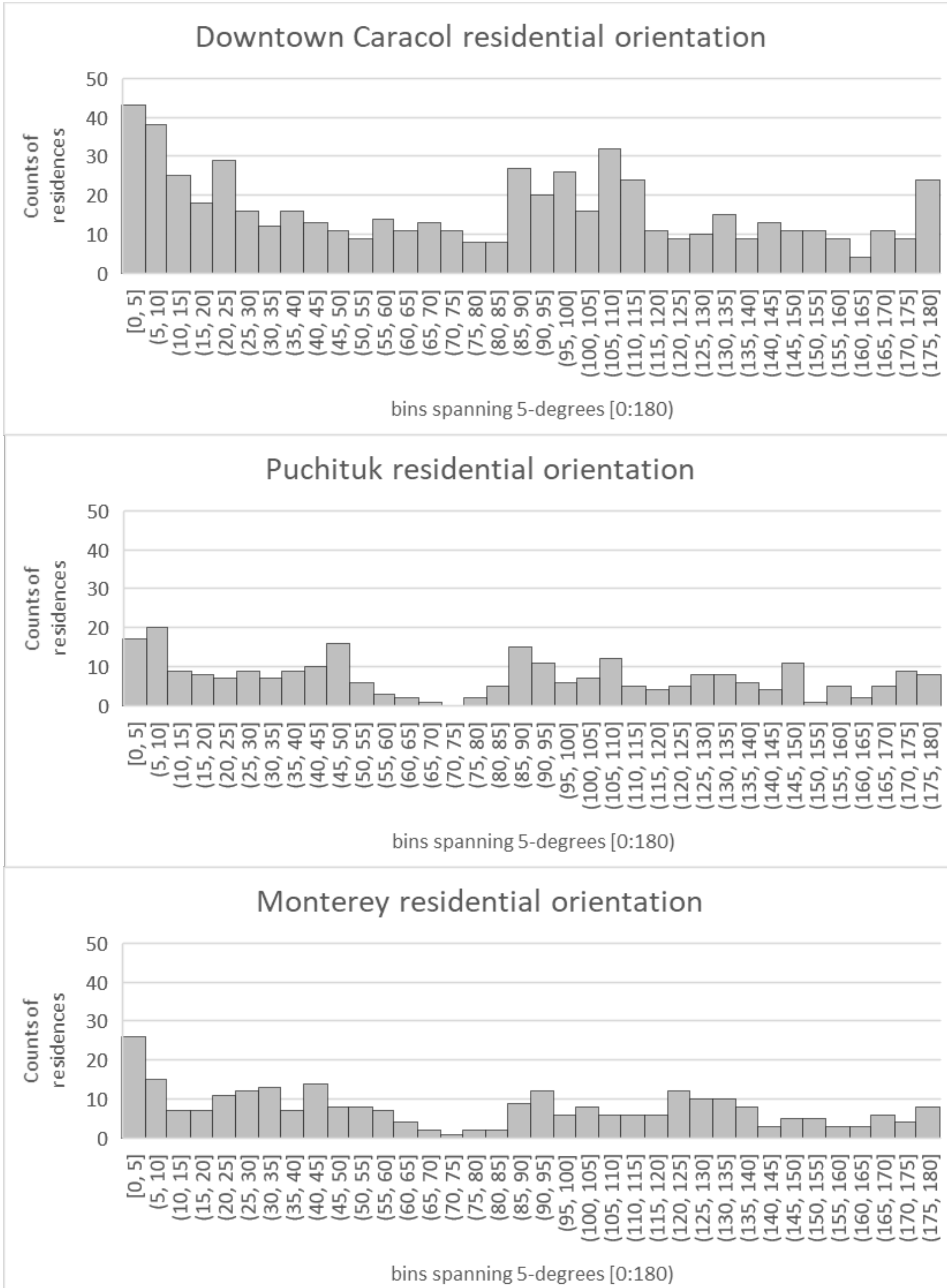


Figure 6.4: Residential orientations in three districts
These orientations are defined as the compass direction of the length by ArcGIS's Minimum Bounding Geometry function shown in histograms of 5-degree bins [0:180). This shows that no single district (among Downtown Caracol, Puchituk, and Monterey) exhibits a distinct difference in lack of residential orientation standardization from the other two.

District-level residential architecture Coefficients of Variation

Name	Area	Height	Length	Width
Epicenter id: CAR	1.070	0.666	0.354	0.359
Puchituk id: PCH	0.590	0.506	0.278	0.288
Monterey id: MTY	0.542	0.452	0.273	0.267

Table 6.2: CVs for residential architecture in three districts
Coefficients of variation for residential area, height, length, and width among the three districts showing in Figures 6.4 and 6.4 above. More variation exists in Downtown Caracol, but all three districts lack standardization in residential size.

6.2.2 Residential Plazuelas: District Level.

The three districts of Downtown Caracol, Puchituk, and Monterey provide a sample for investigating potential residential standardization at the district level. The selection of these three districts augments their use in the next chapter as the three districts for testing neighborhood reconstructions with excavation data. In broad strokes, these data exhibit the same lack of standardization in size and orientation as the citywide dataset described in the previous section (Tables 6.1 & 6.2, Figures 6.2, 6.3, & 6.4). The differences that do exist only seem to emerge due to a few larger residences in Downtown Caracol and the overall smaller sample size from thousands at the citywide level to hundreds at this district level.

The Downtown Caracol district sample contains more than twice as many residences as Monterey or Puchituk and has larger residences on average. Figure 6.3 shows a similar overlap in length and width, area, and height to the citywide dataset (Figure 6.2). The orientation data in Figure 6.4 shows some variation in orientations, but these do not seem to provide significant different orientations from each other or the citywide dataset (Figure 6.2). Finally, the Table 6.2 showcases coefficients of variation that do not differ substantially from those of the city as a whole (Table 6.1). Each coefficient of variation indicates little standardization among values.

As such, this sample of districts appear to indicate that the lack of construction standardization in the built environment at the citywide-level also exists at the district-level. This implies that despite the physical infrastructural power of these districts as shown in Chapter 5, those administrative units did not appear to enforce standardization of residential architecture in the past. While this finding may be expected, it nevertheless provides data on some of the limitations of district governance. However, the general line of length and width with coefficients of variation around 30% could indicate some degree of shared cultural perspective (e.g., built environmental form, see Hall 1966; Rapoport 1988) for residential size (at least in terms of residential *plazuela* lengths and widths) but does not provide sufficient evidence of standardization due to either bottom-up or top-down construction efforts. At least, not without additional comparative urban data. Interestingly, no clear visual clusters exist in the above graphed datasets indicating that the separate residential types of *plazuelas* and acropoleis blend into each other as residences of different size (explored further below).

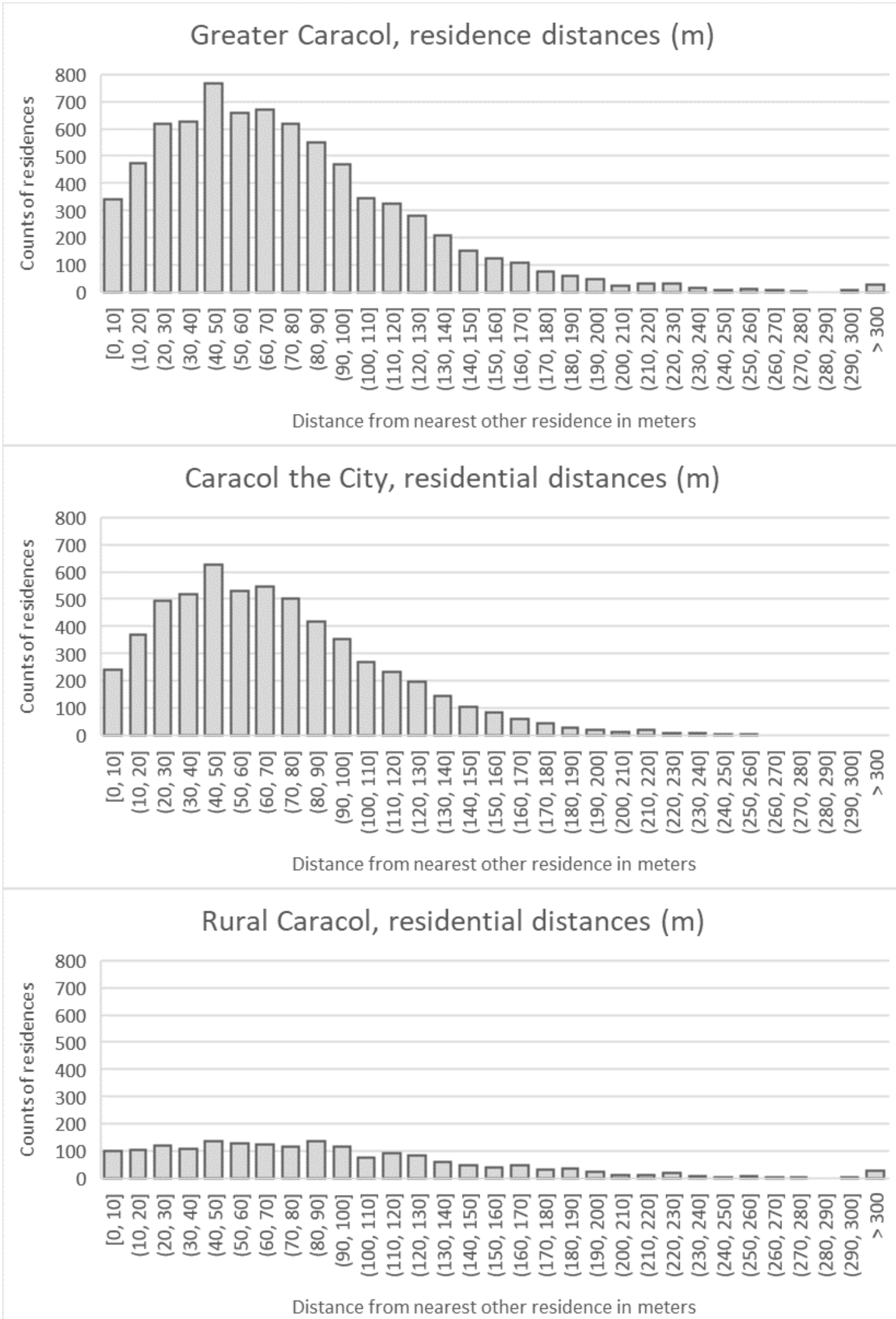


Figure 6.5: Spacing between residences (both *plazuelas* and acropoleis)
This spacing shows a mean distance of 74.5 meters and a median distance of 65.4 meters between residences. However, residences did not exhibit uniform spacing, and this may represent the lack of a standardized house-lot size.

6.2.3 Residential Plazuelas: Spacing Among Plazuelas.

Moving beyond a standardization of individual *plazuela* and acropoleis metrics, the above graphs (Figure 6.5) show that even the distances between residences exhibit only a general trend. These distances represent the direct distance in meters ignoring terrain between a residential structure and its nearest neighbor. Interestingly, 107 of these residential groups exhibit no or nearly no separation indicating at least 53 conjoined groups (e.g., two adjacent *plazuelas*) with at least one triple residential group in the mix. Fundamentally, these residences remain rare representing only 1.4% of the total residential sample at Caracol. These dispersed "double plaza" groups have previously been noted in the landscape of Caracol (AF Chase and Chase 1997) and have been suggested as representing older, well-established households that may have played some kind of unique socio-political role within the city.

For the residential features as a whole, the mean distance between neighbors sits at 74.5 meters while the median distance sits at 65.4 meters. This agrees with prior assessments that each household could maintain space between itself and its neighbors for agricultural uses (Murtha 2002, 2009). These spaces between residences would have been filled with other features including residential reservoirs, kitchen gardens, and agricultural terraces. Maya urbanism has been highlighted for its "garden city" nature of mixing green spaces with settlement and this data accords with those other discussions (Barthel and Isendahl 2013; AF Chase and Chase 1998b; Graham 1999; C. Isendahl 2010).

Unsurprisingly, the distances among *plazuelas* and acropoleis within the city of Caracol exhibit more "closeness" than those within the area of Caracol beyond that boundary of intensive terracing and residential density falloff, but still closer to Caracol than to any other settlement (e.g., rural Caracol; see also Figure 6.8 in the next section). As such, Figure 6.5 provides additional evidence for the more traditionally "urban" (i.e., higher density) nature of settlement within this boundary for ancient Caracol, but also shows variation in density throughout this city (as shown in Figure 6.1). Regardless, these data in conjunction with the residential datasets discussed in the sections above suggest a lack of standardization even among the spacing of *plazuelas* and acropoleis within which the ancient Maya resided.

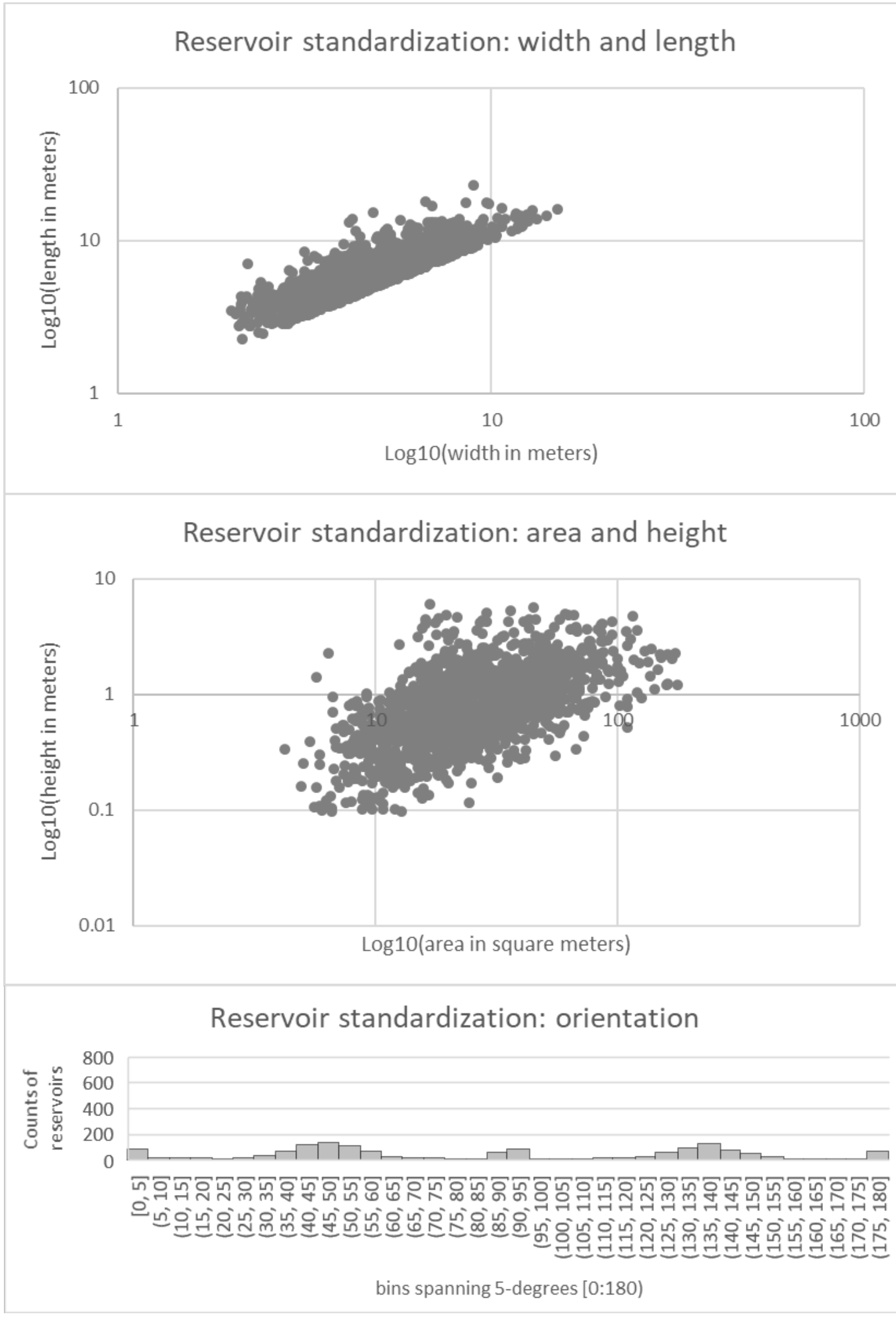


Figure 6.6: Residential reservoir standardization
Though at a smaller sample size, residential reservoirs exhibit even less standardization in length, width, area, height, and orientation at the citywide scale than the residential features shown earlier. Please note that this analysis intentionally excludes both large and monumental reservoirs.

	Citywide residential reservoir Coefficients of Variation							
	Area		**Height**		**Length**		**Width**	
City	**CV**	**Mean**	**CV**	**Mean**	**CV**	**Mean**	**CV**	**Mean**
Caracol	0.726	31.6m	0.802	1m	0.370	6.5m	0.355	5.1m

Table 6.3: CVs for residential reservoirs at the city of Caracol.
These coefficients of variation in conjunction with the Figure 6.6 above represent a relative lack of standardization among residential feature classes.

6.2.4 Residential Reservoirs.

The residential reservoir dataset includes several thousand fewer data-points than that of *plazuelas* and acropoleis; however, it demonstrates an even greater lack of standardization among features. This dataset represents the nearly 1600 reservoirs previously identified at Caracol, excluding those large and monumental reservoirs found in the areas of larger public architecture (see ASZ Chase 2016a). This dataset focused exclusively on identifying features within the boundary of ancient Caracol and does not exhibit the same spatial extent as the dataset of plazuelas above (Figure 6.1). Reservoirs also remain harder to confidently identify than plazuelas. As such, there is currently a ratio of one reservoir per five plazuelas identified at Caracol, but the actual ratio may be closer to one or two reservoirs for every three *plazuelas*, and in some areas of the dataset, that ratio of one reservoir per two *plazuelas* already exists.

In terms of the reservoir data itself, I used the same method for obtaining measurements using ArcGIS (version 10.7) as outlined above for *plazuelas*. However, these residential reservoirs show less standardization in length and width (Figure 6.6 upper) representing the various rectilinear shapes they exhibit. In addition, the graph of area to height (Figure 6.6 middle) showcases even greater diversity of forms, but that height metric itself requires a few caveats due to greater variation in taphonomy due to centuries of disuse. Reservoirs not only have different catchment areas and rates of infilling, but also standing water absorbs the lidar wavelengths used at Caracol. This renders heights from reservoirs with standing water spurious at best. The orientation data (Figure 6.6 bottom) also exhibits a preference for 45-degree angles, but in this case probably represents the much smaller areas of the reservoirs on the one-meter by one-meter grid (differing from the residences in the prior section). These results should not be taken to indicate ancient alignments; instead, these represent potential digital artifacts introduced by the algorithm, dataset, and its digitization. Finally, the coefficients of variation of these residential reservoirs reinforces the lack of standardization present in this dataset (Table 6.3), and do not differ much from those for plazuelas above (Table 6.1). Again, no clear standardization or process of standardization exists for residential reservoirs.

6.2.5 Agricultural Terrace Sample.

While ubiquitous at Caracol, the agricultural terraces do not represent the same type of data as the *plazuelas* or residential reservoirs among these garden city features. Terraces only exist in system form, connected in terms of downhill water flow where the failure of any one terrace impacts every other terrace below it. In other words, following elevation, one agricultural terrace field drains into other agricultural terrace fields, linking hillside terracing with valley terraces and, in effect, embedding households within systems of terraces. This interdependency of agricultural terrace drainage presents a strong argument for some form of community-based management system above the household-level in a similar fashion to other smallholder irrigation systems (sensu Ostrom 1992, 1993; Ostrom 2015). Land tenure is a difficult topic to investigate for the ancient Maya (see LeCount, et al. 2019; AE Thompson and Prufer 2021), but even if fields were individually owned, there would have been a system to manage land or drainage disputes above the household level (e.g., at either the neighborhood, district, or citywide level). The water flow over these terrace systems exists beyond the scope of an individual *plazuela*. As such, the most likely system to handle day-to-day construction, maintenance, and disputes that would arise would be situated at the neighborhood level through community management.

As for the terraces themselves, they do not exhibit standardization in length, width, or height but rather reflect the local topography with a complicated hydrological design (see ASZ Chase and Weishampel 2016). While prior analysis has interpreted these features as possibly centrally managed due to their ubiquity across the entire landscape (AF Chase and Chase 1998b:73-74), a more bottom-up explanation could explain their presence as well (sensu Murtha 2002, 2009). While some may view both of these arguments as fundamentally opposed to each other (i.e., centralized versus decentralized management of terraces), each of them instead suggests the possibility for mediation and management at intermediate levels without specifying if that level existed at either the neighborhood or the district level. The ubiquity of terraces across the city likely required a mixture of both top-down and bottom-up processes of governance for issues of drainage, use, and passage. In addition, the reconstructed neighborhood boundaries identified and tested in Chapter 7 crosscut these agricultural terrace drainage systems suggesting the need for negotiated management strategies between households, neighborhoods, and districts.

Aside from kin-groups or very wealthy and large families, most families would not have managed an entire terrace system given the long distance of flow from terrace to terrace to terrace, *ad nauseum*. Additionally, some terraces are extensive in length and likely cut across individual households; their layout on the landscape was to a large degree based on their continuous use and infilling of that landscape as population increased over time (AF Chase, et al. 2020b:347; DZ Chase and Chase 2014c). The lack of standardization suggests less organization than that behind Incan terraces, but some scholars argue for local construction of those highly standardized terraces as well (Treacy 1987).

Additionally, while the neighborhood-level organization may suggest bottom-up organization to some, from the perspective of each individual *plazuela* in that neighborhood, this would still represent a top-down management system. Cooperation among terrace stakeholders in neighborhood groups represents the most likely (i.e., Occam's razor) system of management (sensu Ostrom 1992, 1993; Ostrom 2015); however, these systems of management can break down and require outside forces to settle disputes (AF Chase, et al. 2020b:122). The districts probably played a role in both the collection of any taxes owed from working the fields and helped settle any land disputes that could not be handled locally.

6.2.6 Standardization and Autonomy.

Taken together, the above analyses provide multiple lines of evidence that demonstrate little or no standardization among the physical measurements of contemporary residential features within the lidar dataset of Caracol's garden city landscape. The garden city features of *plazuelas*, residential reservoirs, and agricultural terraces exhibit no clear pattern of standardization as measured in their built environmental aspects. While collective endeavors may have been undertaken to construct these features, those instances of collective action have not left a standardized mark on their results. At the same time, larger-scale standardization like that seen at Teotihuacan through its standard units of measure (Sugiyama 1993) or its grid plan and orientation general structure orientation and grid plan (ME Smith 2017b) are not evident within this data at Caracol. However, future research will be required to test the standardization of other construction aspects such as lime-plaster recipes (Murakami 2010, 2016; 2019a:750-752). This suggests that the residents of Caracol constructed, built-up, and even reconstructed (see for example AF Chase and Chase 2014a:8) most of their non-monumental, garden city landscape with a high degree of household architectural autonomy from specific top-down and bottom-up forces that would cause standardization.

Some arguments for standardization could be made in terms of the relative residential lengths and widths – at least at a log scale – along with frequent ritual use of eastern constructions as known from excavation (AF Chase and Chase 2009). These will require additional comparison with other settlements, and, at least at this point, the

Caracol data do not present the same argument for a standardized urban unit (Sugiyama 1993) or grid form (ME Smith 2017b) as found in contemporary Teotihuacan. However, future comparative analysis with other Maya cities may suggest greater standardization at Caracol. In other words, the perspective on standardization could change with additional data. As for any similarities that exist, these likely relate to a shared cultural perspective on the built environmental aspects of residential use (e.g., Hall 1966; Rapoport 1988), or similar environmental constraints on these residences rather than on an intentional or enforced process of standardization.

This overall lack of standardization essentially removes the issue of which specific process led to it and instead indicates a high degree of household architectural autonomy. Fundamentally, while specific differences in residential size may be related to wealth inequality (ME Smith 1987:301; 1992, 1994; ME Smith, et al. 2014), family size (BM Brown 1987; LeBlanc 1971; Naroll 1962), or length of occupation (Hutson 2016:153-155; 2020:411-412); no top-down process or collective action resulted in standardized residential construction forms. Instead, each analysis undertaken provides a different metric highlighting relative household architectural autonomy among the ancient Maya of Caracol in regard to construction projects on their local landscapes.

Viewed another way, the physical infrastructural power exhibited both citywide and at the district-level in the last chapter did not penetrate into the neighborhood-level of Caracol. In fact, a paucity of neighborhood-level architectural features exists, except potentially for the agricultural terraces. Caracol also possessed autocratic rule at times (see Martin and Grube 2000:84-99) and, building on Blanton and Fargher (2008) this lack of standardization could represent the ruler's lack of concern with daily life and residential construction efforts within the garden city landscape in a top-down, centralized manner. Either way, the lack of standardization indicates the lack of either top-down or bottom-up processes encouraging it.

6.3 Interpreting Inequality

Some of the specific garden city feature attributes above lend themselves to understanding dimensions of wealth inequality in the past. This permits further exploration of these metrics by using "unevenness" in their respective distributions (Peterson and Drennan 2018:39-40) to look at standardization from another perspective. A wide variety of archaeological material can provide the basis for analyses of wealth including residential area (ME Smith, et al. 2014:312), houselot area (Hutson and Welch 2021a), agricultural field size (Murtha 2015:85), portable material as wealth (Olson and Smith 2016; ME Smith 1987), material in burials (Rathje 1970), the size of burial chambers (DZ Chase and Chase 1996b; Yu, et al. 2019), *etcetera*. Archaeological literature at large has adopted residential area as the standardized measure of household wealth worldwide (Kohler, et al. 2017; ME Smith and Kohler 2018) building on initial research by ME Smith (1992, 1994).

Residential area is often considered to represent a form of non-portable material wealth in the past with two potential caveats: (1) establishing contemporaneity of settlement (Haviland 1988; Rice and Culbert 1990:15-17) and (2) recognizing that this type of wealth gives a long-term picture of inequality in larger-lived settlements with accretional residential construction. As Hutson (2016:151-152; 2020:411-412) points out, accretional construction becomes a larger issue when using residential architectural volume at which point that wealth metric corresponds with inherited familial wealth rather than inequality at large. Either way, three basic concepts are useful to understanding wealth inequality regardless of the dimension of wealth measured: the Gini index (Gini 1912), the Lorenz Curve (Gastwirth 1972), and the f" analysis (aka looking for "kinks" in the curve as described by Shennan 1997:253).

The Gini index has been in use for over a hundred years as a metric for measuring the degree of standardization (e.g., "unevenness") within wealth distributions (Peterson and Drennan 2018:39-40). A completely standardized dataset where, in this case, every family builds and occupies *plazuelas* of the same size would yield a Gini of 0.00 indicating complete standardization in residential groups. In contrast, the highest Gini of 1.00 requires standardization for all but one residential group (i.e., one household owns everything), an unlikely scenario that also represents high levels of standardization for the rest of the population. Values towards the middle can represent less standardization among the measured values. The Gini index is useful in that it provides a singular number; however, it requires a second visualization to understand exactly how much standardization exists among the values, the Lorenz curve.

The Lorenz curve provides the visual representation of the Gini index on a graph where the x and y axes scale from zero to one hundred percent and the line of y = x represents the line of equality with a Gini value of zero. Graphing this dataset, the y-axis represents the proportion of wealth owned by the proportion of houses along the x-axis pre-sorting the dataset from lowest to highest proportion of wealth. Calling the area above that graphed line but below the line of equality at y = x "area A" and the area below our graphed line to the axes "area B", then the Gini index is represented by the equation A/(A+B) as shown in Figure 6.7.

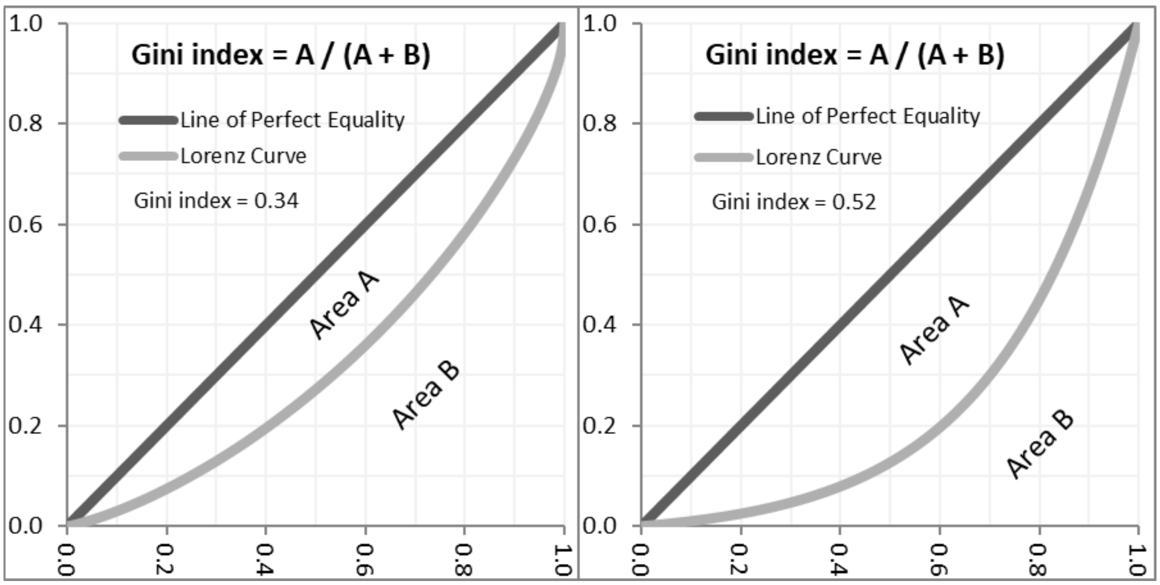


Figure 6.7 Gini index equation of A/(A+B) shown with Lorenz curve
The graph on the left shows a lower Gini of 0.34 while the one on the right shows a Gini of 0.52 instead.

By providing a visual representation of the data, the Lorenz curve by providing a visual representation of the dataset becomes invaluable because multiple different distributions can generate the same Gini index (Peterson and Drennan 2018:Figure 2.1). However, one other important factor can be gleaned from this data, a phase shift along our graphed line representing a change in the acceleration of values (e.g. the f") and visually appearing as a "kink" on the graph (Shennan 1997:253).

Archaeologists have looked for kinks in graphs as a standard point of practice to identify breakpoints in their datasets; however, not all realize that that kink is produced by a peak on the graphed second derivative (the change in change over a distribution, aka its "acceleration") of their distribution, the f". In the context of the Lorenz curve and Gini analysis, this kink may represent a change between social status groups among residences (ASZ Chase 2017:35-37; Hutson 2020:409-412) or a clear class division between "elite" and "non-elite," if sufficient supplementary evidence exists (see examples in ME Smith 1992:Table 12.8; 1993:194-197; ME Smith, et al. 2014:Figures 4 and 5). In conjunction with the above, looking at kinky data can help shed light on fundamental underlying changes in the data distribution.

In addition, inequality may be used as a proxy for the degree of wealth controlled by families within a society. While Boix (2015:64-65,85-87) identifies categories of Gini values with forms of governance (e.g., 0.15 with republics, 0.19 with imperial republics, and 0.44 to 0.54 with monarchies), this model focuses on familial wealth distributions based on access to resources and the resulting implications rest on game theory models of governance. These models assume that elite families actively attempt to aggregate their own wealth and hamper others. In these models, higher inequality indicates a more oligarchic or despotic concentration of wealth, while more equal distributions indicate that more families participated in wealth generation and could serve as balances to a single family gaining a monopoly on wealth generation. However, it is not clear how applicable these numbers are to different metrics of inequality.

Even so, this model has been used to highlight social implications of wealth inequality for ancient Teotihuacan in conjunction with other archaeological data (Carballo 2020:78). However, the different dimensions of inequality can alter this relationship; no singular metric of inequality should be taken as indicative of government form, and analyzing multiple dimensions of inequality provides a better perspective on the cultural norms for how wealthy members of society exhibited their wealth (see Oka, et al. 2018:71-73).

Other studies of multiple Gini indices provide additional perspectives. In particular, a global comparison of results from hunter gatherer, horticultural, and agricultural peoples settled in villages, towns, and cities provides insight on the expected variability among Gini indices (Kohler, et al. 2018:Figure 11.2). In general, these global results show two distinct patterns. First, the average inequality increases with social complexity and the movement toward agricultural cities, and second, that these increases also correspond with greater variability in inequality values. In other words, both larger settlement size and more permanent agricultural form appear to correlate with greater and more varied inequality among urban residents. However, research focusing on volumetric instead of area Gini values will produce different results (AE Thompson, et al. 2021:Figure 5); however few sites have published volumetric inequality data and volume provides a better metric for long-term familial wealth than inequality at large following Hutson (2016:151-152; 2020:411-412). Essentially, this topic remains an active area of future research and the multiple approaches and results all suggest that any investigation of collective to autocratic governance with Gini indices should take a multi-metric approach similar to that of Feinman and Carballo (2018).

Moving toward the case at hand, based on prior archaeological work (AF Chase and Chase 2009; DZ Chase and Chase 2004b), I would expect Caracol to exhibit relatively low residential Gini values indicative of relative equality. A sample study using about half of the current dataset, but including both plazuelas and acropoleis, as well as Caana, identified a Gini of 0.34 (ASZ Chase 2017) for residential area. Even with the addition of several thousand more data points this value does not change, suggesting that Caracol's Gini index of 0.34 for residential area provides a robust measurement of relative equality (Lorenz curve shown in the next section).

Other archaeological data also suggest relative equality at Caracol. Previous work has shown that about seventy percent of both average residential households and wealthier households practiced ritual caching and possessed large tombs in their eastern shrine structures (AF Chase and Chase 1996a; AF Chase, et al. 2020b:355). In addition, items viewed as "prestige" goods in other contexts, including polychrome pottery and jadeite, were widely available and distributed among all residences during the Late Classic Period (AF Chase and Chase 1992a, 2009; DZ Chase and Chase 2004b). During this time, the wealthiest burials at Caracol showcase far fewer wealth items than equivalent high-status burials at other sites like Tikal (AF Chase and Chase 2020b:39; Coe 1990:539-540; Coggins 1975:372-380). Other scholars (Feinman and Carballo 2018:13) have also identified Caracol as a relatively collective society during the Late Classic period based on its market exchange, low mortuary differentiation, bureaucratic offices, and communal architecture. These practices - when taken together - suggest a system of less wealth exhibition by the highest status individuals, greater wealth among the average residents, and similarities in ritual practices throughout the social spectrum, indicating the presence and effects of both bottom-up collective action and top-down collective action through a process that has been called symbolic egalitarianism (AF Chase and Chase 2009; DZ Chase and Chase 2004b). Based on the information above, I expect that the other dimensions of wealth will continue to show relatively low inequality at Caracol, as will the dimensions of inequality: residential area, residential height, and service access to formal plazas, ballcourts, and e-groups.

6.3.1 Defining Inequality.

The following inequality analysis relies on two bounded datasets (one a universe and one a sample) and three distinct types of metrics, all serving as proxies for the multiple dimensions of inequality. The two different datasets are focused on Caracol the City and Greater Caracol (see Figure 6.8 below). Caracol the city is bounded by a slight falloff in both settlement and intensive agricultural terracing (ASZ Chase 2016b), while Greater Caracol includes the area beyond the settlement falloff included in the digital survey. Each dot in the map below (Figure 6.8) represents a residential group, either a *plazuela* or an acropolis, situated closer to Caracol than to any other settlements. The residences beyond the boundary of intensive terracing and denser settlement around Caracol potentially represent a more “rural” settlement associated ancient Caracol (e.g., Lamb 2020), but the use of the term rural can be problematic, especially given the fact that agriculture provides a primary feature of urban Caracol as well through the role of infield urbanism (see AF Chase and Chase 2016a; AF Chase and Chase 2016b; Fisher 2014). In any case, each of the five dimensions of inequality below demonstrates higher levels of inequality with the inclusion of those rural residential groups that lay outside the city boundaries.

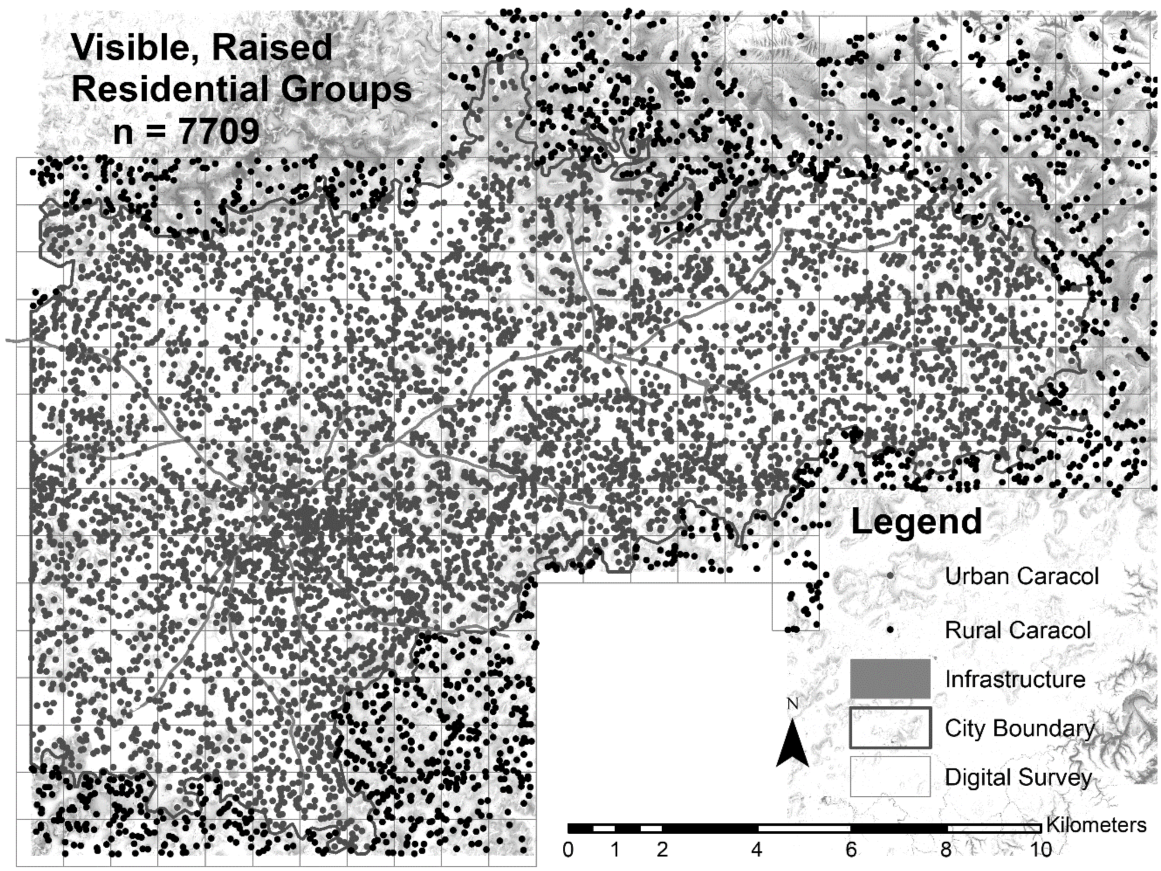


Figure 6.8: Map of 7709 residences at Caracol
This map shows the sample of raised *plazuela* groups and acropoleis located within Caracol. "Greater Caracol" includes both sets of points labeled urban and rural and is based on presence within or beyond the reconstructed city boundary. Settlement beyond this boundary would still be located closer to Caracol than another settlement.

The first metric considered here is the current gold standard for ancient inequality analysis, residential area in meters-squared, to represent a dimension of nonportable material wealth. While a variety of definitions for residential area exist, here I focus on the *plazuela* as the fundamental residential unit. Unfortunately, Gini indices developed from different datasets cannot be directly compared because of differences in what researchers consider to be a "residence." A residence is defined as the houselot area as at Chunchucmil (Hutson and Welch 2021a) and as the area of a single structure at Mayapan (CT Brown, et al. 2015:313-315). Thus, these residential Gini values cannot be directly compared to the residential area used here with the *plazuela* defined as "the roofed and unroofed living space" (sensu Naroll 1962). As noted above, this area metric has some issues, including potential accretion through time at longer-lived settlements (Hutson 2016:150-152) and a potential correlation to family size (see BM Brown 1987; LeBlanc 1971; Naroll 1962); however, this form of inequality can be taken as a representation of household wealth that incorporates some heritable wealth but to a lesser degree than that which would be indicated by volume measurements.

The second metric for consideration negotiates the space between residential volume and area by focusing on height (in meters) alone in an attempt to obtain a metric to complement area. While higher structures will require larger basal areas, height provides a 90-degree (i.e., orthogonal) geometric measurement to complement area. In general, volume measurements should greatly increase Gini indices over their area counterparts (see ASZ Chase 2017). Volume acts as a proxy and represents one aspect of energetic analysis in the form of bulk labor invested in a residential area, but with simplifying assumptions about construction form and material distance (e.g. Abrams 1994; Erasmus 1965; McCurdy and Abrams 2019). These assumptions have flaws. Over time, ancient Maya construction practices at Caracol change. For example, Early Classic Period building construction cores consist of compact small-volume construction fill while Late Classic Period constructions are filled with bulky dry core; and the distance to stone quarries remains difficult to determine. While future analysis interested in volume will likely transition more fully toward residential energetic analysis, this analysis focuses instead on height for the reasons outlined above. Height is here defined as the maximum vertical difference between the lowest and highest DEM elevation cell under a residential shapefile, providing additional data to complement area.

Finally, the third metric of this analysis focuses on inequality as reflected in a residential group's ability to access services, or the spatial inequality of residences measured as time in minutes to the nearest urban service facility feature in question. Using least cost analysis, following White (2015), the travel time to the nearest formal plaza, ballcourt, and E Group (building on the 1-hr analyses in the previous chapter) provide a dimension of inequality separate from physical attributes of the residence. This metric incorporates the critique in Oka, et al. (2018:71-73) about inequality in the USSR exhibiting itself through proximity to services instead of available residential area. While that article (Oka, et al. 2018:73-75) focused on presenting a single method for integrating separate inequality metrics, I have found that presenting five different dimensions of inequality as distinct entities provides additional information to help with interpretation.

6.3.2 Gini & Lorenz: Residential Area.

In 2017 the first Gini index for the city of Caracol appeared in print (ASZ Chase 2017). It used a sample of just over four-thousand residences (4058), including all of the large acropoleis in the epicenter (which comprise the largest residences on this landscape). After adding several thousand more residential groups to this sample, the citywide Gini index for residential area (structure area plus plastered, unroofed living space) remains unchanged at 0.34 (Figure 6.9). Given the sample sizes of 5852 residences for the City of Caracol (urban) and 7709 residences for Greater Caracol (both urban and some “rural” areas as per Figure 6.9), obtaining the same measure seems impressive, especially given the several thousand additional residential data points added. Both numbers differ at the third decimal place, so each Gini index below shows three significant figures as well; however, the standard in other inequality literature focuses on only two significant figures.

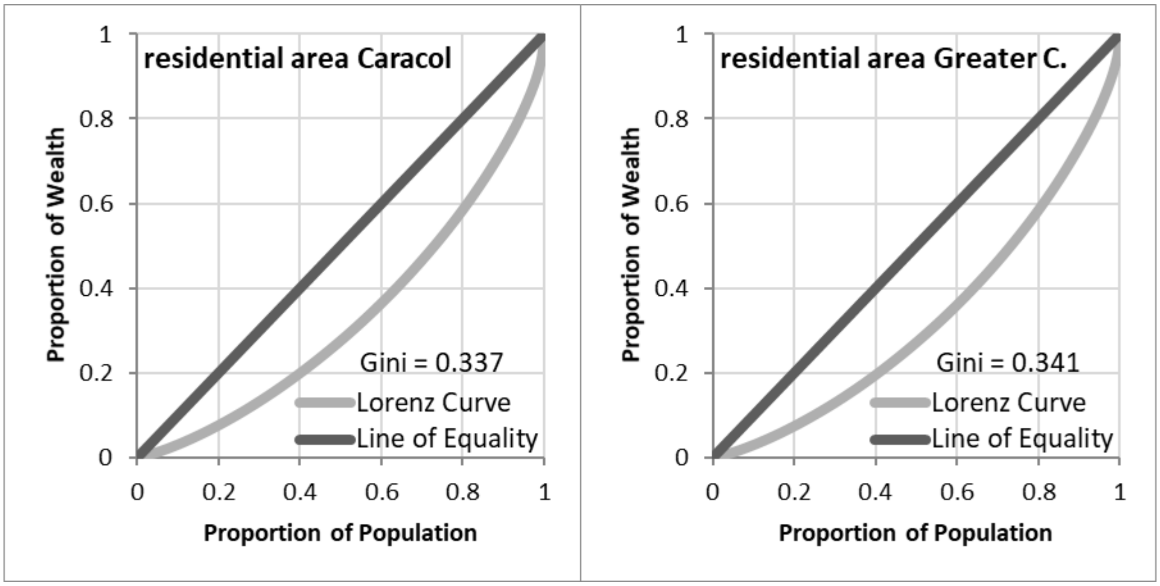


Figure 6.9: Gini indices and Lorenz curves of residential area
These Ginis include plazuelas, acropoleis, and Caana with values of 0.337 for Caracol the City and 0.341 for Greater Caracol.

6.3.3 Log Normality of Residential Area.

Looking into the nuts and bolts of the residential area dataset demonstrates an interesting feature. This dataset appears to exhibit log-normal behavior (see Figure 6.10's top and bottom histograms). Fundamentally, the area dataset contains many residences with smaller residential area with a long tail of larger and larger residences. This fits expectations for wealth inequality more broadly and results from one of the three primary types of expected wealth distributions: lognormal, Pareto, or exponential (Strawinska-Zanko, et al. 2018:174). However, it can be difficult to distinguish between these types of distributions and this issue has emerged independently in multiple fields of research (see overview in Mitzenmacher 2004).

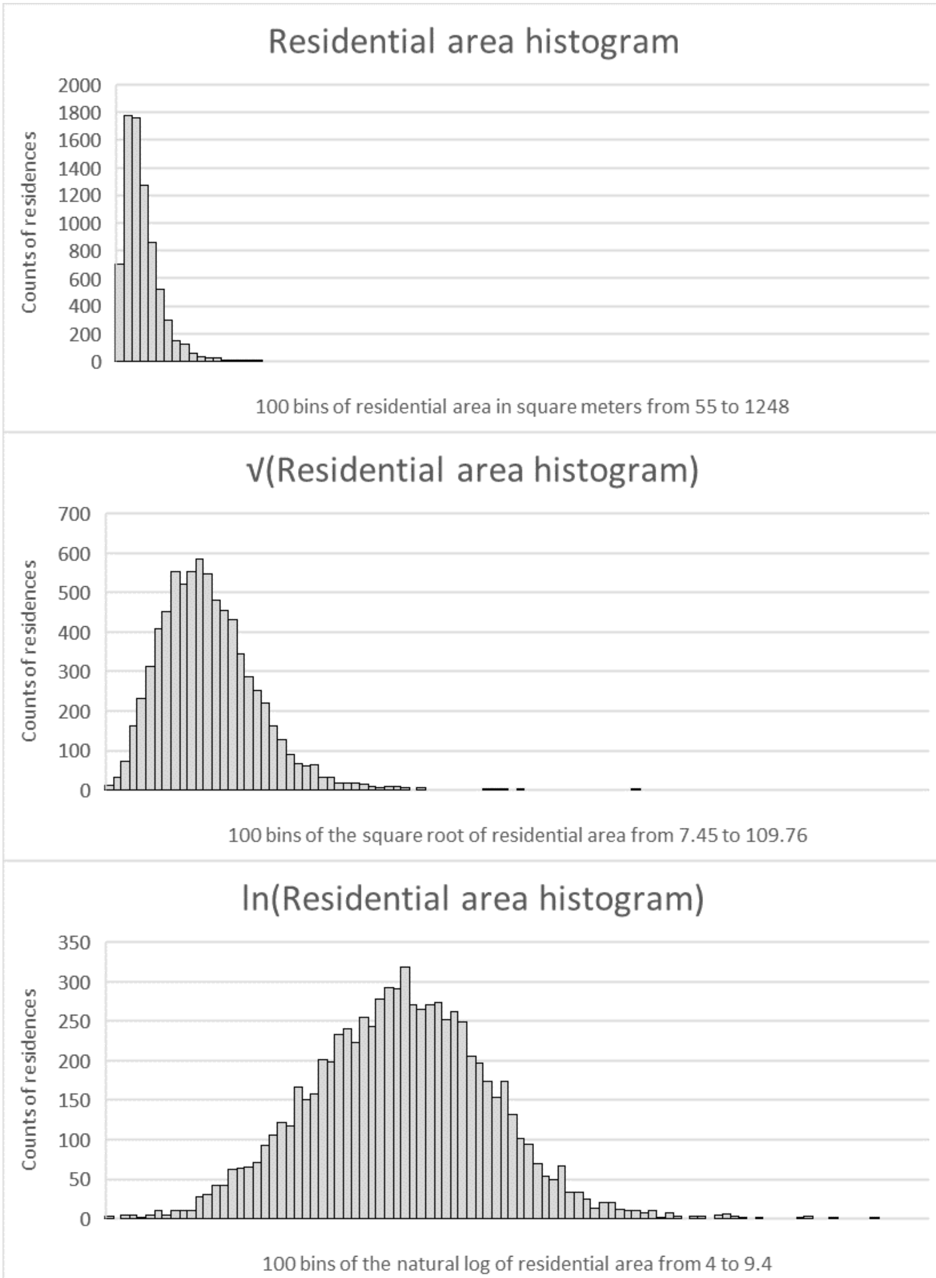


Figure 6.10: Three histograms of Caracol's residential areas
Each histogram has 100 equally sized and distributed bins of the smallest to largest values to facilitate comparisons. The top shows the residential area in m^2, the middle shows the square root of residential area (e.g., in meters), and the bottom shows the natural log of residential area. These indicate that the distribution of residential areas is log-normal but not simply a result of the multiplicative length times width of area.

Log-normal distributions result from underlying multiplicative processes (i.e., where at least two forces increase each other's potential effects on that distribution), and taking the logarithm of the dataset produces data with a "normal" distribution, often called a "bell curve" (see also discussion by Crabtree, et al. 2017:74-77; and Limpert, et al. 2001). By definition, area results from the multiplication of length times width. As such, I tested the square-root of the dataset to see if this would produce a normal distribution, but it does not (Figure 6.10 middle). Only the log transformed data demonstrates that characteristic "bell curve" (Figure 6.10 bottom), but with some rightward skewed data. This suggests that the wealth inequality observed among residential areas at Caracol relates to underlying multiplicative processes but requires additional investigation to fully test, as such Figure 6.10 only provides evidence of a heavy tailed distribution that looks like a lognormal distribution.

Inequality measures at other Maya cities, using structure area instead of residential area, have been used by Strawinska-Zanko, et al. (2018:184-186) to identify their datasets as roughly Pareto or exponential distributions rather than as lognormal ones. However, Strawinska-Zanko, et al. (2018:186) also suggest that a shift from exponential to Pareto wealth distributions corresponds to the existence of state-level society because that is the pattern they observe for Komchén. In this case, Caracol may provide a counter-example - in that simplifying interpretations of wealth inequality distributions this way perhaps overgeneralizes the past and ignores processes that intentionally reduce inequality like those seen at Caracol (e.g., AF Chase and Chase 2009; DZ Chase and Chase 2004b), although the authors also suggest this possibility

(Strawinska-Zanko, et al. 2018:186). It may also be the case that residential area and structure area possess different exponential distributions.

Either way, this research avenue provides a unique means of moving forward in understanding ancient inequality. Do other cities exhibit lognormal distributions when using residential area but Pareto distributions when using structure area? And how do these differences exhibit themselves at differently sized cities across space and time? These questions require archaeologists to get into the nuts and bolts of the underlying patterns within their datasets and build them robustly for cross-cultural comparison but may also have implications both on social complexity and the rise of inequality more broadly.

6.3.4 Kinks, f", and Univariate Results.

Another method of looking at the dataset details involves considering the f" and univariate graphs in tandem. The f" graph (Figure 6.11) shows where the potential "kinks" in the dataset are located (Shennan 1997:253) and the univariate graph (Figure 6.12a) simply shows the 7709 real values in the dataset arranged from smallest to largest. When taken together, these graphs shed insight on fundamental changes and where they occur within the dataset.

F" graphs (Figure 6.11) represent taking the second derivative of the univariate graph. With a physics analogy, if the univariate graph shows distance of a walk (m), the first derivative (f') shows velocity or the change in distance covered over time (m/s) and the second derivative (f") shows acceleration or the change in change in distance over time (m/s^2). In terms of residential area arranged from smallest to largest, the second derivative has peaks of its largest values at the inflection points (aka "kinks) where residential area "accelerates" the most within the univariate dataset. In other words, the f" derivative provides a mathematical method for identifying the "kinks" that archaeologists currently identify visually on the original univariate graph (Shennan 1997:253).

The f" graphs for Caracol's residential area highlight a few interesting higher values. First, most of the greatest changes in values occur at the extreme upper end of the scale. Out of 7709 points in the dataset, values 7695, 7701, 7702, 7703, 7704, and 7707 show the greatest change in value with 7702 and 7703 showing less change than their neighbors of 7701 and 7704 (Figure 6.11). Looking at the univariate data (Figure 6.12a), Values 7707 and 7704 represent two adjacent residences with similar sizes rather than fundamentally distinct points of increased acceleration. However, none of these points occur at the major inflection visualized on the univariate graph (Figure 6.12a) and, looking in that range, one point remains higher than others, but not nearly as high as those previously mention, 7563. This value represents the fundamental pivot point from the smallest residences to the largest residences, but it itself does not have a high peak. This ties into the overall low Gini index for residential area at Caracol and the difficulty in identifying clear breakpoints that required this f" method to identify any "kinks" at all (see ASZ Chase 2017:35-37; Hutson 2020:409-412).

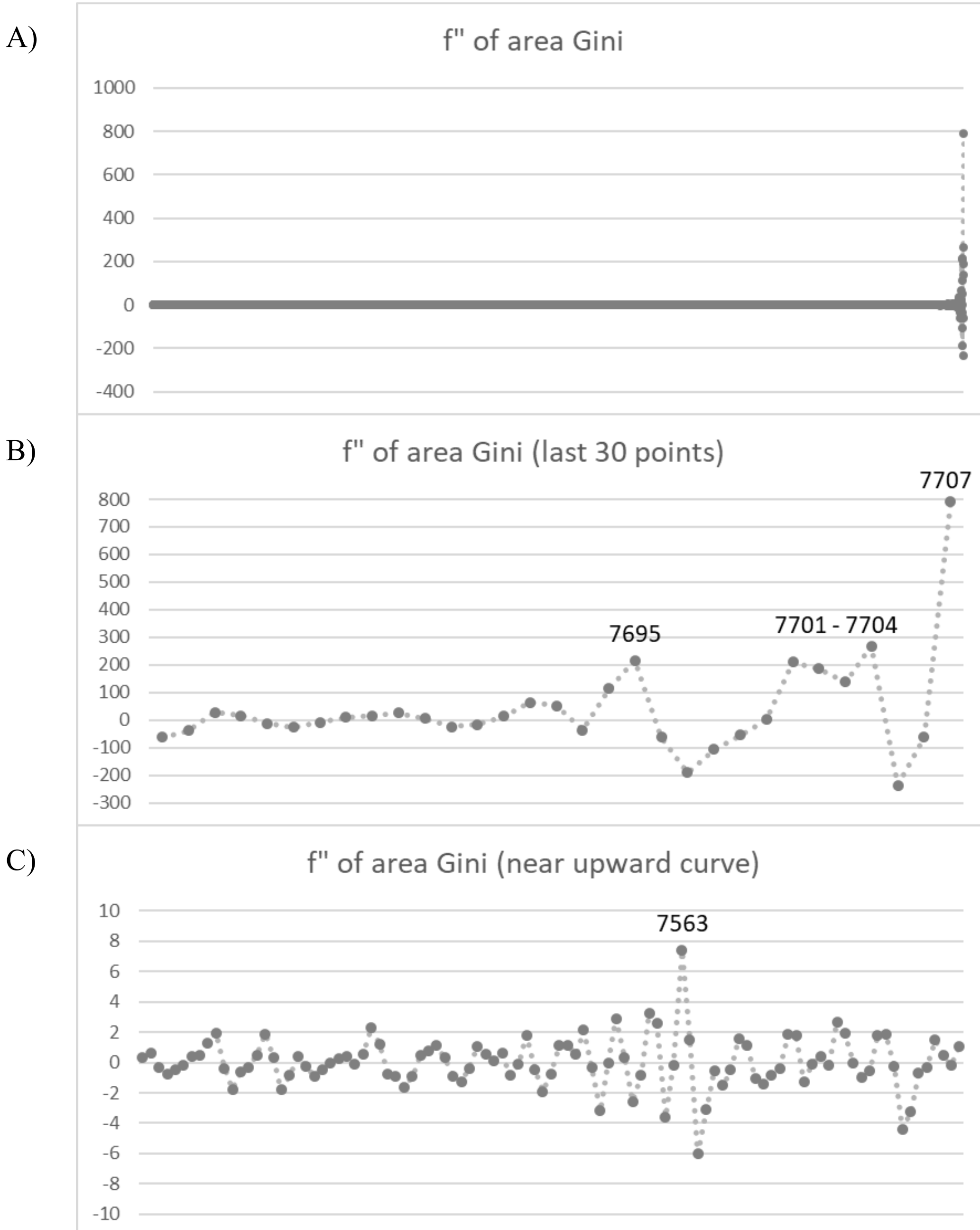
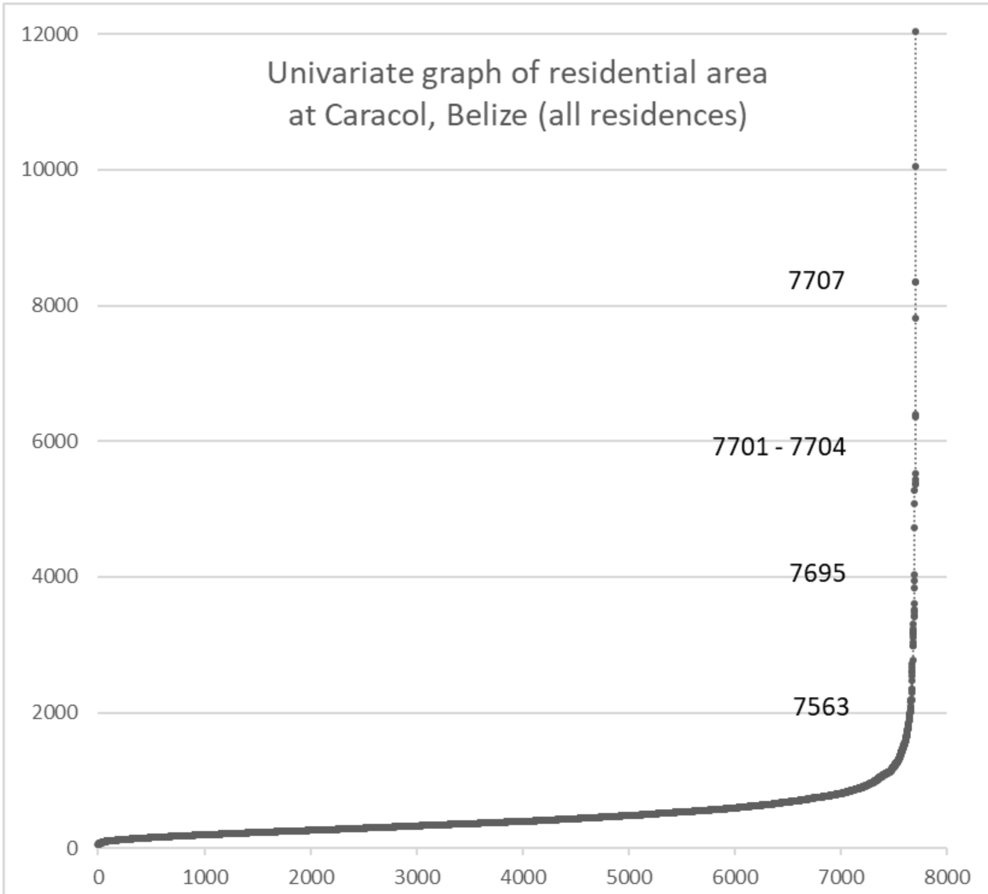
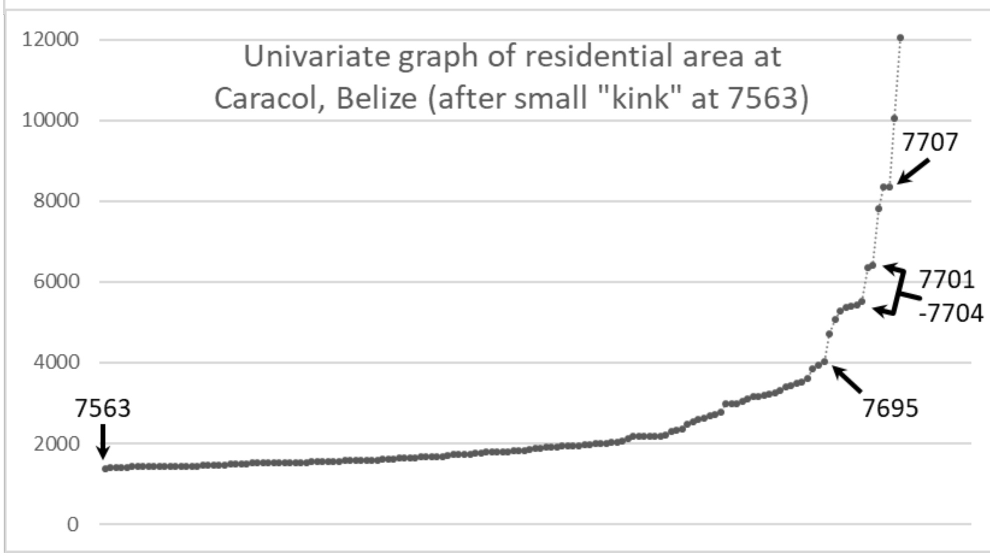


Figure 6.11: Three graphs of f" (f-double-prime) of residential areas
These graphs show the second derivative (the f") of the univariate graph of residential areas in Figure 6.12 on the next page. These graphs highlight areas of significant acceleration in ordered house size also known as "kinks" in the data. The numbers indicate residential position in size order. A) shows the overall f" curve, B) shows the f" of the last 30 points, and C) shows the f" points near the shift toward an upward curve in the Lorenz curve of the original non-f" dataset.

A)


Univariate graph of residential area
at Caracol, Belize (all residences)
12000
10000
8000
6000
4000
2000
0
0
1000
2000
3000
4000
5000
6000
7000
8000
7707
7701 - 7704
7695
7563

B)


Univariate graph of residential area at
Caracol, Belize (after small "kink" at 7563)
12000
10000
8000
6000
4000
2000
0
7707
7701
-7704
7695
7563

C)

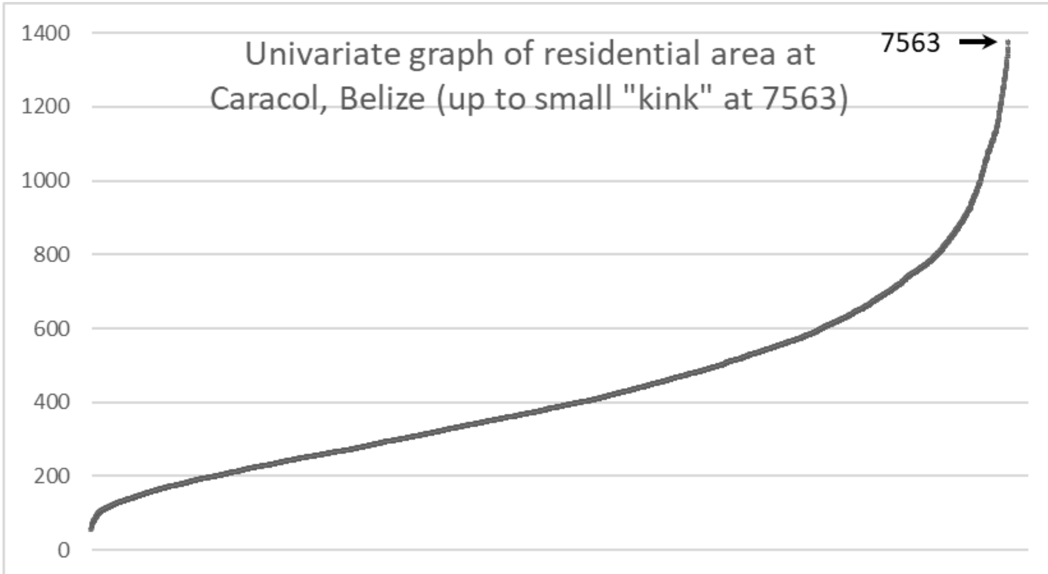


Figure 6.12: Univariate graphs of residential areas at Caracol
The significant "kinks" shown on all three graphs are based on the f" graphs (Figure 6.11). Figure A) shows all the complete dataset, Figure B) shows the residences with larger areas above the "kink" at the 7563rd largest residence out of the 7709 residential sample, and Figure C) shows the residences with smaller areas below that kink. Interestingly, Figure C) also shows a similar overall wealth curve to the residences in the upper part of the curve in Figure A).

Zooming into the uppermost points (Figure 6.12b), Values 7702 through 7709 all fall along the same line of best fit, while values 7696 through 7701 fall along another. This leaves all values below 7695 along a separate trajectory down to the "kink" at 7563 with the final bin of all points of 7563 and below. These categories are shown in Table 6.4, along with the distribution of known *plazuelas* (7682 total) and acropoleis (27 total) within each bin. Importantly, while 7563 provides the lowest identifiable "kink" in the data, it separates the data into two groups of 7562 residences (~98% of the dataset) and 147 residences (~2% of the dataset). These bins represent clusters of residences between peaks in the f" graph while ignoring peaks occurring from equally sized adjacent residences. These clusters do represent real breakpoints in the data (in the sense of this dataset as a near universe); however, the known elite residences of acropoleis fall into each of the four categories (Table 6.4) and the largest plazuela at Caracol exists within the second largest set of residences. In other words, both residential feature types exhibit overlaps, meaning that a clear division of wealth between the two cannot be ascertained from this dataset alone.

Breakpoint Groups		All Residences		Acropoleis		Plazuelas	
		Count	Percentage	Count	Percentage	Count	Percentage
#s	7702-7709	8	0.10%	8	29.63%	0	0.00%
#s	7696-7701	6	0.08%	5	18.52%	1	0.01%
#s	7563-7695	133	1.73%	12	44.44%	121	1.58%
#s	1-7562	7562	98.09%	2	7.41%	7560	98.41%
	Totals	7709	100.00%	27	100.00%	7682	100.00%

Table 6.4: Residential area breakpoints with proportion of residences
This table shows the proportion of acropoleis and *plazuelas* between each significant breakpoint shown in Figures 6.10 and 6.11. Known acropoleis (the largest and most formal residences) fall into each category, and one plazuela exists in the second largest set of residences.

Peaks in the f" graph (Figure 6.10) cross-referenced with the univariate datasets (Figure 6.12) demonstrate that residential area does not exhibit clear divisions in socio-economic status defined by boundaries in social relationships (following AF Chase and Chase 2011a) or in this case across the higher f" values identified above. In particular, looking at the lower end of the dataset below the "kink" at 7563 (Figure 6.12c) provides a graph with a similar overall shape to the points above 7563. In other words, this dataset shows that the thousands of residences at ancient Caracol exhibit a multitude of sizes, without any clear evidence that smaller residences could not become larger. In fact, this distribution provides even more support for arguments against a bi-modal class system of elites and commoners for the ancient Maya (ASZ Chase 2017:35-37; AF Chase and Chase 1996a; DZ Chase 1986:362; Hutson 2020:409-412; Masson and Pereza Lope 2005). Fundamentally, the residential area at Caracol as a representation of wealth shows that most of these residences existed in the middle with blurry gradations between different status groups (see Table 6.4; Figures 6.10, 6.11, and 6.12; and see also AF Chase and Chase 2011a).

6.3.5 Gini & Lorenz: Residential Height.

Maximum height of the residences provides a complementary dataset to residential area described in detail within the prior sections. This dataset simplifies volumetric analysis in order to provide a separate dimension of inequality that complements and does not inherently utilize area. While larger residences will tend to be taller, the next section below will further explore the relationship of height with area and demonstrates a lack of correlation. Interestingly, the Lorenz curves and Gini indices for residential height demonstrate more equality than in area (figure 6.13). However, in this case the value for Greater Caracol - 0.262 - exhibits less variation than the values for Caracol the city - 0.265. This makes sense because the tallest residences tend to occur near monumental nodes (also explored in a separate section below). Adding the more outlying "rural" residential groups reduces the overall variation by adding more residences of smaller heights. Fundamentally, this dimension of inequality provides an interesting metric to integrate with residential area in the next section; the low Gini index again suggests relative equality.

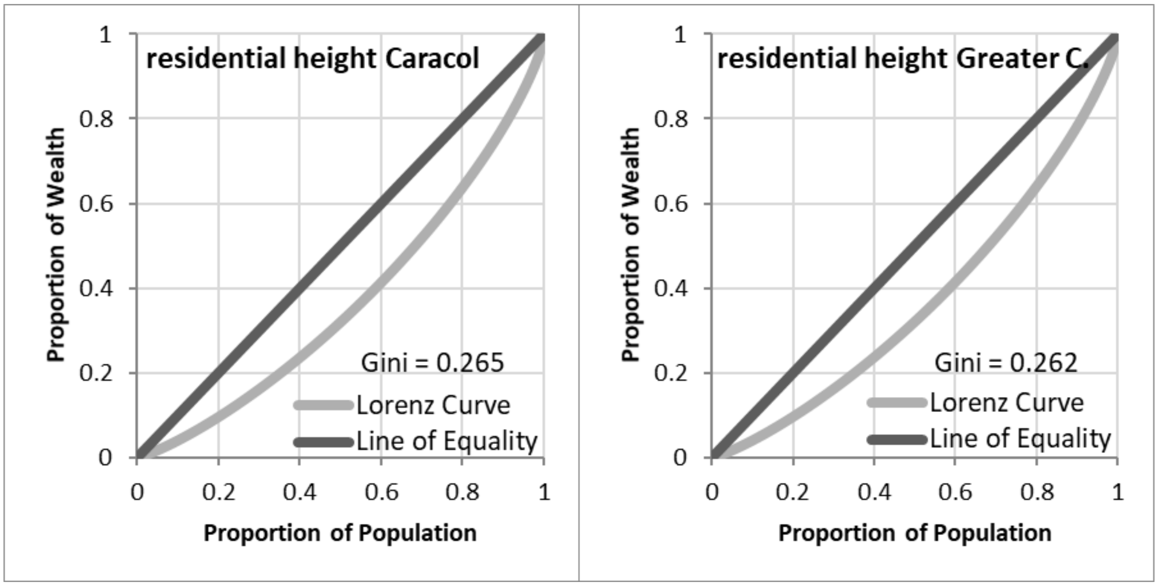


Figure 6.13: Gini indices and Lorenz curves of residential height
These Ginis include plazuelas, acropoleis, and Caana with values 0.265 for Caracol the City and 0.262 for Greater Caracol. Height represents a more orthogonal measurement to area than volume.

6.3.6 Social Mobility: Plazuelas and Acropoleis.

The graph in Figure 6.14 depicts the natural logs of residential area and residential height and shows overlapping ellipses for the two types of residences: *plazuelas* and acropoleis. The expectation for both of these metrics is that they should exhibit a tight linear relationship, but even on a log-log scale plot these two factors do not perfectly correlate at Caracol. Since each residence has endured similar taphonomic conditions, this suggests a difference in construction efforts instead of formation processes. The loose relationship between residential area and height suggests that height may act as a dimension of inequality, and the overlap in formal residence types suggests the lack of a firm status attribution related to acropoleis. Acropoleis are described as having more formal construction with higher quality materials, occupying larger residential areas, and possessing more height and volume than plazuelas; however, the overlap in Figure 6.14 suggests instead that acropoleis may simply be an extension of plazuelas and not a separate architectural category.

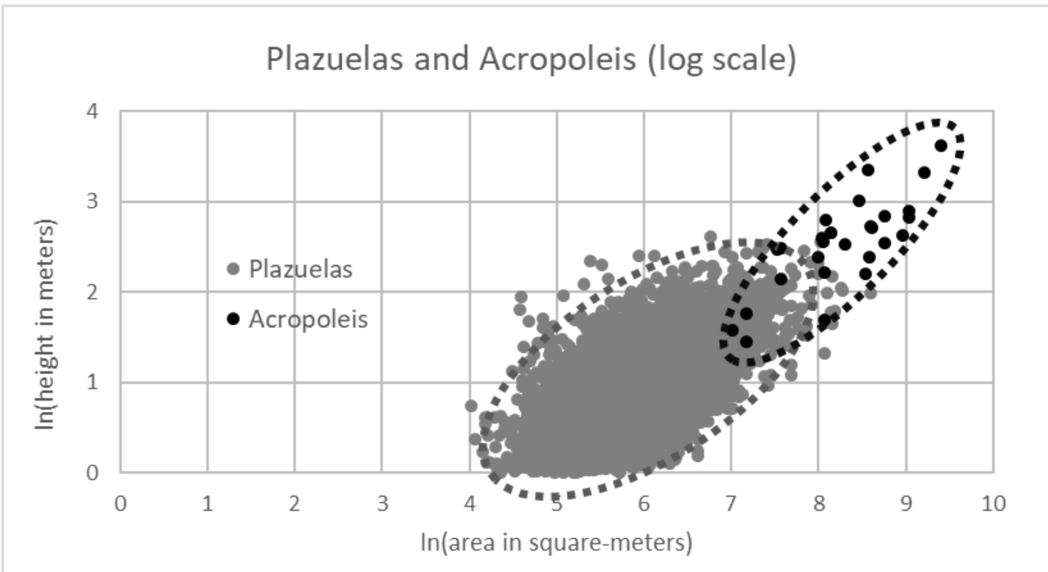


Figure 6.14: Overlap between *plazuelas* and acropoleis
Graph of the natural logs of area and height plotted for residential features identified as both plazuelas (grey) and acropoleis (black). The dashed ellipses help show a slight overlap exists between both feature types. This indicates that Acropoleis initially formed from plazuelas, and perhaps that the potential for social mobility existed.

All 7709 known residences depicted on the graph (Figure 6.14) sub-divide into 7682 *plazuelas* and 27 acropoleis. As expected from the deep dive into residential area above (see Table 6.4), both types of residential architecture exhibit overlap. While some area and height combinations unambiguously show up as either *plazuelas* or acropoleis, a significant number of *plazuelas* overlap with the acropoleis in terms of both height and area. This overlap provides additional support against assigning an inherently elite label to all individuals residing in any given acropolis. While an acropolis generally possesses higher quality stone construction, a raised platform, and, often, a restricted entryway, the residents of some plazuelas could have managed to achieve sufficient wealth to eclipse these “higher status” acropoleis groups.

Importantly, the fuzziness shown between both ellipses, the dashed lines in Figure 6.14, provides evidence against a strict correlation of residential type and status. For example, the assumption that elites live in an acropoleis and non-elites live in *plazuelas* is not borne out by the data as shown in Figure 6.14. As mentioned earlier, this data suggests a fuzzy group of ancient statuses and not a bimodal distribution (e.g., ASZ Chase 2017:35-37; DZ Chase 1986:362; Hutson 2020:409-412; Masson and Pereza Lope 2005), similar to what is seen in tomb volume at Caracol (AF Chase 1992a:Figure 3.2). In terms of household architectural autonomy, this also suggests that no specific laws or regulations prevented a wealthy *plazuela* household from eclipsing the grandeur, size, or height of an acropolis.

6.3.7 Gini & Lorenz: Formal Plaza Access.

While residential areas may provide one of the most reliable means for evaluating ancient inequality (ME Smith 1987:301), some societies intentionally mask externally visible inequalities in house size and exhibit inequality through other means such as access to services (Oka, et al. 2018:71-73). As such, mapping the least-cost-path times over the lidar-derived digital elevation model (White 2015; White and Surface-Evans 2012) from residences to urban services provides a means of looking at a separate dimension of inequality (or disparity following J Munson and Scholnick 2021) independent of residential area or height. Ease of time moving to and from urban services represents either a savings of time or a greater ability to interact with those services. However, proximity itself may or may not lead to greater overall wealth.

In the previous chapter, formal plazas demonstrated their ubiquitous accessibility across the city with an average 25-minute transit time. As expected, the distribution of accessibility to these formal plazas generates low Gini indices for both Caracol the City at 0.276 and Greater Caracol at 0.328 (Figure 6.15). For all accessibility metrics, Greater Caracol will increase the Gini index due to the addition of houses farther from formal plazas and monumental nodes. However, this analysis builds on prior analyses to suggest that the distributed service distribution at Caracol represents greater equality through accessibility of the services associated with those features. This Gini index also provides a very different perspective of residences and access explored more in the next section.

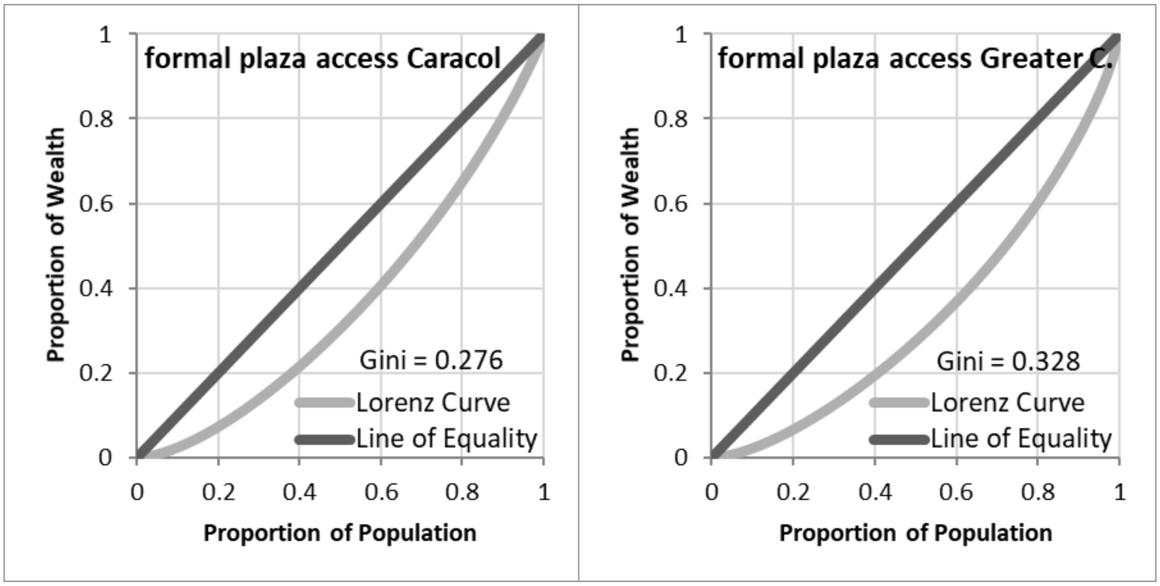


Figure 6.15: Gini indices and Lorenz curves of formal plaza accessibility
These residences had Gini values of 0.276 for Caracol the City and 0.328 for Greater Caracol.

6.3.8 Inequality/Disparity in Urban Service Accessibility.

Accessibility Gini indices differ from residential area and height due to the fundamental difference that "wealth" – in this case accessibility of these services which represents a form of residential wealth separate from residential size following the discussion in Oka, et al. (2018:71-73) – along this dimension represents lower time costs to access services whereas higher values represent residences with lessened service access. However, ancient walking cities like Caracol exhibit intermixing between wealthier and poorer households (see AF Chase and Chase 2016b:365; Hutson and Welch 2021a; Storey 2006:9-10). As expected, Figure 6.16 (below) shows no strict correlation between time to formal plazas and residential area. While residences with larger areas tend to be located closer to formal plazas, they are intermixed with many other smaller residences.

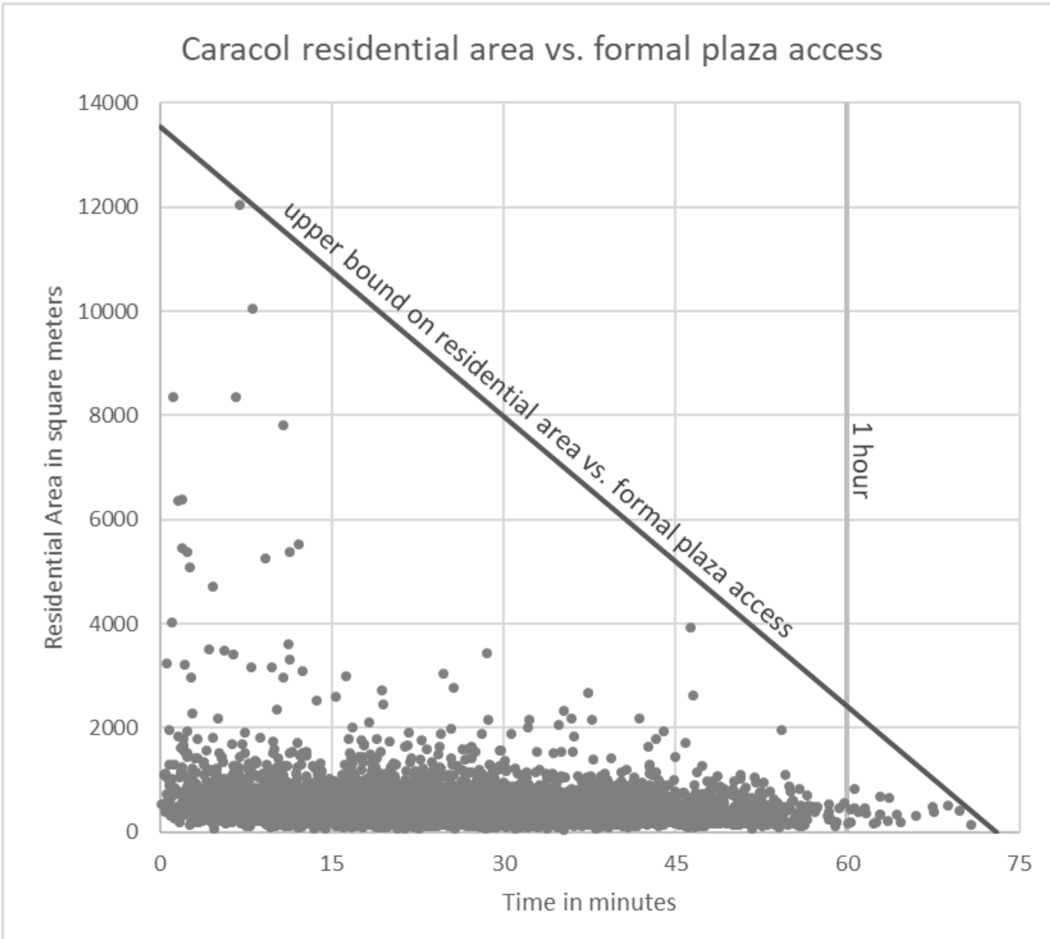


Figure 6.16: Caracol residential area versus their time from a formal plaza
Larger residences at Caracol tend to be located near the formal plazas; however, social mixing between larger and smaller residences exists as expected for a walking city.

However, a hard-upper limit appears on the maximum residential area and the distance from formal plazas (diagonal line in Figure 6.16). Larger households, those located in the upper left register of the Figure, in general appear occur more frequently nearer to the formal plazas; this includes the formal plazas in the districts. This suggests that formal plaza access may have played a necessary role to complement other processes in the accumulation of wealth among these larger residences. Put differently, the right triangle formed by both axes and the diagonal line in Figure 6.16 represent a theoretical maximum size of residential group areas for households at Caracol, and this reinforces the idea that service access provides a dimension for understanding ancient wealth distribution. For the larger residences, this represents both aggregation of wealth through market exchange at the formal plazas (AF Chase, et al. 2015; DZ Chase and Chase 2014b; King 2015; Masson and Freidel 2012) or aspects related to managing these plazas such as taxation (e.g., Levi 1988; ME Smith 2014a) potentially administered in the marketplace (see DZ Chase and Chase 2020c).

However, smaller residences still exist near these formal plazas as shown in Figure 6.16. This argues that proximity to formal plazas alone does not generate wealth. At the same time, smaller residences occur along the entire spectrum of values from zero to about seventy minutes from the formal plazas (Figure 6.16). This pattern where wealthier and poorer households are intermixed is characteristic of other walking cities (see AF Chase and Chase 2016b:365; Hutson and Welch 2021a; Storey 2006:9-10).

6.3.9 Gini & Lorenz: Ballcourt Access.

Following the longer time to reach a ballcourt than a formal plaza from the last chapter, ballcourt accessibility shows more inequality/disparity than the formal plaza accessibility above. The values of 0.309 for Caracol the city and 0.349 for Greater

Caracol (Figure 6.17 below) still represent relative equality, but to a lesser degree than formal plazas. In addition, the relative difference between access within Caracol the city and Greater Caracol relates to the more central placement of ballcourts than formal plazas. Unlike ballcourts, the ancient Maya of Caracol built many formal plazas near the boundaries of Caracol the city, which facilitated access by surrounding populations.

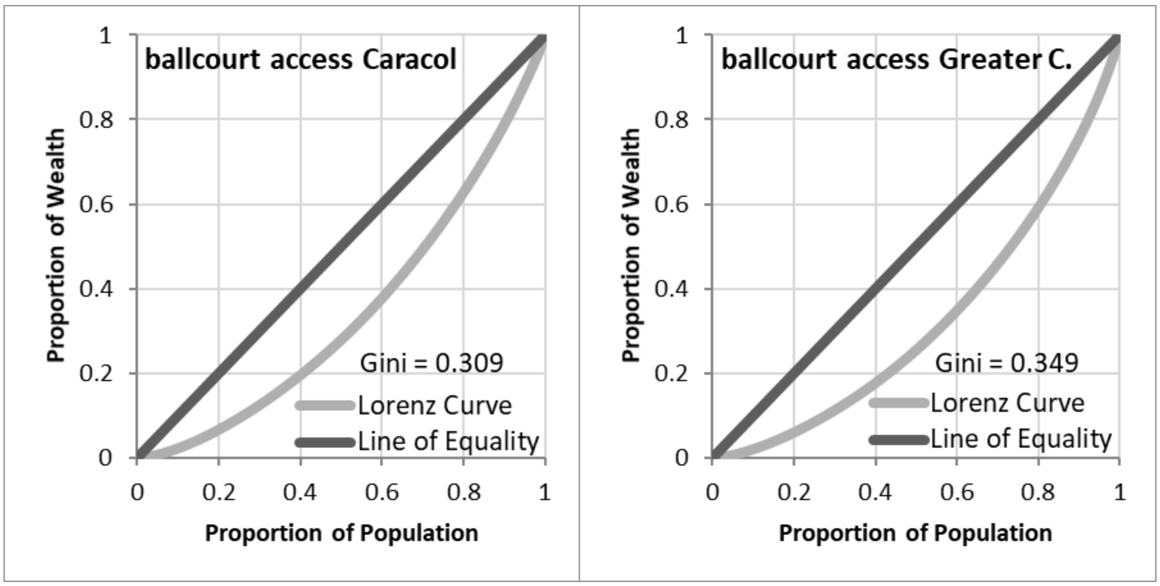


Figure 6.17: Gini indices and Lorenz curves of ballcourt accessibility
These residences had Gini values of 0.309 for Caracol the City and 0.349 for Greater Caracol.

6.3.10 Gini & Lorenz: E Group Access.

Finally, E Group distribution remained even more restricted than ballcourt distribution at Caracol (again see previous chapter for more info); however, the relative inequality/disparity in ability to reach an E Group remains lower than those for ballcourt access, measuring 0.305 within Caracol the city and 0.336 for Greater Caracol (Figure

6.18 below). This indicates that the time to walk to these E Groups remained more equal for residences than for ballcourt access in spite of the fact that the overall time to access E Groups remains higher overall with ballcourts remaining more accessible and better distributed across the landscape (see 1-hr analysis in the previous chapter).

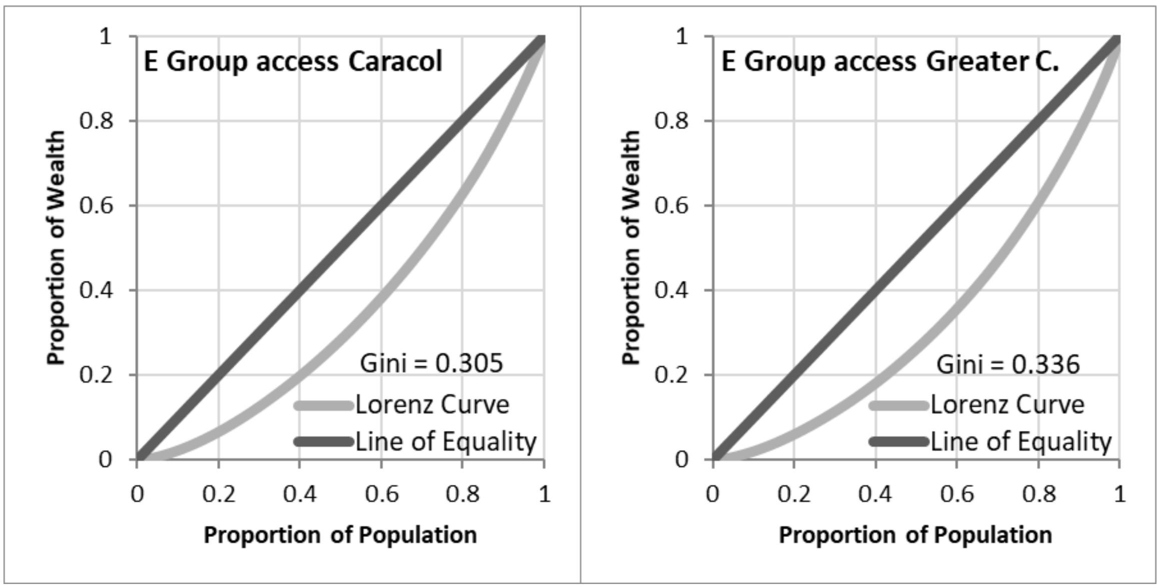


Figure 6.18: Gini indices and Lorenz curves of E Group accessibility
These residences had Gini values of 0.305 for Caracol the City and 0.336 for Greater Caracol.

Gini indices and Lorenz curves, as discussed earlier in this chapter, provide quick metrics for assessing the standardization within distributions, but they can mask large differences between distributions without additional information about the underlying datasets (see Peterson and Drennan 2018). The lower Gini indices that exist for E Group access than ballcourt access despite the more restricted distribution of E Groups on the landscape provides a concreate example of this potential flaw in using Gini indices alone.

However, from a comparative perspective these indices, averages, and Lorenz curves provide useful information for shorthand comparison, while still allowing researchers to share additional information to contextualize the nature of these distributions.

6.3.11 Interpreting Inequality.

All ten of the Gini indices demonstrate the relative equality present at ancient Caracol. While the Lorenz curves are shown in the above Figures (6.8, 6.13, 6.15, 6.17, and 6.18) the Table 6.5 below shows the Gini indices for side-by-side comparison to three decimal places instead of the two significant figures commonly used. For residential area and height measurements, it takes three figures to differentiate a few of the results between Caracol the city and Greater Caracol indicating an insignificant difference with the addition of 1,857 additional residences. Interestingly, across all of these dimensions the Gini values range from 0.265 at the lowest to 0.349 at the highest, which fall on the lower end of expected inequality.

	City of Caracol	**Greater Caracol**	**Absolute Difference**
Residential Area	0.337	0.341	0.004
Residential Height	0.265	0.262	0.003
Formal Plaza Access	0.276	0.328	0.052
Ballcourt Access	0.309	0.349	0.040
E-Group Access	0.305	0.336	0.031

Table 6.5: Summary Gini data of Caracol the city and Greater Caracol
This table provides a summary of all the Gini indices reported in the above sections comparing Caracol the city and Greater Caracol along with the absolute difference between the two in the final column.

One interesting relationship among the indices in the Table 6.5 is that there is more inequality in Greater Caracol than in the city of Caracol with the possible exception of residential height, which is only larger by 0.003. The implication, then, is that there was less inequality in the city of Caracol than there is with the addition of its surrounding more rural settlement, or, put differently, that the addition of surrounding settlement increases the variability within these datasets. For the three access-based metrics analyzed above, this makes sense due to the lack of urban service facility feature distribution beyond the city. However, this may also in part result from the social mixing present at Caracol or from other urban processes relating to interaction. Either way, this pattern should be investigated in other contexts, including the area beyond the current dataset boundary.

More importantly, these Gini coefficients represent values of relative equality. While this type of data may be different from the following analyses, they sit in an indeterminant intermediate territory of the Boix (2015) game theory model between the expectations for a republic (e.g. 0.15 – 0.19) or a monarchy (e.g. 0.46 – 0.54). Additionally, within Kohler, et al. (2018:Figure 11.2) this represents relatively high equality for an agricultural city. It should also be highlighted that Kohler, et al. (2018:Figure 11.5) uses the original residential area Gini index of Caracol as an "autocratic" city; however, it is an extreme outlier in that graph. Additionally, Caracol with its low Gini value sits under the median values for cities identified alternatively as "collective" or "intermediate" in governance.

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Similarly, in related research that does not use Gini values, Feinman and Carballo (2018:13) identify Caracol as having more collective than autocratic governance. This takes multiple factors into account and allows for intermediate values for each factor. Importantly, this avenue of future research suggests that collective regimes tend to have greater equality and lower Gini indices than autocratic ones, but this pattern depends on the indices used (e.g., AE Thompson, et al. 2021:Figure 5). In fact, the same dataset can produce two very different Gini indices as shown by the initial area and volume calculations for Caracol (ASZ Chase 2017). Yet, the data in Table 6.5 provides several measures of inequality (or disparity as per J Munson and Scholnick 2021) that when taken together demonstrate that Caracol – despite having a known ruler – exhibits Gini indices indicative of what others assume to be more collective governance systems, but this research perspective remains relatively new and will benefit from both additional research and comparative datasets.

6.4 Comparative Ginis for Caracol, Tikal, and Teotihuacan

Not only does the above analysis provide five dimensions of inequality among two comparable samples for Caracol, but this sample remains larger than any other for an ancient Mesoamerican city with 100,000 people as shown in Table 6.6 below. A potentially similar Gini of household area for Tikal sits at 0.62 (Kohler, et al. 2017; ME Smith and Kohler 2018) while another potentially similar Gini of subdivided apartment compounds for Teotihuacan sits at 0.412 (ME Smith, personal communication 2021) – updated from an initial calculation of 0.12 (ME Smith, et al. 2014:319-320). While household areas generally provide comparable data for Gini analysis, when they are not defined in the same it prevents comparison. Household area can be interpreted as individual residential structures (i.e., single roofed living spaces), aggregated clusters of structures in residential compounds (i.e., multiple roofed spaces), the *plazuela*/patio group area (i.e., aggregated roofed and unroofed living space), or the houselot area (i.e., the entire plot of a residence including its gardens and green space).

Assuming that these three Ginis above are based on *plazuela* areas, these three cities also align in other ways for comparison. Both Caracol and Teotihuacan had populations of roughly 100,000 people (AF Chase and Chase 1994; ME Smith, et al. 2019:17) during their apogees; Tikal had between 45,000 and 62,000 people in its urban area during its height (Culbert, et al. 1990:116-117; Lentz, et al. 2014:18515; Webster 2018). In terms of population these cities would have been three of the largest contemporary urban centers in Mesoamerica during the Classic Period.

City	Gini Value	Sample Size	Reference
Caracol	0.34	7709	ASZChase 2017
Teotihuacan (old)	0.12	39	Smith et al. 2014
Teotihuacan (new)	0.41	72	*Smith 2021
Tikal	0.62	762	Kohler et al. 2017

Table 6.6: Residential area Gini data for Caracol, Teotihuacan, and Tikal
These comparative Gini indices of residential areas are likely comparable with each other in terms of household area and include the sample size used. These data are likely comparable with each other as household area metrics. Please note that both Teotihuacan estimates include up-sampling to 14,485 residences (ME Smith, et al. 2014:Table 1) from the sample sizes listed above. *Smith, personal communication 2021

While Caracol possesses the lowest Gini index of the three cities, it also has the largest sample size. These Gini indices and Lorenz curves use a sample of 5852 for the city of Caracol or 7709 for Greater Caracol compared to 762 for Tikal (Kohler, et al. 2017:Supplemental Table 2) and 39 (ME Smith, et al. 2014:Supplemental Table 1) for the first Teotihuacan Gini estimate and 72 (ME Smith, personal communication 2021) for the recalculated Teotihuacan Gini estimate all shown in Table 6.6. These datasets from three of the largest cities of Classic Period Mesoamerica each represent an order of magnitude increase from each other (10^4 for Caracol, 10^3 for Tikal and 10^2 for Teotihuacan). In other words, Caracol exhibited greater equality than either of its contemporaries, even with a larger sample size. This, again, suggests that Caracol likely had social leveling mechanisms in place that were absent from Teotihuacan or Tikal. At the same time, it suggests that despite the presence of the ruler, Caracol exhibited a more collective governance system overall.

6.4.1 Other Comparative Gini Indices.

Scholars have also calculated Gini indices for other Maya cities (see Table 6.7 below); however, not all of these data have been based on household area in the form of an extended family *plazuela* group (as at Caracol and potentially also Tikal) or the relatively equivalent measurement of a sub-divided apartment compound (as at Teotihuacan). The reported Gini values based on individual structure sizes vary widely - from as low as 0.32 at Mayapan to as high as 0.71 at Sayil - indicating a high level of variance (CT Brown, et al. 2015:316-318). In addition, Hutson and Welch (2021a) have used construction volume for a Gini index of 0.599 and houselot area for a Gini index of 0.338 at Chunchucmil, providing two other dimensions of inequality.

City	Gini Value	Metric Used	Reference
Mayapan	0.32	structure size	Brown et al. 2015
Sayil	0.71	structure size	Brown et al. 2015
Chunchucmil	0.599	construction volume	Hutson and Welch n.d.
Chunchucmil	0.338	houselot area	Hutson and Welch n.d.

Table 6.7: Residential area Gini data from Chunchucmil, Mayapan, and Sayil
These comparative Gini values use three different metrics of residential area. These are not comparable with the values in Table 6.6 due to the use of structure size, construction volume, or houselot area instead of *plazuela* area.

Future investigations of cross-cultural inequality require both standardization within individual measurements of inequality (e.g., residential area, construction volume, houselot area, feature accessibility, etcetera) and widespread comparisons among cities (sensu Kohler, et al. 2017; ME Smith and Kohler 2018; Vésteinsson, et al. 2019). Different wealth metrics, such as construction volume and residential area, provide an apples-to-oranges problem for comparisons (e.g., ASZ Chase 2017:37); however, and more beneficially, each of these metrics provides a unique dimension for understanding multiple kinds of inequality in the past, yielding more nuanced research results (e.g., Oka, et al. 2018).

6.5 Household Architectural Autonomy at Caracol

This chapter provides insight into ancient governance through the garden city and its built environment at Caracol. The results showcase a relatively high degree of household architectural autonomy through the diverse sizes of *plazuelas*, residential reservoirs, and agricultural terraces. This lack of standardization present suggests that construction of these features did not experience any standardizing force from either top-down or bottom-up processes. Other analyses reinforced this lack of standardized measurements and orientations. In terms of the governance forms present, the results from the standardization analyses and the Gini ones suggest similar interpretations based on independent measures.

Residences at Caracol have been described as both *plazuelas* and acropoleis, but the use of these terms hides some underlying similarities. First, distance between these residential features exhibits a long-tailed normal distribution on the landscape. This pattern suggests a diversity in how much land each residence had to manage; however, it does not contradict the prior estimate of about 2.2 ha of agricultural fields per residence (AF Chase and Chase 2015:17). Beyond that, area and height values from both *plazuelas* and acropoleis overlap. This strongly suggests that they do not represent two clear status classes of residential form. Instead, it provides a partial overlap where the largest acropoleis exist as outliers, the smaller ones fall into the distribution of larger residences. In other words, substantial overlap in residential form between these two types exists.

The above results accord with Gini values for residential area. These results reinforce the lack of clear bi-modal distinction and provide additional support for arguments against a class system of elites and commoners for the ancient Maya described previously (supporting research by ASZ Chase 2017:35-37; AF Chase and Chase 1996a; DZ Chase 1986:362; Hutson 2020:409-412; Masson and Pereza Lope 2005). In addition, Caracol appears to have been relatively equal, especially when contrasted with comparable residential area inequality measurements from Tikal (Kohler, et al. 2017) and the revised value from Teotihuacan (ME Smith, personal communication 2021). At the same time, the other Gini values derived from residential height, formal plaza access, ballcourt access, and E Group access all show relatively low inequality.

This chapter demonstrates the lack of standardization present in Caracol's garden city architecture through a variety of methods. The relatively high household architectural autonomy identified could represent more autocratic governance, but the Gini analyses in the latter half of this chapter suggest that Caracol was relatively equitable. Given the multiple interpretations of autocratic and collective governance based on Gini analyses by different authors (Boix 2015; Carballo 2020; Kohler, et al. 2018; AE Thompson, et al. 2021) this relationship suggests more collective governance, and future analysis and research on this topic is required.

7 RECONSTRUCTING AND TESTING NEIGHBORHOOD COHESION

The prior two chapters focused on physical infrastructural power and household architectural autonomy at the district level and residential level, respectively. This chapter reconstructs potential neighborhoods at ancient Caracol – using an algorithm outlined below – and tests the cohesiveness of eight of these neighborhoods through excavation data in residential shrines. I combine data from excavations conducted as part of this dissertation research with decades of data from other residential excavations at Caracol. Analysis evaluated the potential for these neighborhoods to participate in collective action (see Chapter 2) based on similar categorical identity (represented by similar ritual materials). In essence, the more similarities between neighbors, the lower the barrier for collective efforts. This process is further defined below.

This chapter provides a complementary, but intermediate, perspective by considering collective action potential through the neighborhood level. The collective action potential is the capacity for collaborative action that results from multiple overlapping relational and categorical identities (see Nexon 2009:48; Peeples 2018:27-28; Tilly 1978:63). This corresponds with the ability of people to come together cooperatively for joint endeavors, and it rests upon foundational research by various scholars in political science, sociology, and archaeology (Blanton and Fargher 2008; Levi 1988; Nexon 2009:48; Ostrom 2007; Peeples 2018; Tilly 1978:63). In terms of governance, higher collective action potential would reduce the friction for initiating collective endeavors and facilitate collective action in general. This neighborhood analysis also provides an analytical pivot-point between the administrative district and individual plazuela levels helping to understand how and why the ancient residents of Caracol cooperated through shared categorical and relational identities (sensu Nexon 2009:48; Peeples 2018; Tilly 1978:63). A consideration of collective action potential can also illuminate the overall collective or autocratic nature of governance.

Collective action theory, as applied to archaeology, derives from two primary bodies of theory in political science and sociology. The political science perspective focuses on the role of taxation in governance (Levi 1988) as well as the continuum from more autocratic to more collective governance. It builds on notions of collective action for services in reaction to internal (versus external) taxation (Blanton and Fargher 2008:12-24) and focuses on the rational human actor (i.e., *homo economicus*). Alternatively, a number of scholars working in the area of relational sociology focus on collective action at the individual actor level through studies of cooperation focused on the kinds of social connections that keep groups together and motivate collective action (Nexon 2009:48; Tilly 1978:63). These sociological analyses of collective action do not require the *homo economicus* game theory perspective demonstrated by the "prisoner's dilemma"; instead, they align more fully with notions of smallholder agriculturalists cooperating without the need for centralized state intervention (Ostrom 1992, 2007, 2015). Within the archaeological discipline, Peeples (2018:25-28) has created a framework for understanding the potential for this form of collective action by focusing on relational identity (direct interaction between individuals) and categorical identity (perceived similarities among individuals). Using collective action potential to understand governance begins the process of combining both the top-down, state-based perspective from political science and the bottom-up, individual-actor perspective from sociology.

By definition, neighborhoods entail frequent, repeated face-to-face interaction (ME Smith 2010:139), indicating strong relational identity through those repeated interactions among neighborhood residents. Categorical identity in shared cultural practices, symbols, or beliefs provides other similarities among individuals and augments these personal connections (relational identity) to increase the potential for collective action by these neighborhood units. As such, this chapter focuses on categorical identity by looking at the material record of residences within neighborhoods which interacted and had direct relationships in the past. The ritual contexts of burials and caches provide contexts of shared ritual practices (e.g., a citywide categorical identity) among all residences at Caracol. Over 70% of plazuelas (AF Chase and Chase 2014a:9) exhibit an eastern shrine focus that usually includes the deposition of caches and burials in similar residential patterns. This pattern extends even to the ruling family's residence on top of Caana (AF Chase and Chase 2017a:16-18). Residential groups of all wealth levels at Caracol engaged in similar ritual practices revolving around the (primarily) eastern shrine of their plazuela residential group. Inherently, this similarity provided some degree of a site-wide categorical identity; however, the intentional deposition of specific materials and the associated actions and events accompanying these deposits can also provide information on localized neighborhood categorical identity through each residence's choice of items and materials to deposit.

7.1.1 Operationalizing Collective Action Potential.

The patterning and distribution of ritual artifacts and their correlation with proposed neighborhoods serves as a proxy for collective action potential. As such, I use relational identity (frequent, repeated face-to-face interactions) to reconstruct ancient neighborhoods. Then, I test these reconstructions through the use of archaeological materials related to burials and caching in residential eastern shrine structures using the concept of categorical identity. While described below as discrete categories, it is expected that these results can fall into a continuum among the following options:

1.) High collective action potential demonstrated through distinct artifact distributions between the neighborhoods and similar distributions within them indicating neighborhood level categorical identities.

2a.) Moderate collective action potential with distinct artifacts in districts indicating district-based categorical identity – moderate due to the greater difficulties in maintaining strong relational identity over larger distances and with larger populations.

2b.) No collective action potential with patterns simply due to market distributions and restrictions on materials in marketplaces alone.

3.) Low collective action potential with similarity in artifacts between all neighborhoods regardless of district indicating a lack of neighborhood or district level potential collectivity but indicating a citywide categorical identity.

4.) Or no collective action potential with no clear pattern of similar materials at any scale indicating that these materials do not likely contribute to categorical identity at any urban level.

In short, more similarities among residential materials and practices at any urban scale indicates a higher potential for collective action among residents by reducing the friction to more cooperative endeavors. However, based on these hypotheses, distance analysis (both similarity and dissimilarity metrics, e.g., Horn 1966; Morisita 1959; Wolda 1981) on some special deposit material from eight sampled neighborhoods (Alta Vista, Dos Aguadas, Machete, Rebel, Boulder, Ace, Chak, and Sage) located within three districts (Downtown Caracol, Monterey, and Puchituk) provides information on the collective action potential at Caracol and demonstrates statistically significant similarities within and dissimilarities between neighborhoods.

At least two distinct processes affect the distributions and content of tombs, burials, and caches: a desire to express similarity in cultural practices (e.g., categorical identity) and the effects of market access as the fundamental means of acquiring the goods to place in these contexts. The first helps determine the level of collective action potential while the second provides a confounding factor. Fundamentally, the more similar the items deposited among residences, the stronger the potential categorical identity within that neighborhood due to similar ritual practices.

As described in Section 4.3.2, these materials provide a special case through their nature as mortuary deposits which are slow to change and provide more than relational connections. However, this similarity in materials may extend to all neighborhoods within this sample, especially if a citywide set of shared ritual practices (e.g., a citywide categorical identity) provided the impetus for eastern shrine use; this case would indicate that any neighborhood categorical identity would have been subsumed within broader ritualized behavior. In addition, differential market access may have generated district-based practices with equifinality between that market exchange and district level ritual patterns. On the other hand, the smaller the overlap of material similarity within neighborhoods, the less categorical identity these residences likely shared, meaning that the potential collective action would have been weaker among neighbors.

The potential patterns, outlined above, all highlight the importance of similarities at the citywide and neighborhood levels. A more top-down, collective governance system should showcase strong categorical identities at the citywide or district-levels with all residences roughly overlapping in their caching and burial practices. A more district-level focus could indicate either the effect of market forces or that this collective action potential revolved around district-level categorical identity; this would effectively show that the "administrative" districts were in fact more like the "social" districts from ME Smith (2010:140). A more bottom-up, collective approach instead would focus on neighborhood or potentially even district-level similarities. As such, district-level similarities possess equifinality between both processes, but would fundamentally indicate a more collective, rather than autocratic, governing system. As for more autocratic governance, it should exhibit less categorical identity among the neighborhoods or districts due to the lack of households needing to engage in collective action to advocate for urban services (sensu Blanton and Fargher 2008) or to generate local community services; however, a more top-down autocratic system could also demonstrate citywide similarity through heavy-handed, autocratic-style imposition (sensu M Mann 1984; M Mann 2019). This last possibility does require very strong infrastructural power and underscores the fundamental difference in expectations for collective action's role in infrastructure between the M Mann (1984) and Blanton and Fargher (2008) governance models.

7.1.2 Neighborhoods.

Importantly, at Caracol no single structure or architectural unit provides information for visually identifying neighborhoods (ASZ Chase 2016b:15) such as the walled areas or community compounds present in other parts of ancient Mesoamerica or the monumental nodes used to reconstruct Caracol's districts. Other methods of neighborhood identification have relied upon specific neighborhood level features such as elite households (Manzanilla 2012:59-64; Walden, et al. 2019:4), various clustering algorithms using household locations while mixing clustering with other geospatial algorithms (ME Smith 2010:149; AE Thompson, et al. 2018), and overlapping routes to plazas (see analysis in Richards-Rissetto 2012). Multiple methods (e.g., Hutson 2016:60-73) of identification focuses on a specific idea of what a neighborhood represents, but often incorporate the idea of frequent, repeated face-to-face interaction among residents. Caracol's "elite" households do not provide a clear means of identifying neighborhoods; clustering algorithms assume – much like gravity models – that the closer the spatial proximity the more likely people are to interact, but most clustering algorithms do not factor in rugged terrain (like the very hilly landscape of Caracol) terribly well; finally, overlapping routes assumes that interaction occurs along the way to and from a location instead of at the location of energized crowding itself. Each of these methods captures aspects of neighborhoods, and each could yield different results based on the same dataset.

As such, neighborhood reconstruction in this dissertation rests on operationalizing the definition from ME Smith (2010:139) where neighborhoods had frequent, repeated face-to-face interaction in the past. To reconstruct past neighborhoods, I use this idea of face-to-face interaction in combination with the notion of energized crowding in formal plazas (see ME Smith 2019). For each residence and each formal plaza, the least-cost-path travel cost in time (using White 2015) provides a metric for the likelihood of interaction, assuming that people tend to frequent more proximal plazas. This changes the problem space to one of residential distances to each of the 22 formal plazas (contained within the lidar dataset) where energized crowding occurs, essentially a 22-dimensional clustering problem. Co-located residences interact more frequently if they possess similar routes to formal plazas (see Richards-Rissetto 2012), and residents could interact both on their way to these plazas, their way from these plazas, while at these plazas, or near their places of residence.

The use of travel times covers the patterns outlined above. Similar distances (in time) from each formal plaza to two residences indicate greater spatial co-location, and in the case of Caracol avoids the issues caused by simple x-y clustering on the vertical, rugged landscape. Other researchers have successfully used k-means clustering to identify likely neighborhoods (e.g., Lemonier 2011; Lemonnier 2012; Robertson, et al. 2005; Robin 2003:330-331; ME Smith and Novic 2012:11-12), and that method has also been applied to this time dataset below. Future research can test alternative clustering methods for more ideal solutions to this neighborhood reconstruction problem.

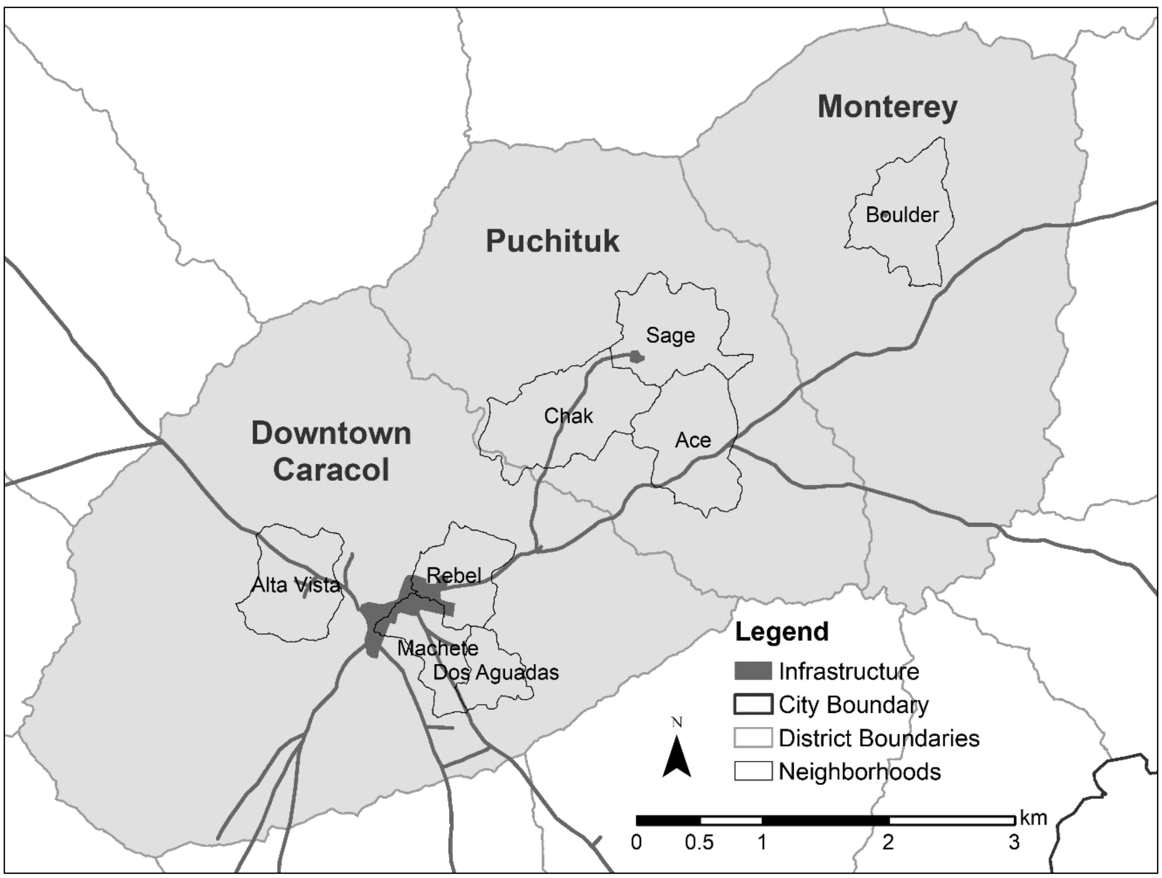


Figure 7.1: Sampled neighborhoods (also Figure 4.4)
This map shows excavation groups at Caracol, the district boundaries, and the approximate locations of sampled neighborhoods (see Figure 7.11 in Section 7.4.1 for a map of all reconstructed neighborhoods).

The map shown in Figure 7.1 illustrates the approximate locations of the eight sample neighborhoods (see Chapter 4 for description of sampling) and their districts within the context of all excavations undertaken by the Caracol Archaeological Project through 2020. (Further details on the full set of reconstructed Caracol neighborhoods follows in Section 7.4.1). Each sampled neighborhood sits adjacent to the formal plaza in its district. The Downtown Caracol district has four sampled neighborhoods: Alta Vista (west), Dos Aguadas (east), Machete (southeast), and Rebel (northeast). In terms of non-epicenter districts, Puchituk has three local neighborhoods: Ace (southeast), Chak (west), and Sage (northeast), which roughly align with the three hilltops surrounding that district node. Finally, Monterey has a single circumscribing neighborhood called Boulder. These last four neighborhoods between both the Puchituk and Monterey districts provide a check against the role of market forces and their effects on categorical identity. If local district markets had access to different goods (or if districts demonstrated high internal categorical identity), then neighborhoods should be more similar within each district than between districts.

This chapter conjoins neighborhood reconstructions and theory with separate bodies of literature on collective action to discuss the collective action potential of neighborhoods. In conjunction with the analyses in two previous chapters, this section provides neighborhood-level information on ancient governance. While no single architectural feature indicates the presence of a neighborhood at Caracol (ASZ Chase 2016b:15), the nature of agricultural terraces and water drainage from field-to-field strongly suggests the presence of minimally neighborhood-level governance to adjudicate these features in conjunction with the district-level governance to handle any disputes (see the agricultural terrace section in previous chapter). The absence of neighborhood-level architecture in general, however, indicates that physical infrastructural power largely stopped at the district-level and reinforces the idea of household architectural autonomy at the plazuela-level. Put another way, the collective action potential represented through shared categorical identity provides the best means of identifying the presence and strength of neighborhoods at ancient Caracol.

7.2 Modeling Neighborhoods

The data and analysis in this chapter builds on the neighborhood as a fundamental social unit in concert with the work of multiple scholars who argue that neighborhoods are intrinsic entities within both ancient and modern cities (e.g., Arnauld, et al. 2012; Hutson 2016:19-21; ME Smith, et al. 2015). However, a multitude of definitions for and usages of the term neighborhoods exist. Table 7.1 shows some of the variation in terminology used to define socially and spatially co-located units of people, the numbers of individuals included in those groupings, and the relationships of these terms to those used as part of the urban level framework described in Chapter 2. Assumptions about neighborhood size vary substantially. Thus, a neighborhood "cluster" could consist of 50 people (Bullard 1960:355) and a modern neighborhood could also be considered to be substantially larger, housing up to 10,000 people (PH Mann 1958:96). Nevertheless, these upper and lower population thresholds represent fundamentally different units of social organization in terms of how the people within them interacted. Most definitions of a neighborhood are in line with my own in focusing on groups of people who could have had frequent, repeated face-to-face interaction (e.g., Hutson 2016:71-73; ME Smith 2010:239). While this level of interaction remains unlikely with a group of several thousand people, the optimal and maximum number of individuals that would make up an ancient Maya neighborhood remains unclear. However, potential answers emerge from a different research context.

Cognitive science and management studies have identified a few common, repeated numbers of individuals that are optimal for social interaction. These include both 150 individuals (Dunbar 2010:24-28) and 291 individuals (McCarty, et al. 2001:29); however, recent research by Lindenfors, et al. (2021) has re-run Dunbar's data and obtained cluster values with that dataset ranging from 3 to 500. At the same time, other scholars have used or identified Dunbar's initial 150 average as corresponding with the optimal exploitation of socio-ecological systems (Casari and Tagliapietra 2018:2729-2733), social media interaction (Gonçalves, et al. 2011), and settlement longevity (Dunbar and Sosis 2018). In the initial formulation, this 150-person number represents a somewhat fractal, scalar unit representing the largest sets of interaction limits with an alternating 3 or 3 and 1/3rd exponent (see Dunbar's numbers in Table 7.1 and discussion below). Given this, the recent re-evaluation of Dunbar's suggests that instead of focusing specifically on 150 individuals, any group size under 500 should approximate frequently interacting groups (Lindenfors, et al. 2021).This aligns with prior analysis by Kosse (1990, 2000) which identified 500 – in addition to 150 – as a significant threshold in various societies and mental templates. Given these various investigations of group size above, neighborhoods might be expected to have populations below 500 people as well.

Source	Term / Label	Definition	Population	Urban Level
Bullard 1960:355	Cluster	residential groups in clusters of five to twelve	50 to 120	Neighborhood
Bullard 1960:355	Minor Center	formal architectural node near 50 to 100 residential groups	500 to 1k	District
Bullard 1960:355	Major Center	formal architecture with ballcourt, stelae, or other minor centers	over 1000	District/City
Dunbar 2010:32-4	5 people	small, close group of really good friends	5	n/a
Dunbar 2010:32-4	15 people	known in psychology as a "sympathy group" of close individuals	15	Plazuela
Dunbar 2010:32-4	50 people	typical size of small hunter-gathers group overnight camps	50	n/a
Dunbar 2010:24-8	150 people	Dunbar's number based on interaction; appears in various contexts	150	Neighborhood
Dunbar 2010:32-4	500 people	acquaintances and individuals people interact with more rarely	500	Neighborhood
Dunbar 2010:32-4	1500 people	average size of entire hunter-gatherer tribes & facial recognition	1500	District
Dunbar 2010:32-4	5000 people	based on Plato's ideal size for a democracy at 5300	5000	District
Hutson 2016:71-73	Community	a cohesive group of individuals (not like other units in this list)	n/a	n/a
Hutson 2016:71-73	Ward	top-down administrative district, often larger than a neighborhood	n/a	District
Hutson 2016:71-73	District	large residential zone with a social identity (aka social district)	n/a	Neighborhood
Hutson 2016:71-73	Cluster	physically separate groups potentially with spatial boundaries	n/a	Neighborhood
Hutson 2016:71-73	Neighborhood	distinctive residential area with people who interact (face-to-face)	n/a	Neighborhood
Hutson 2016:71-73	Focal Node	location of energized crowding with face-to-face interaction	n/a	District
McCarty et al. 2001:29	Killworth's no.	~291 people that the average person "knows" and contacts in a year	291	Neighborhood
Mann 1958:96	Neighbourhood	isolated urban unit with 5k to 10k people and face-to-face interaction	5k to 10k	District
Smith 2010; 1992	Small capolli	clusters of houses and patio groups	about 200	Neighborhood
Smith 2010; 1992	Large capolli	clusters of small capolli around a larger house	803	District
Smith 2010:139	Neighborhood	residential zone of frequent, repeated face-to-face interaction	n/a	Neighborhood
Smith 2010:140	District (Admin.)	residential zone for urban administration	n/a	District
Smith 2010:140	District (Social)	residential zone with unique social identity	n/a	District

Table 7.1: various definitions of intra-urban units.
Population is included when specified by the authors.

While urban scholars do not present a unified front on expected population size, other fields may help to inform us with answers to theoretical expectations of neighborhood population size. The fundamental idea of neighborhoods as loci of frequent, repeated face-to-face interaction – which may occur in places of energized crowding – integrates well with an operationalization of least-cost-path distance to formal plazas from residential plazas at Caracol. However, the theoretical underpinning for a normal distribution of around 150 individuals per neighborhood depends on research found in three different bodies of research: geography, social network analysis, and cognitive science.

7.2.1 Geography: Spatial Autocorrelation.

Archaeology and geography have a history of positive research connections focusing on human-environmental interactions (for example Sluyter 1994; Turner 1978; Turner and Harrison 1983) In addition, modern geographic information systems (GIS) and spatial analyses in archaeology owe a debt to geography even if GIS as a subfield has transformed into a fully interdisciplinary field beyond the ownership of "academic geography" (Longley 2000). However, geography provides one primary lesson for understanding neighborhoods in the past or the present, spatial autocorrelation. The first law of geography essentially states that, while all things are related, closer things are more related to each other (Tobler 2004); however, scholars had investigated spatial similarities and distance before Tobler coined the phrase (see for example Sahlins 1965:Figure 1 on kinship distance).

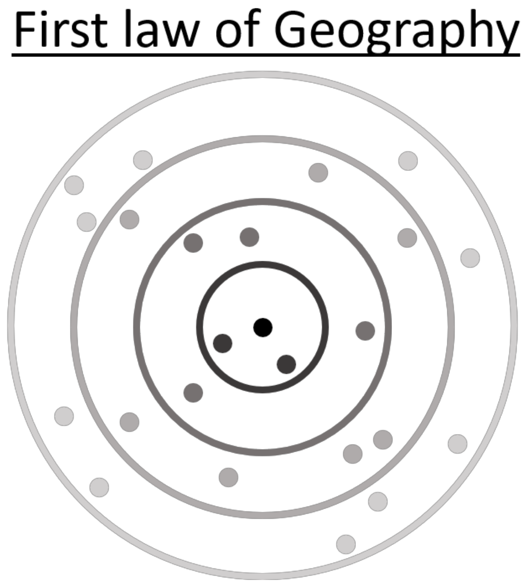


Figure 7.2: First law of geography
The first law of geography specifies that closer things are more closely related (e.g., spatial autocorrelation). This is indicated in this Figure by the fading colors. Dots closer to the center of the Figure more closely match the center dot.

This spatial autocorrelation (closer things are more similar to each other than those further away), when applied to urban residences, suggests that neighborhoods should exist as "groups" of more similar residences (see Figure 7.2). While this may be related to spatial clustering of residences, spatial autocorrelation only suggests that proximal things will be more similar. Alone, this generates fuzzy neighborhoods of various sizes and does not imply any specific population size. This fuzziness arises from the potential of neighborhoods to sprawl over large areas while residences on either end of a neighborhood may not themselves interact on a regular basis. If spatial autocorrelation alone creates neighborhoods, then urbanists should expect gradients of neighborhoods to form across their cities. As such, this law from geography alone does not account for the sometimes-sharp boundaries that exist between neighborhoods. However, inherent in the first law of geography is the logic behind least-cost-path analysis – that as distance increases cost for travelling that distance increases and the likelihood of regular contact is reduced.

7.2.2 Social Network Analysis: Triadic Closure.

Social Network Analysis (SNA) as used in multiple academic fields provides a solution to the boundary issues that arise with only spatial autocorrelation. The principle of triadic closure (also called cognitive balance) helps provide a framework for understanding social bonds, and how boundaries persist in a network of interactions. It is based on the idea that if one individual has strong social bonds with two others, then those two other individuals will, over time, either form a strong bond with each other or one of their bonds to the first individual will become a weak bond (Granovetter 1973; Peeples 2019:458).

Put another way, individual T in time 1 (represented as T_1) has two strong ties to individuals U and V, and the passage of time will result in either one of two outcomes (T_{2A} or T_{2B}). Either T_{2A} will maintain both strong bonds and a new strong tie will form between individuals U and V, or T_{2B} will experience the deterioration of one strong bond into a weak bond (e.g., T_{2B} to V), as shown in Figure 7.3. Cognitive balance represents the common pattern of forming or closing triadic cliques of individuals.

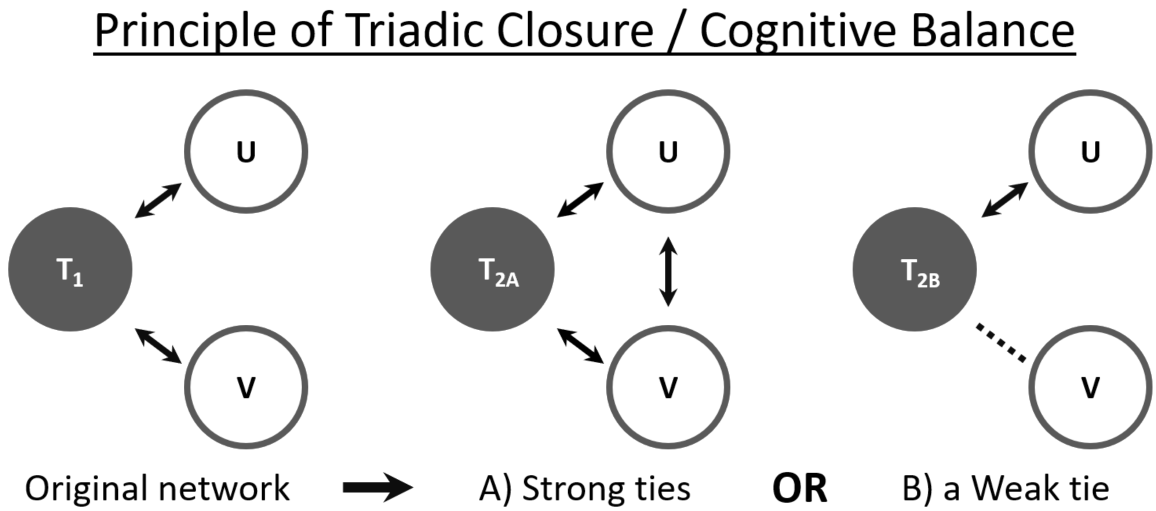


Figure 7.3: The principle of triadic closure (aka the cognitive balance)
Triadic closure shows that when one person, (T), has strong connections to two other people, (U and V), then over time either a strong connection will form between the other two individuals (U and V), or one of the two strong connections will become a weak connection (T_{2B} to V in this example).

When considered in relation to neighborhoods, the expectation is that the tie between two neighbors in different neighborhoods would be weak while a clique of individuals in the same neighborhood would show strong ties between residences. The fundamental definition of neighborhoods as locations of frequent, repeated face-to-face interaction entails a social network to socially tie those neighbors together. Frequent interactions would generate stronger ties between neighbors, while weak ties still represent beneficial connections, as Granovetter (1973; but see also Peeples 2019:465) demonstrated decades ago by highlighting the role of weak ties in propagating information through a social network. Weak ties interlink many stronger local networks and thereby serve as brokers of moving information across the larger network (see also brokerage in Peeples and Haas Jr. 2013 observed among settlements), and interactions at district nodes would facilitate these beneficial types of weak ties for Caracol's residents.

In addition, persistent ties are more likely to form between "more similar" individuals (i.e., individuals with more shared categorical identities), the social network principle known as homophily (Feld and Grofman 2009). Within a neighborhood context, homophily indicates that strong ties will persist over time more often when the two linked residents possess more inherent similarities. Combined with the principle of triadic closure, this would create a strong "neighborhood identity" with triads located in neighborhoods and a few "brokers" among neighbors connecting different neighborhoods (following the use of brokerage by Peeples and Haas Jr. 2013). While the possibility that a "neighborhood identity" or the sense of "common distinctiveness" may have existed in the past has been mentioned by archaeologists (e.g., Hutson 2016:70-73; ME Smith 2010:139-140; ME Smith and Novic 2012:4,9); it is difficult to operationalize. However, the SNA mechanisms of homophily and triadic closure can lead to the creation of distinctive neighborhoods that form categorical identities.

Triadic closure also provides one solution for how distinctive boundaries between neighborhoods form and persist. Clear boundaries between neighborhoods exist when there are rifts with weak social ties between residents from different neighborhoods. In contrast, strong intra-neighborhood interactions create groups of households with multiple strong ties interconnecting them. This provides the long-term picture of the results of these frequent and repeated face-to-face interactions. However, in any given slice of time there would also be strong ties between residences in different neighborhoods. The long-term perspective suggests that those ties would not likely persist over time given triadic closure. Yet, when considering the human scale of social network analysis, archaeologists must remember the dynamism of the underlying system of strengthening, weakening, forming, and closing network ties among residents. As such, the processes of social interaction over time creates hard boundaries between different neighborhoods, but those processes do not address the issue of absolute neighborhood size and could, without other factors, permit neighborhoods of 50 to sit next to neighborhoods of 10,000 without considering any potential temporal or mental limits among the residents participating in those face-to-face interactions.

7.2.3 Cognitive Science: Cognitive Limits.

Cognitive science provides yet another puzzle piece that helps provide a theoretical understanding of neighborhood organization. Based on analysis of social groups in various contexts, Dunbar's number of 150 people represents a frequent, repeated cognitive limit on interaction (Dunbar 2009, 2010; Dunbar and Sosis 2018). While some scholars have challenged Dunbar by providing different average group sizes such as 291 by McCarty, et al. (2001); others have focused on the higher limit for all interactions instead of close ones, the overlapping nature of social interactions, and the artificiality of the tier structure (see Wellman 2012). However in rejecting Dunbar's initial 150 calculation, Lindenfors, et al. (2021) also provide a solution by demonstrating that average group sizes can vary from 3 to 500 people. For our purposes, that upper 500 threshold provides a boundary that captures nearly all of the average group sizes proposed by various scholars (for example by Kosse 1990; Kosse 2000). As such, this concept of cognitive limits provides a framework for discussing human interactions and social organization multiple research contexts but does not need to rely on a specific 150-person limit.

In its initial formulation, the body of theory derived from cognitive science suggests that average group sizes exist at 5, 15, 50, 150, etc. individuals, following a pattern of raising numbers by alternating factors of 3 or 3 and 1/3rd (Dunbar 2009, 2010; Dunbar and Sosis 2018). Each numbered tier theoretically represents a drop in the frequency of interaction and higher tiers represent less and less frequent interaction (Figure 7.4). This number of 150 people for "optimal" interaction has appeared multiple times in different fields of research (Casari and Tagliapietra 2018; Gonçalves, et al. 2011; Zhou, et al. 2005), all of whom suggest that it may represent an underlying aspect of human cognition or a pivot point for the mental fatigue associated with social interactions at least in these contexts (but again also see Lindenfors, et al. 2021; Wellman 2012).

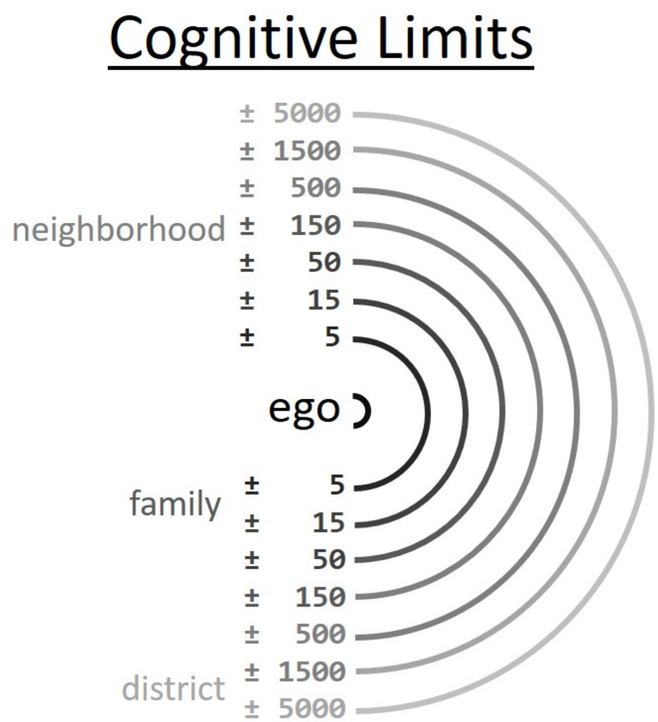


Figure 7.4: cognitive limits using significant values from Dunbar's research. Dunbar's number of 150 lines up with the sizes of neighborhoods at Caracol (explained later in this chapter), but fundamentally neighborhoods should exhibit populations below a 500-person of threshold of frequent, repeated interaction.

While cognitive limits, then, might provide an "optimal" upper limit for the expected size of neighborhoods around 500 people, operationalizing the definition of frequent, repeated face-to-face interaction brings to focus the mental and temporal limits on human interactions. While it suggests that neighborhood groups would exhibit similar average sizes, it is likely that variation in these average values would reflect both cultural and physical facets of interaction through social norms and the built environment of cities (e.g., R Fletcher 1995). In either case, these cognitive limits provide guidelines to ultimate neighborhood size where neighbors interact frequently.

7.2.4 Unifying a Neighborhood Model from Disparate Disciplines.

Integrating these three different disciplinary perspectives (geography, social network analysis, and cognitive science) on space and interaction can be used to provide a model for neighborhood size and structure. Spatial autocorrelation highlights both the importance and rationale for spatial co-location of residences in a neighborhood. Cognitive balance provides the potential basis for sharp delineations between neighborhoods with strong neighborhood identities related to the homophily of individuals with stronger ties. And cognitive limits on interaction yield the "optimal" neighborhood size below 500 people. Various researchers have also suggested that communities tend to fission after reaching 150 members (Dunbar and Sosis 2018:110) and that long-lived communities have between 140 and 176 people per settlement unit (Casari and Tagliapietra 2018:2732). Both numbers represent the average value of normal distributions, which accounts for variation in neighborhood sizes (see section on Caracol's neighborhoods below). These processes and the smaller groups associated with them also likely represent part of the success of small-scale self-governing irrigation systems. While Ostrom (1992, 2015) does not focus primarily on identity, these self-governing communities and their long-term success may be due in no small part to the strong, intertwined relational and categorical identities that form among the individuals living within them. These social factors would provide a higher collective action potential that could facilitate the patterns observed by Ostrom (1992, 2015).

Cognitive limits of common group size also conform well with Mesoamerican settlements. This includes characterizations of Aztec calpulli as neighborhoods with an average of 200 residents at Cuexcomate by Smith (1992:340-341; 1993), the 40 household (i.e., 200 people at 5 people per house mound) breakpoint identified within scaling results from smaller Maya settlements (ME Smith, et al. 2021b:Figure 2), and archaeological descriptions of house mound clusters with 50 to 120 residents (at 10 people per house as a patio group with between 5 to 12 houses in a cluster) by Bullard (1960:359, Figure 2, and Figure 7). Together, all these separate sources – while not an exhaustive sample – suggest that neighborhoods under 500 people may have been common within the ancient Mesoamerican world (Table 7.1). These numbers also sit in opposition to the five to ten thousand people per neighborhood described by PH Mann (1958:96). This larger neighborhood value indicates the fundamental mismatch between some modern neighborhood definitions with the goals of other scholars to reintroduce *social* neighborhoods back into the urban landscape (see Talen 2019). *Social* neighborhoods require a consideration of residents and their interactions while *administrative* neighborhoods require a consideration of urban servicing needs at the neighborhood level (akin to mini districts based on the urban lenses presented in Chapter 2 for our very large modern cities). Researchers have used neighborhoods as a concept without always thinking through the spatial, social, and cognitive implications of those groups of residences as units with frequent, repeated face-to-face interaction at the scale of human interaction.

7.2.5 Kinship and Settlement.

The various *plazuela* groups at Caracol had longevity; individual residences survived for hundreds of years. While it might logically be assumed that neighborhoods represent kin groups of related individuals and that kin-based neighborhoods would indicate both a very strong categorical identity and relational identity due to the nature of family ties, the assumption that descendent kin built adjacent residences over time is more complicated as shown ethnographically by Hayden and Cannon (1984). While co-located descendent residences may be found at some sites, at Caracol the number of conjoined households makes up only 1.39% of the total sample (see below). Furthermore, plazuela size analysis and stable isotope analysis of human bone suggest that some nearest neighbors were eating different diets and were of different status (e.g., AF Chase, et al. 2001).

As mentioned in the prior chapter, out of the sample of 7709 residences digitized in the lidar, only 107 were adjacent to each other, creating 53 double *plazuelas* and a single triple *plazuela* group. However, the city of Caracol lasted from minimally 600 BCE until 900 CE representing over 1,500 years of occupation and the potential of 75 generations (at 20 years per generation) of its residents (see also Vadala and Walker 2020:153-156). In that length of time, if kin groups spawned adjacent residences, then double or triple groups should represent far more than 1.39% of all residences (107 conjoined plazuelas out of a sample of 7709) identified in the lidar dataset.

Instead, the lack of directly adjacent residential plazuela groups is likely due to ancient land tenure, agricultural practices, and the need to maintain sufficient spacing for fields amidst housing, (e.g., AF Chase and Chase 2016a; Fisher 2014). While some scholars have begun to investigate land ownership among the ancient Maya (Kwoka, et al. 2021; LeCount, et al. 2019; AE Thompson and Prufer 2021), more research needs to be conducted to tease out these relationships. The lack of adjacent groups at Caracol may indicate a lack of adjacent kin networks with the idea that budding households needed to build their residences elsewhere to obtain agricultural land (e.g., DZ Chase and Chase 2014c). This would fill in the landscape within or at the fringes of the city and correspond with the construction of some district nodes to accommodate urban sprawl (i.e., Termini A and C in the Terminal Classic period). It would also drive settlement into new agricultural areas, leading to a sprawling low-density city.

Any research avenue towards an understanding of kin relationships in the past requires either written evidence or ancient DNA analysis of both mitochondrial aDNA matrilines and Y chromosomal aDNA patrilines. However, even ethnographic kinship can demonstrate complicated relationships among households (Hayden and Cannon 1984). Even so, this patterning of both genetic relationships within individual plazuelas, in neighborhood groups, or across the city could provide information about land tenure, kin networks, and the impact of neighborhoods as social units. This represents a future avenue of ancient urban research at large, and a project for Caracol is currently being undertaken by Dr. Rick W.A. Smith of George Mason University but is so far only in its initial stages.

7.2.6 The Neighborhood in Mesoamerican Archaeology.

Neighborhoods constitute a fundamental urban unit in Mesoamerican archaeology (e.g., Hutson 2016; ME Smith 2010; ME Smith and Novic 2012). However, as noted above, the formal definition of neighborhoods has not often included the size of these communities. It also often lacks consideration of the potential spatial, social, and cognitive mechanisms that can shape these units. The above discussion provides an underlying set of theories on which to base an operational model for the study of archaeological neighborhoods. Spatial autocorrelation indicates that closer residences should be more similar, creating sprawling, fuzzy neighborhoods. Triadic closure introduces social mechanisms of strong and weak ties to create hard neighborhood boundaries among homophilous residents. Finally, cognitive limits to social interaction introduce a 150-person (or 291-person) normal distribution on absolute neighborhood sizes. Taken together, these ideas from these disparate disciplines all reinforce the core definition of a neighborhood as a place of frequent, repeated face-to-face interaction embedded in spatial and social landscapes.

7.3 Operationalizing Neighborhoods

With the theoretical underpinnings outlined above, this section describes the archaeological operationalization of neighborhoods as social units of repeated, frequent face-to-face interaction. Incorporated in this operationalization are interactions within the neighborhoods, at the loci of energized crowding, and on the routes to those loci. The dataset for this analysis depends on the survey extent of the 2009 and 2013 lidar datasets and does not include every formal plaza (i.e., the loci of energized crowding) or every residence (both due to those missed in lidar digitization and those located outside the lidar dataset in modern Guatemala). I discuss the method and results below before covering the impact of these caveats.

Within this context of Caracol the city, the 5852 identified residential groups within the lidar boundaries of urban Caracol (both *plazuelas* and acropoleis) and the 22 identified district nodes located within the lidar data form the two halves (e.g., rows and columns) of this optimization problem. While the total sample for this dissertation has 7709 residential groups, many of these exist beyond the falloff in agricultural terracing and population density used to denote the edge of the city. These other residences also had less preferential access to the urban services provided by Caracol the city as discussed in the Gini section of Chapter 6. While clusters of these residential groups formed either neighborhoods or local communities they are not all as well integrated into Caracol's system of formal plazas as the 5852 residential sub-sample as mentioned in the 1-hr access section of Chapter 5. However, even with this subsampling of the raw data, this represents 128,744 individual travel times (22 district nodes * 5852 residences); a relatively large dataset from an archaeological perspective.

At the same time, this subsample possesses evidence of clustering. A nearest neighbor analysis using the default settings for the average nearest neighbor tool in ArcGIS 10.7 found that this sample of 5852 residential groups (*plazuelas* and acropoleis) exhibited strong clustering, with a p-value of under 0.000000 and a z-score of -25.701284. These results, before the rest of the analysis that follows, already suggest that an inherent clustering exists within this dataset without providing that specific clustering. A method to identify those clusters follows below.

To operationalize this clustering problem, I calculated the reciprocal least-cost travel times to district nodes in hours following the method outlined by White (2015), using the same underlying data shown in the 1-hr access section of Chapter 5. For each residence, I algorithmically recorded the travel time from its centroid to each of the twenty-two district nodes using the zonal statistics in ArcGIS (r.stats.zonal in GRASS GIS). This created the 128,744 cells of travel time data for analysis. Prior research has used clustering algorithms to identify neighborhoods (e.g., Robertson, et al. 2005; Robin 2003:330-331; ME Smith and Novic 2012:11-12) – in particular the k-means clustering algorithm familiar to many archaeologists (Hartigan and Wong 1979). While a variety of other clustering algorithms exist (see Kononenko and Kukar 2007), k-means remains one of the few that archaeologists often use (Shennan 1997:249-258) and was selected for this analysis due to this ease of use and explanation. However, future research will investigate other clustering algorithms that avoid some of the limitations of k-means on this dataset.

K-means analysis requires the number of clusters (the "k" value) to be specified in advance. This then randomly seeds k points around the search space and an iterative hill climbing search algorithm identifies optimal results. Because of this random seeding and the variation in hill climbing algorithmic results and their sum of squared errors, each run for a value of k can produce a distinctive result. However, most results tend to produce similar values (when testing the ultimately successful value of k = 373 in this analysis, none of the residences within the sampled neighborhoods changed or moved between clusters). After running k-means on the dataset for various values of k, in this case from 1 to 1000 in ten in ten separate runs, to determine an ideal value of k requires looking at the "kink" in the residuals graph or the peak in the f" value (as described in Section 6.3.4).

For this analysis, I ran over 10,000 k-means analyses. This included ten separate sets of runs with k values from 1 to 1,000. Within each of these ten sets of runs, I selected the k values that produced second-derivative residuals above the two-sigma standard deviation of those values within that set of runs. These values form the local peaks of reduced sums of squared error, and present local algorithmic optima. In other words, for each of these ten runs I aggregated all f" peaks (i.e., the kinks) from each run and placed those into a single graph (Figure 7.5). Unlike a standard k-means reduction in the sum of squared error graph, this graph plots the k-values that produced significant (above 2-sigma) residuals from the lowest to the highest value of k. Each individual run had a kink for the value of 3 while the values of 8 and 373 appear significant within this analysis. As such, the values of 8 and 373 highlighted in Figure 7.5 represents inflection points – potential optimum cluster solutions calculated across all 10 sets of runs.

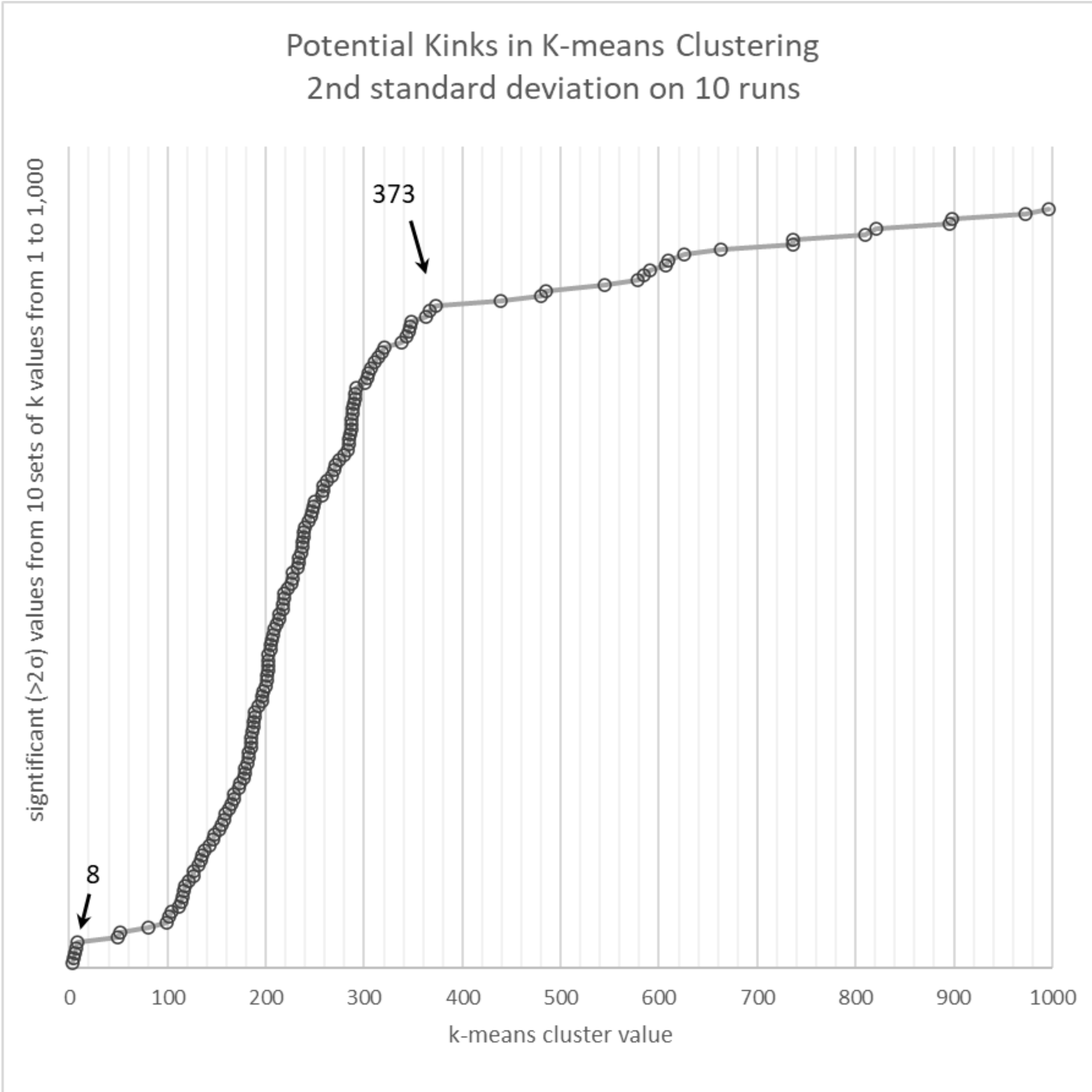


Figure 7.5: Potential neighborhood k-means clustering values
A graph of the f” local optima (i.e., “kinks”) at 373 k-mean clusters for neighborhoods after 10,000 runs (10 sets of k from 1 to 1000). These values show their own inflection points at k values of 8 and 373.

I conducted all k-means runs with R’s k-means function in RStudio version 1.2.5042 and version 3.6.3 of the R programming language (R Core Team 2020). Inherently, k-means may not be the optional algorithm for this analysis due to its stochastic nature; running the same inputs through k-mean can yield similar but different results. Ergo, running the set of potential k values at least at least ten times. While the combined analyses suggest 373 neighborhood clusters provide the f'' pivot point (aka "kink" as described in Chapter 6) within this dataset of 5852 residences, the actual value could change slightly with additional runs. However, the aggregated results of all ten runs demonstrate a clear inflection point at 373 (Figure 7.5) suggesting the validity of this clustering.

Other factors could also affect these results. The 5852 residential groups represent a sample and not a complete recording of all residences at Caracol. There are also three potential district nodes and multiple residential groups in modern Guatemala beyond the current lidar dataset. The results of k-means with these additional datasets would affect the resulting clustering; however, it is likely that identified clusters (i.e., neighborhoods) would remain more similar to each other than to the new data. Either way, additional data could change the results from a re-analysis.

Population is yet another confounding variable. Given the projected 100,000-population estimate at Caracol during the early Late Classic Period and the size of these neighborhoods from the analysis above, the ranges of possible neighborhood numbers and neighborhood population size are projected in Figure 7.6. Applying a higher overall population to these data would either increase the number of people per neighborhood, the number of neighborhoods, or both. The range in number of neighborhoods and neighborhood populations in the current 100,000 population estimate forms a line representing potential expectations of neighborhoods and mean neighborhood population with the equation y = 100,000 / x where x can vary from [157:269] people per neighborhood (Figure 7.6). At one extreme this represents 637 neighborhoods of 157 people and at the other it represents 373 neighborhoods of 269 people (see next paragraph for additional considerations and potential issues). As such, both extremes show neighborhood sizes that would fall near either Dunbar's number of 150 or Killworth's number at 291 (Dunbar 1998, 2009, 2010; McCarty, et al. 2001), and both fall within the wider range of group sizes (i.e., 3 to 500) identified by Lindenfors, et al. (2021).

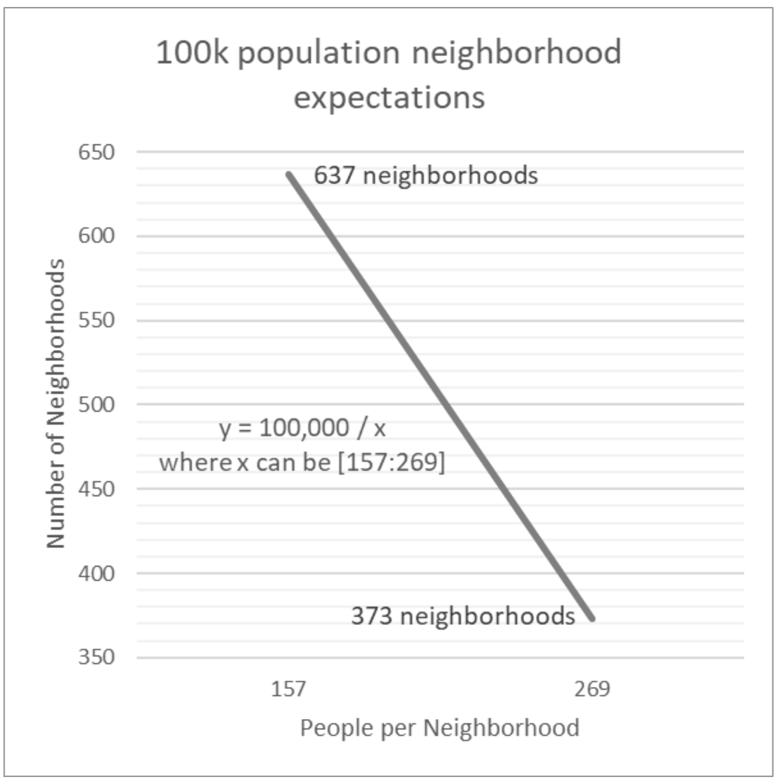


Figure 7.6: Variation in reconstructed neighborhood population expectations
Expectations for maximum neighborhood populations or sizes at Caracol given a population of 100,000 people: 637 neighborhoods with an average of 157 people or 373 neighborhoods with an average of 269 people.

Population reconstruction itself can also obviously impact this analysis. The current population estimate at Caracol uses 10 people per *plazuela* or acropolis regardless of residential size as well as a corrective factor for vacant terrain structures (or in the case of lidar data, a second corrective factor for structures identified on the ground or through excavation but missed in digital survey). Population estimates used in other parts of Mesoamerica of five people per mound would generate far higher population estimates for the three to twelve structures around the central plaza of each *plazuela* group (see Culbert and Rice 1990). The Caracol population estimate instead treats each plazuela not as a collection of family residences, one per structure (e.g., mound), but as an extended family household (Becquelin and Michelet 1994:303). This means that the above numbers provide a best-case scenario, but other methods for calculating population will increase the population values of these results.

Finally, while the k-means results do have some interesting clustering patterns by highlighting the three k-values of at 3, 8, and 373 in individual runs and the distribution shown in Figure 7.5 above, the method as used here leaves room for future improvement and streamlining. The stochasticity of k-means inherently implies that re-running this analysis could produce slightly different results. However, while re-running k-means or other clustering algorithms may move residential groups between neighborhoods and change the sum of squared errors, it is likely that the overall number of neighborhoods would remain the same or similar unless additional households were added to the sample. As such, even with the caveats outlined above, the k-values of 3, 8, and 373 provide interesting values to explore along with potential implications of these results.

7.3.1 K-means of 3.

An inflection point occurs at k of three in all ten k-means runs of 1 to 1000, indicating that this value formed a common division within this dataset. However, this value provides a subdivision larger than the set of districts identified in Chapter 5 or even the subset of Tier 1 and 2 districts from Section 5.2. This clustering has also identified civic subdivisions with populations far larger than that expected for a neighborhood.

However, this k-means value of three produces a clustering pattern that aligns with the three monumental nodes that conurbated to form the city of Caracol (e.g., Downtown Caracol, Cahal Pichik, and Hatzcap Ceel) visible in Figure 7.7. This tripartite division suggests that these three oldest district nodes, and oldest settlement centers at the city of Caracol, may provide a fundamental reason for settlement clustering at the citywide level.

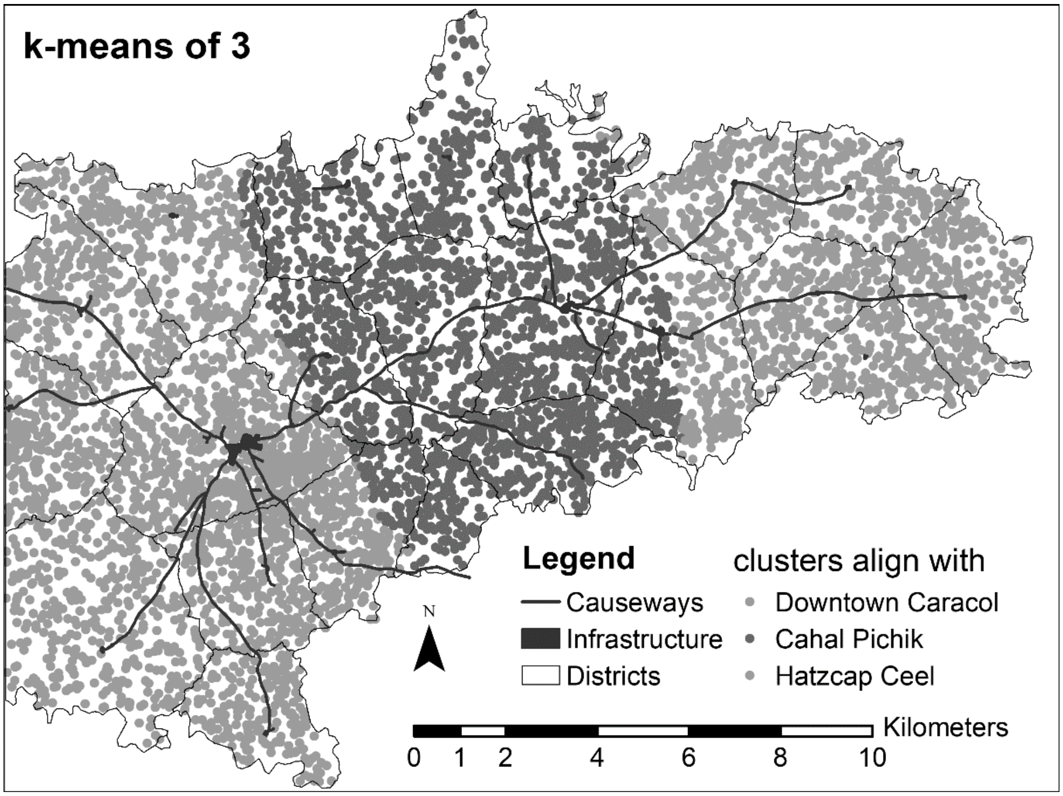


Figure 7.7: Map showing the k-means results for k=3
This clustering roughly aligns with the three monumental nodes that conurbated to form the city of Caracol (i.e., downtown Caracol, Cahal Pichik, and Hatzcap Ceel).

7.3.2 K-means of 8.

The k-means of eight, occurred frequently in individual runs and provides one inflection point (f" kink) in the meta-analysis shown in Figure 7.5. With eight distinct values, this subdivision incorporates multiple district nodes in any specific cluster, and it does not seem to align with any particular architectural feature, district typology, or other easily ascertained aspect of settlement. These potential civic subdivisions occur above the district level of the formal plaza, and do not appear to line up with expectations for neighborhoods.

In addition, while three letter district identifications appear in Figure 7.8, these only represent the largest district node (by architectural size) within each of the eight clusters. These clusters neither align with ballcourts, reservoirs, nor formal plazas. They also do not integrate well with the causeway system, in fact, many include dichotomous causeways in the same cluster. In other words, this k value, while identified in the meta-analysis of inflection points, will require future investigation to understand with regards to its potential role at the district level.

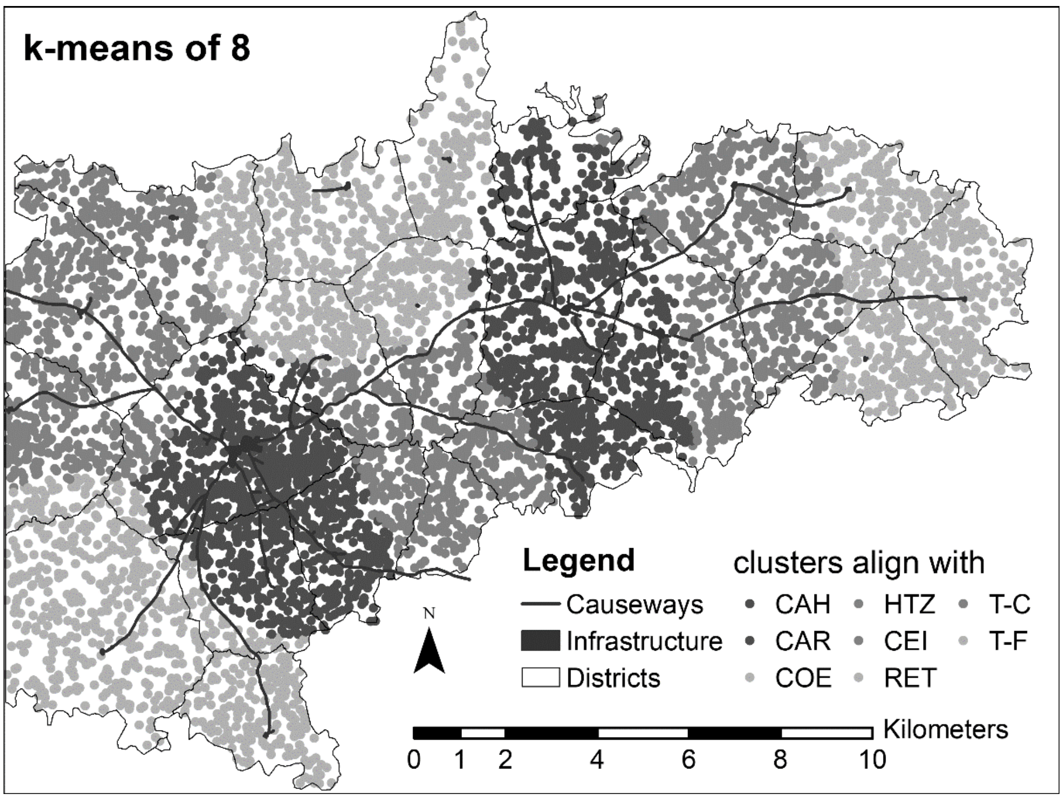


Figure 7.8: Map showing the k-means results for k=8
This set of clusters does not align with any particular urban feature. The labels represent the largest district node in each cluster. These results represent rough spatial co-location at best.

7.3.3 K-means of 373.

Finally, as indicated above, the k value of 373 provides the inflection point that reconstructs the potential neighborhoods within Caracol the city (Figure 7.9). This value represents the inflection point of the full meta-analysis of k-means runs (Figure 7.5) and is useful to consider in terms of on-the-ground population estimates (see the next section below). As with most clustering algorithms, clusters near the periphery do not tend to appear as cohesive; this leads to more reasonable looking neighborhood boundaries away from the border around Caracol the city. This analysis results not only in multiple neighborhoods within each district, but in multiple neighborhoods immediately surrounding each of the district urban service features. Additionally, these reconstructed neighborhoods align with the neighborhood expectations outlined in Section 7.2.

Tying this into the archaeologically sampled contexts, around Puchituk, this analysis results in three separate neighborhoods, one centered around each of the three tall hilltops around Puchituk's district node. Downtown Caracol has a variety of neighborhoods in each direction including four adjacent ones with several more just a little further past the valleys surrounding the site epicenter. As for Monterey, the two hills to the southeast and northwest of its monumental architecture encompass a single neighborhood. In other words, this algorithm appears to have reconstructed neighborhoods, while respecting the topography of the local landscape in a way that simple x-y location clustering could not.

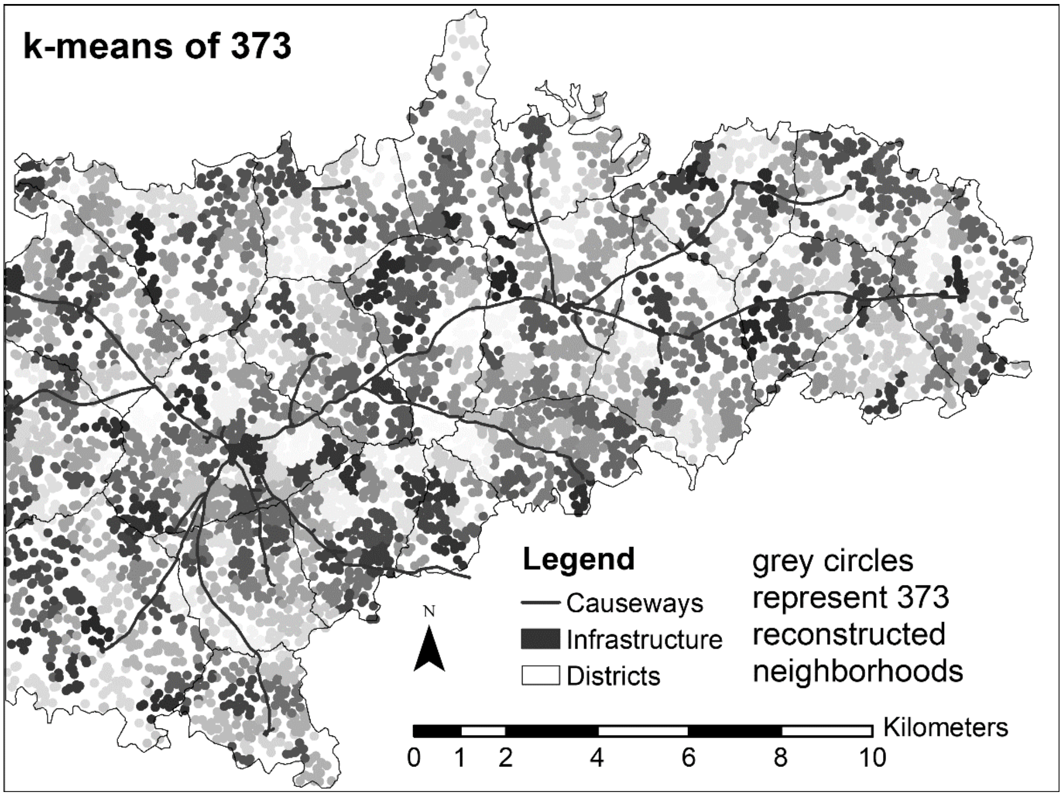


Figure 7.9: map showing the k-means results for k=373.
This represents the "kink" or inflection point of reduced error values in the k-means analysis of identified residences within Caracol the city. These reconstruct the most likely neighborhoods (based on the operationalization described above) for the 5852 residences within Caracol the city. (See also Figure 7.11 below.)

7.3.4 Population in Neighborhoods and Districts.

In terms of the results from k equals 373 neighborhoods, if each residential group had a population of about 10 individuals per residential group, the result is the bell curve visible in Figure 7.10. This distribution visually appears "normal" around the mean of 15.7 residential groups per neighborhood; however, this is not confirmed by either a Shapiro-Wilk test or a Kolmogorov-Smirnov test (respectively shapiro.test and ks.test in R 3.6.3; see also (respectively shapiro.test and ks.test in R 3.6.3; see also R Core Team

2020)) indicating that the distribution is not quite normal. Using the estimate of ~10 people per residential plazuela unit, regardless of size or structure count, generates an average population of 157 people per neighborhood. The median size of 15 generates a population of 150. The standard deviation of 5.1 residences provides a 1-σ population range of 106 to 208 representing 68% of all neighborhoods at Caracol, and a 2-σ population range of 55 to 259 representing 95% of all neighborhoods at Caracol. However, as noted above, there are caveats. This analysis is missing structures identified during ground survey and excavation that remain invisible in the lidar survey, and this sample also excludes any of the residences or neighborhoods in modern Guatemala (estimated to include about 40 square kilometers of additional urban settlement and three more monumental nodes). While future research will revisit the population estimate question along with the ratios of vacant terrain and missed structures, the current analysis at 5852 residential plazuela groups provides a far larger and more comprehensive sample than has been analyzed for any other Maya site.

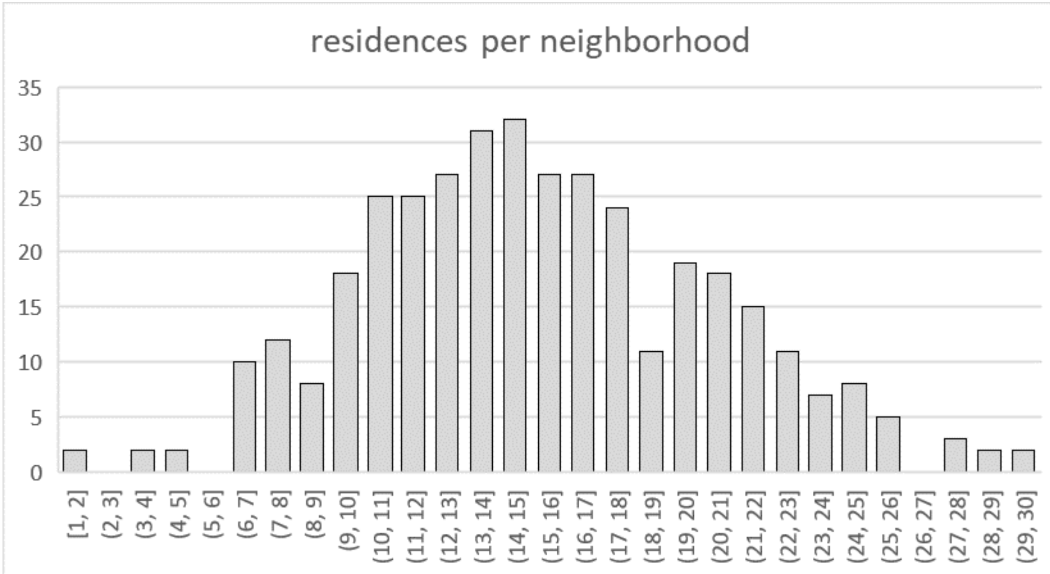


Figure 7.10: Histogram of the residences per neighborhood cluster
This histogram produces a normal looking distribution of residences with a mean population of 157 and a median of 150.

This analysis resulted in a dataset of neighborhood sizes with a distribution that appears normal and has a mean and median near 150. This falls in line with the model presented earlier in this chapter on expected neighborhood population size, and similar to the averages for other Mesoamerican neighborhoods described in the last paragraph of Section 7.2.4. Plotted differently as a stem-and-leaf-style graph in Table 7.2 provides another visualization of the alignment between Dunbar's model and these neighborhoods. This dataset fundamentally agrees with other studies highlighting the occurrence of 150 individual groupings in various communities and contexts. At the same time, the data from Caracol does not represent social organization near the upper limit of 500 in any of these neighborhoods. While the districts possess much larger populations (explored below), this data does not match the interlocking set of threes presented in Dunbar's initial formulation particularly well.

Neighborhood sample counts and average population

Range	count	2-σ ct.	1-σ ct.	mean pop.	median pop.	Dunbar's #s
[0:10)	-	-	-	-	-	5
[10:20)	1	-	-	-	-	-
[20:30)	1	-	-	-	-	-
[30:40)	-	-	-	-	-	-
[40:50)	2	-	-	-	-	-
[50:60)	2	-	-	-	-	50
[60:70)	9	9	-	-	-	-
[70:80)	13	13	-	-	-	-
[80:90)	8	8	-	-	-	-
[90:100)	18	18	-	-	-	-
[100:110)	25	25	19	-	-	-
[110:120)	25	25	25	-	-	-
[120:130)	27	27	27	-	-	-
[130:140)	31	31	31	-	-	-
[140:150)	32	32	32	-	-	-
[150:160)	27	27	27	157	150	150
[160:170)	28	28	28	-	-	-
[170:180)	24	24	24	-	-	-
[180:190)	9	9	9	-	-	-
[190:200)	20	20	20	-	-	-
[200:210)	18	18	12	-	-	-
[210:220)	15	15	-	-	-	-
[220:230)	11	11	-	-	-	-
[230:240)	7	7	-	-	-	-
[240:250)	8	8	-	-	-	-
[250:260)	5	-	-	-	-	-
[260:270)	3	-	-	-	-	-
[270:280)	2	-	-	-	-	-
[280:290)	2	-	-	-	-	-
[290:300)	-	-	-	-	-	-
≥ 300	-	-	-	-	-	500

Table 7.2: Stem-and-leaf plot of Caracol’s neighborhood sample

The k-means analysis with a k of 373 produces an average population per neighborhood equal to the Dunbar number of 150 people but below the 500-max established by Lindenfors while rejecting Dunbar’s number. Additional residential data could change these results or may continue to fit the same distribution shown above.

The 22 districts at Caracol exhibit a population mean of 4,545 and median of 4,416 through the allocation of 100,000 people within these districts proportionally to the *plazuelas* recorded within them and shown in Table 7.3. Instead of aligning with 500 or 1,500 both of these values sit very close to 5,000 the value that Dunbar (2010:32-34) ascribes to Plato as the ideal size of a "democracy" at 5,030 people. While this suggests that Plato considered this value closer to the "ideal" administrative or governing capacity of his ancient Greek polis, but it does not provide a solid foundation for modern scholars using this 5,000-population value. As such, it remains a fun curio that administrative districts at Caracol roughly aligning with 5,000 individuals in Table 7.3, especially given their function in urban governance as described in Chapter 5. However, a better understanding of any significance of this population count with urban administration will require additional testing and data from other contemporary and ancient cities and settlements worldwide. It may, however, be likely that the populations of independent villages and small cities in other Mesoamerican contexts line up with the populations seen in Caracol's districts.

District counts and average populations

Range	Count	mean pop.	median pop.	Dunbar's #s
(1,000:2,000]	-	-	-	1,500
(2,000:3,000]	3	-	-	-
(3,000:4,000]	5	-	-	-
(4,000:5,000]	7	4,545	4,416	5,000
(5,000:6,000]	4	-	-	-
(6,000:7,000]	2	-	-	-
(7,000:8,000]	-	-	-	-
(8,000:9,000]	-	-	-	-
(9,000:10,000]	-	-	-	-
(10,000:11,000]	1	-	-	-
> 11,000	-	-	-	15,000

Table 7.3: District data and Dunbar's numbers
This table highlighting the overlap in Caracol's average district population sizes and Dunbar's number of 5000 people.

7.3.5 Summary.

The results from the neighborhood and district reconstructions at Caracol, in conjunction with the digitization of residential features, suggests that both of these social and administrative units align with some of the significant numbers provided by Dunbar (1998, 2009, 2010), and fall under the revised 500 person maximum identified in reanalysis by Lindenfors, et al. (2021). Neighborhoods at Caracol possessed around 150 individuals (157 mean and 150 median) while the districts at Caracol appear to have included closer to 5,000 individuals (4,545 mean and 4,416 median). Future work to add missed residences and recalculate the population might shift these values. However, based on current data and information available these values represent the most likely results. While these observations align with the neighborhood theory presented above, they do not inherently apply to the collective action potential. Instead, the neighborhood reconstruction provides the necessary groundwork to identify neighborhood groups in the lidar dataset. This represents a necessary precondition for the analyses that follow in the next section.

7.4 Archaeological Data

While the neighborhood reconstruction described above operationalizes the model of neighborhoods presented earlier in this chapter, these features need independent verification from the archaeological record. Theoretically, the relational identity of shared neighborhood interactions (sensu Peeples 2018:25-27) and the principle of homophily underlying social connections (Feld and Grofman 2009) should generate the preconditions necessary for neighborhood-level categorical identity to form. However, without verification, these neighborhoods remain hypothetical and etic constructs instead of analytically useful units.

As mentioned briefly in the introduction, there are two known processes in the past that could have obscured these shared neighborhood patterns including the extensive nature of market accessibility (see Chapter 5) and widespread sale of materials in those markets at Caracol (AF Chase and Chase 2015; AF Chase, et al. 2015; DZ Chase and Chase 2014b; Johnson 2016). If markets had restricted sales of sampled ritual materials, then the analysis could instead pick up market district boundaries. Another potential complication of this pattern exists in excavation data at Caracol that demonstrates several aspects supporting a citywide pattern within the ritual materials sampled for neighborhoods (AF Chase and Chase 2009; AF Chase, et al. 2020b:357), which could hide local, neighborhood diversity in ritual practices. Thankfully, as the archaeological evidence below shows, neighborhoods at Caracol exhibited more intra-neighborhood similarities than inter-neighborhood similarities at a statistically significant level despite the overarching citywide similarities.

7.4.1 Sampled Neighborhoods.

While Figure 7.9 above showcases the sampled residences along with unique greyscale colors for each neighborhood, Figure 7.11 shows that same data in 373 distinct shapefiles instead, one per neighborhood. I generated these shapefiles with the exact same methodology used to identify districts (Chapter 4; ASZ Chase 2016b:24). Importantly, while the method remains identical for neighborhoods and districts – with the exception of using plazuelas instead of monumental nodes – these two sets of shapefiles do not perfectly align. Given the nature of the algorithm and its treatment of the landscape, this makes sense. Both reconstructed features focus on least cost area analysis so that any location within a district or neighborhood provides a visual dataset of which specific district or neighborhood remains closer to that location than any other (Figure 7.11). This algorithm also does not consider other factors in the reconstruction, including differing feature boundaries, causeway routes that would facilitate movement, or agricultural terraces that would hinder movement. While these shapefiles represent hard boundaries, the actual spatial extents in the past would likely have included a bit more fuzziness toward the edges.

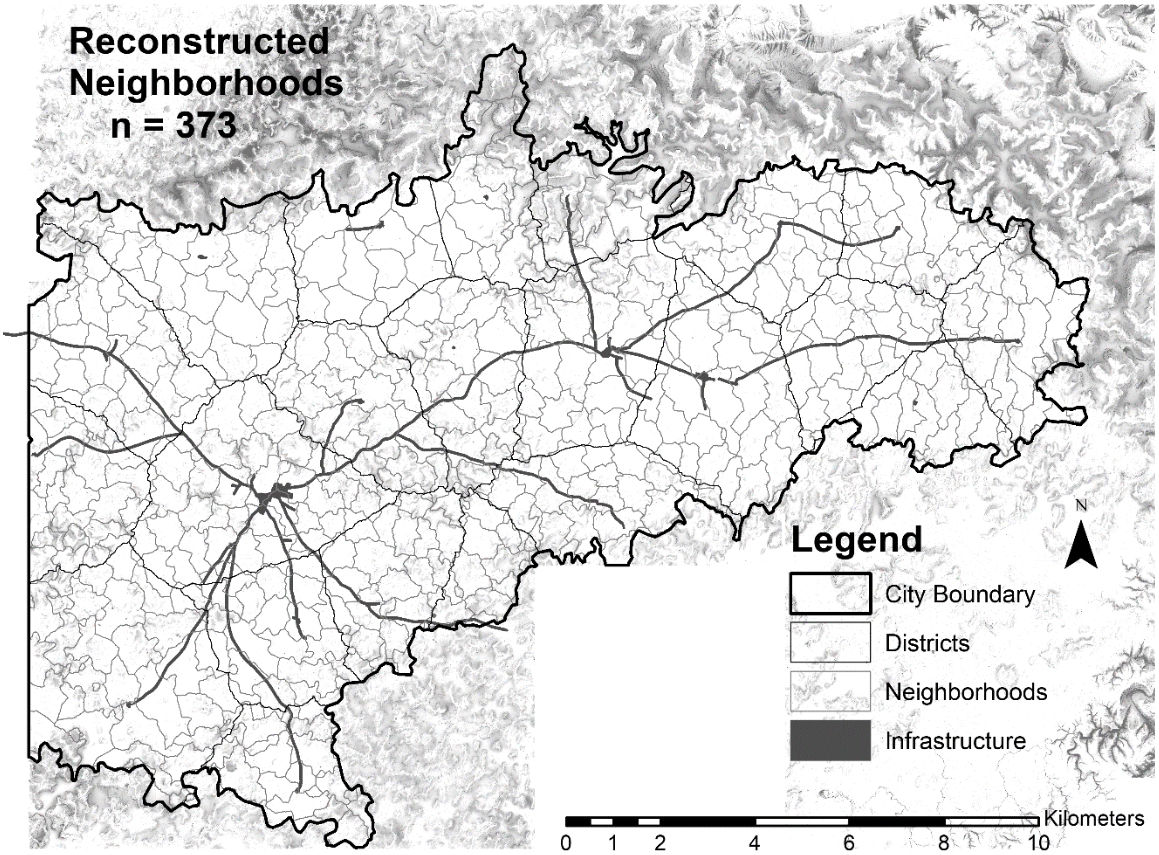


Figure 7.11: Reconstructed neighborhoods shown as shapefiles

With this new shapefile version of the neighborhood dataset, Figure 7.12 overlaps the excavations that have occurred at Caracol by the Caracol Archaeological Project (see https://caracol.org/drs-chase/publications/) as well as the Tourism Development Project (AF Chase, et al. 2020c:447; Hoggarth, et al. 2020:706), J. Eric S. Thompson (JES Thompson 1931), and Linton Satterthwaite (Beetz and Satterthwaite 1981) on top of the reconstructed neighborhoods and districts; however, only excavation data from the Caracol Archaeological Project is used in this analysis. The algorithmic nature of reconstructed neighborhoods resulted in some interesting differences among those neighborhoods; the results do not necessarily line up with expectations based solely upon survey, visual inspection of the DEM, and topographic preconceptions. For example, excavations by the Caracol Archaeological Project from 2012, through 2014 (AF Chase and Chase 2012b, 2013a, 2014a) focused on plazuela groups to the southeast of downtown Caracol as a single neighborhood (defined in terms of the topographic appearance of the plazuelas on top of a higher area of group called the Machete Plateau). Instead, the algorithmic reconstruction generated a division between those plazuelas along the causeway running to the south (note, the algorithm did not use the causeways or other shapefiles as input) and those plazuelas further east as two separate neighborhoods respectively, and informally now referred to as Machete and Dos Aguadas for the largest residences in each algorithmic neighborhood.

The reconstructed neighborhoods in Puchituk roughly fall around the three largest hills near the Puchituk monumental node. The three residences excavated through NSF SBE DDIG funding (Grant No. 1822230; AF Chase, et al. 2019) for this dissertation fall into two neighborhoods instead of one. Analytically, this reflects the landscape as a whole, but it was not intuitive when moving through the modern jungle to find these *plazuelas*. However, the longevity of the Caracol Archaeological Project and its standardized sampling strategy over decades of research still provided an ample archaeological sample to address the three hills of Puchituk and their respective neighborhoods.

As for Monterey, the reconstruction allocates *plazuelas* on both of its hillsides into a single neighborhood. Of all the samples used below, Monterey, due to its distance from camp and the logistics of modern movement through this rugged landscape provides the fewest excavated residences in any of the sampled neighborhoods. Even this sample still provides a high degree of cohesiveness and neighborhood identity, but with additional funding and time additional structures would have been sampled (although it may not have changed the overall excavation results reported in this analysis).

Regardless, taken together these eight potential neighborhoods from three districts provide a robust sample and go beyond the expected four neighborhood sample proposed for analysis in the initial NSF research proposal (designed to be a combination of the 2019 excavations and other Caracol Archaeological Project data). This speaks to both the importance of maintaining a clear and comparable sampling strategy over the lifetime of an archaeological project, and the importance of working with legacy datasets. While this section alone describes excavation data, this dissertation required both the lidar and the excavations that were undertaken in the other residential groups to provide fruitful conclusions about ancient Maya urbanism at Caracol.

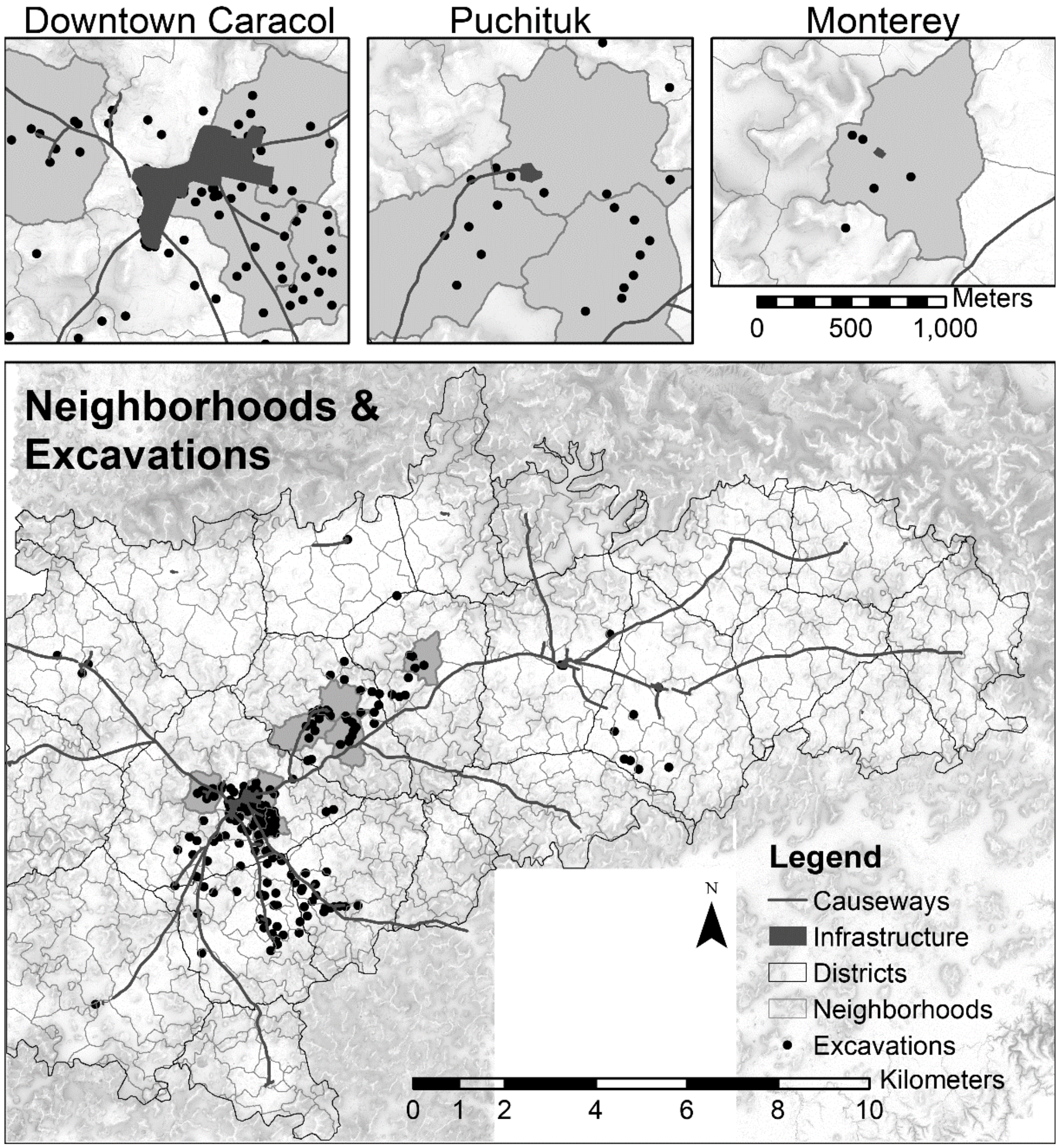
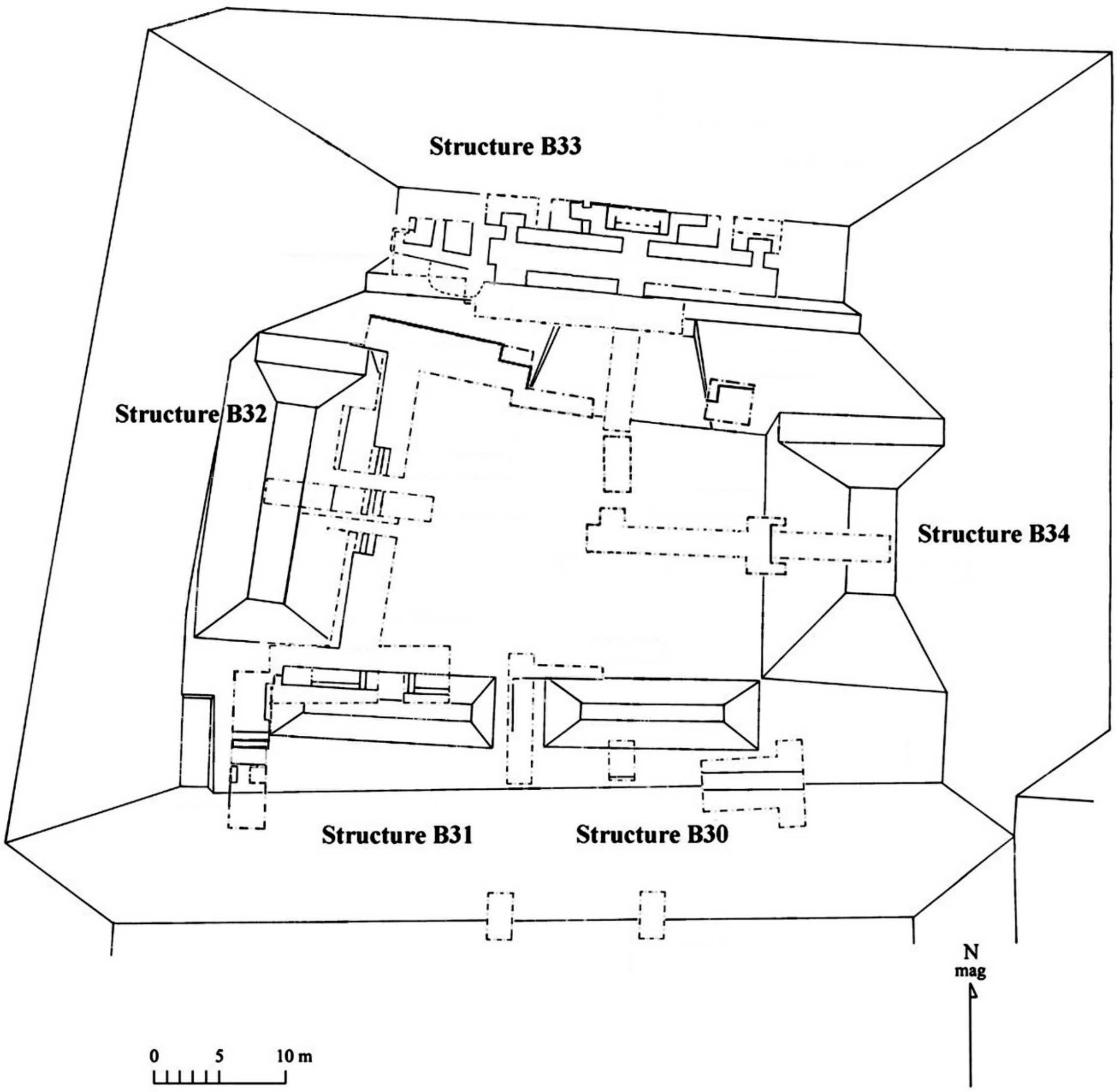


Figure 7.12: Excavations at Caracol shown with sampled neighborhoods.

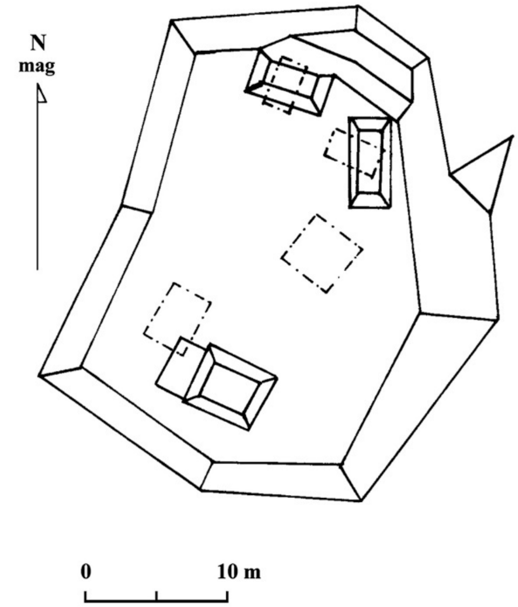
7.4.2 Special Deposits.

In order to assess social interaction through categorical identity to get at collective action potential in the past and test the reconstructed neighborhoods, I assessed archaeologically recovered ritual offerings related to shared practices within the residences. Among the sampled neighborhoods described above, each *plazuela* provides a singular, unique data point. Excavations of these structures over almost four decades of research by the Caracol Archaeological Project have shown that the eastern structures within the *plazuela* groups and acropoleis are most often ritual constructions that include burials and caches. Nearly all residential groups investigated by the Caracol Archaeological Project included excavations in association with these eastern structures; these samples range from test excavations in front of eastern buildings to two-meter-wide trenches through these structures (see Figure 7.13). The vast majority of these contexts contained caches and burials, and the contents of these caches and burials form the subject of the next set of analyses. While the investigation of Caracol *plazuelas* may include the investigation of other residential structures or their residential plaza centroids, I have excluded those datasets from the analyses below. However, I did include plaza excavations in front of eastern structures and chultun contexts associated with such buildings. Most two-meter-wide trenches include excavations of the plaza in front of the structure and quite a few cache deposits come from those contexts. By focusing on similar excavation and reporting methods from decades of research, it allowed me to create a sample of 60 distinct *plazuela* groups among 8 reconstructed neighborhoods within Caracol that contained 268 “special deposits” contexts (out of a total of 347 deposits in these eastern buildings including earlier contexts).

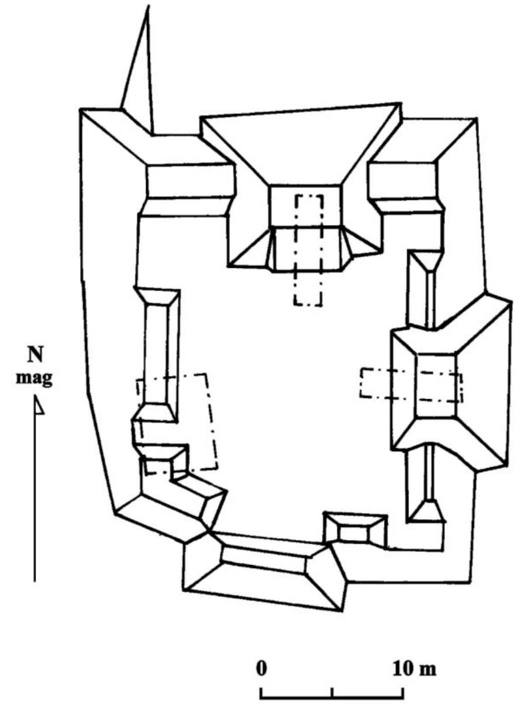
CARACOL Northeast Acropolis



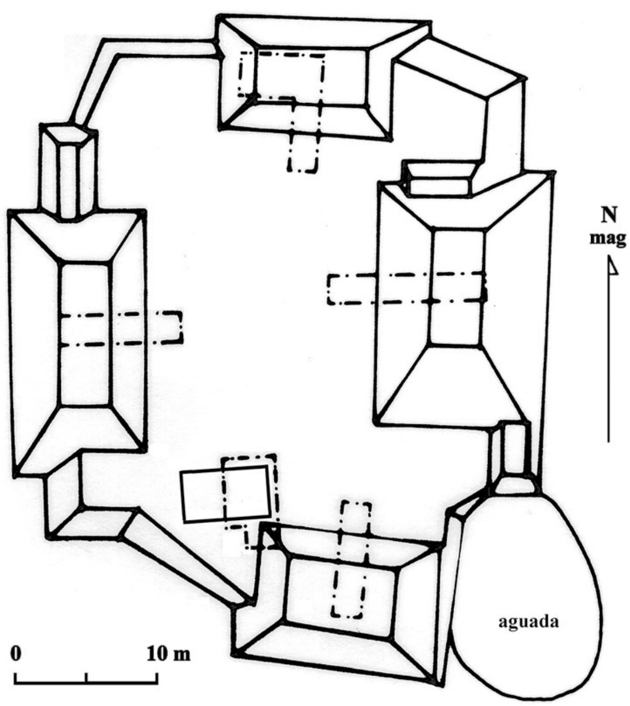
Tango



Zumba



Dos Aguadas



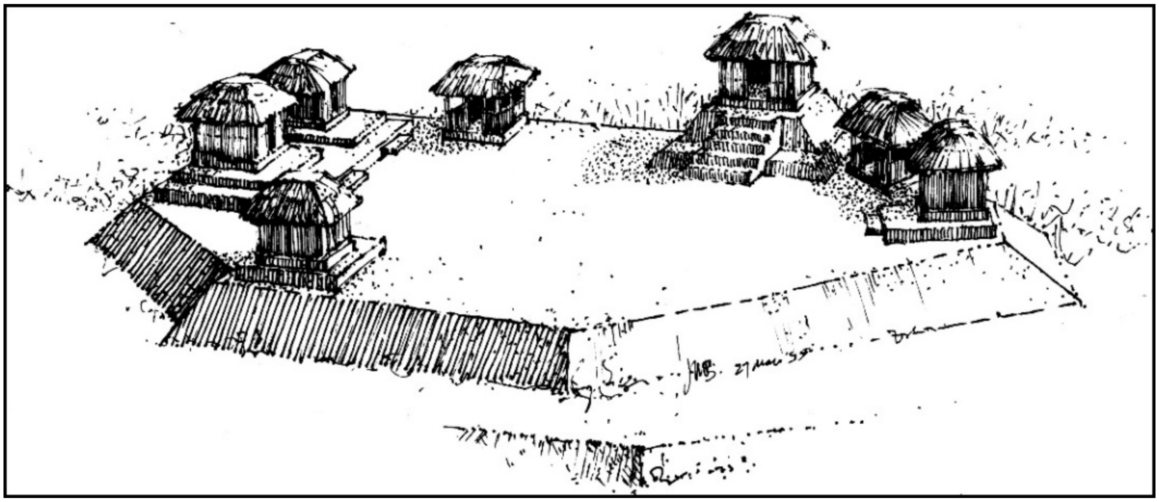


Figure 7.13: Residential excavations and artistic reconstruction
Illustrations of excavations at the Northeast acropolis, three *plazuela* groups showing size variation within the same neighborhood (Tango, Zumba, and Dos Aguadas), and an artistic reconstruction of a *plazuela* group by Joe Ballay. In each residential excavation, the two-meter-wide trench through the eastern structure can be seen, (Illustrations are reproduced with permission from AF Chase and Chase 2014a:Figures 1 and 2).

Within each of these excavations, I focused only on the "special deposits" – caches and burials – and not on general fill or other contexts. Unlike the general fill material, special deposits represent intentional curation of material in the past associated with either burials or caching. The ancient residents of Caracol often returned to these deposits and added, moved, or even removed material over generations (DZ Chase and Chase 1996b). The ancient Maya intentionally returned to these contexts in a cyclical manner, demonstrating that residents remembered these deposits across generational timespans (see also Ashmore 2015; DZ Chase and Chase 2011b), and the overall similar contexts and material within these contexts provides information pertinent to any shared categorical identity resulting from shared ritual practices among neighborhoods. These formalized, ritual deposits incorporated the intentional choice of materials and an aspect of more public visibility before their deposition (both final and transitory).

Within each of these 60 plazuelas, I reviewed the excavation provenience or lot cards, archaeological illustrations, and season reports (see www.caracol.org's "season reports" tab for accessible summaries of these contexts and materials) for the relevant lots associated with the special deposits of each. This meant reviewing archaeological data from 268 specific special deposits (designated as such in both the field and the laboratory during their respective field seasons). Within these several hundred lots, I focused specifically on broad categories of materials and markers that would likely relate to identity instead of wealth. This included dental modification or inlays (without specifying the type of modification or inlay materials, see Figure 7.14) and fourteen distinctive but broadly defined ceramic forms (see Figure 7.15 and the columns in Table 7.4).

Figure 7.14: Examples of teeth with dental modification.
Jadeite inlays are shown (top) and two styles of filing are shown (bottom).

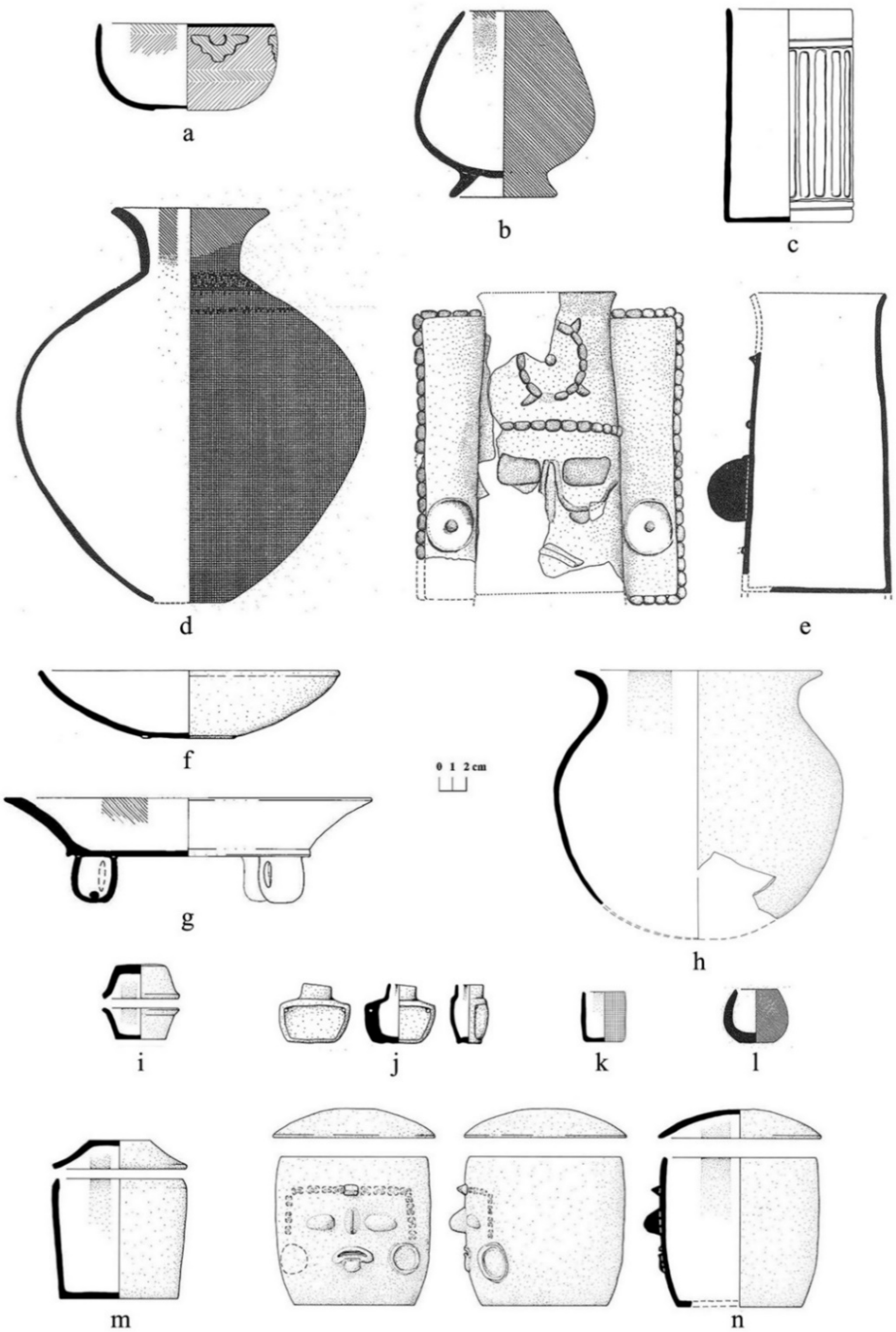


Figure 7.15: The generalized vessel forms used in this analysis
(a) bowl, (b), cup, (c), cylinder, (d) jar, (e) incensario, (f) dish, (g), tripod plate, (h) olla, (i) lip-to-lip cache, (j) medicine bottle, (k) paint pot, (l) miniature vessel, (m) barrel/urn, and (n) face cache.

Dental modification has a spatially restricted distribution among these neighborhoods, only occurring in five of the eight neighborhoods. Also, differences in ceramic forms had been informally noted in the 2018 and 2019 field seasons (AF Chase and Chase 2018; AF Chase, et al. 2019). As such, these informal patterns formed an essential part of the preliminary exploratory data analysis to identify likely material related more to categorical identity within neighborhoods than to wealth or status among individual residences. At Caracol, both higher and lower status households exist side-by-side (Chapter 6; AF Chase, et al. 2020b:354). As such, these values were then aggregated (i.e., counts were summed) by *plazuela* as shown in Table 7.4. There are, as noted above, 268 special deposits represented in 16 columns and 60 rows as 960 individual data cells.

Part 1 of 2

Plazuela nickname	Op.	Neighborhood nickname	#LC SDs	cylinders	bowls	cups	jars	incensarios	dishes	ollas	tripod plates
Rag	C006	Machete	4								
Castle	C015	Rebel	1	1							1
Machete	C019	Machete	7	2	2				3		
Tabanos	C022	Machete	3	2					3	1	1
Estrellas	C029	Machete	2	1	1				1		1
Ultimo	C049	Machete	14	3	8		2		13		1
Pech	C051	Dos Aguadas	4	2	3			1		2	
Frog (&C7)	C079	Alta Vista	4		8			1	1		1
Alta	C101	Ace	2	1	1	2					1
Sage	C106	Sage	2								
Midget	C107	Sage	5		2				1		
Tenedor	C111	Sage	1								
Centro	C116	Rebel	4		4			1			
Monterey	C118	Boulder	6		1			2	1		
Ramon	C121	Alta Vista	3	1					3	1	3
London	C123	Chak	1	1					1		
Madrid	C124	Chak	1								
Berlin	C125	Chak	7								
Rome	C127	Chak	0								
Incensario	C145	Alta Vista	1					1			
Mono	C158	Machete	6		3		1		2		
B42 Group	C171	Rebel	9	2	8	1			5		
Gateway	C174	Rebel	0								
Baja Vista	C184	Alta Vista	7	5	4			2	3	1	3

Part 1 of 2

Plazuela nickname	Op.	Neighborhood nickname	#LC SDs	cylinders	bowls	cups	jars	incensarios	dishes	ollas	tripod plates
Alta Vista	C185	Alta Vista	13		4		1	3	3	3	
Chalpat	C186	Alta Vista	4		3				2		
Dos Aguadas	C188	Dos Aguadas	8	8	6	2	1		6		3
Zumba	C189	Dos Aguadas	14	11	15				12		3
Terraza	C190	Dos Aguadas	4	8	8	1	1	2	8		2
Tango	C191	Dos Aguadas	1		1				2		
Salsa	C192	Dos Aguadas	0								
Bimbo	C193	Machete	3	8	18		1		18		1
Dulce	C194	Dos Aguadas	10		14			1	9	2	3
Pan	C195	Dos Aguadas	8		1						
Galletas	C196	Dos Aguadas	1		2					1	
Tortilla	C197	Machete	0								
Migas	C198	Dos Aguadas	5	1					1		1
Alegre	C199	Dos Aguadas	3	1	1	1					1
Dormir	C200	Dos Aguadas	1								
Sonrisa	C201	Dos Aguadas	6	4	4	1	1		4		2
Renegon	C203	Machete	16	8	17		1	1	12		2
Vergonsoso	C204	Machete	4	1	3			1	3		1
Cheech	C209	Sage	1		1				2		
Rebel	C210	Rebel	13	5	9		1	2	5		2
Rogue	C211	Rebel	6	1	2				1		
Risk	C212	Rebel	0								

Part 1 of 2

Plazuela nickname	Op.	Neighborhood nickname	#LC SDs	cylinders	bowls	cups	jars	incensarios	dishes	ollas	tripod plates
Chon	C213	Chak	3	1							1
Chak	C214	Chak	6		2			1	3	4	
Barracuda	C216	Sage	7	2	3				3	1	1
Tuna	C217	Ace	12	1	9				9	1	
Snapper	C218	Ace	0								
Pebble	C219	Boulder	1								
Public Arch.	C220	Boulder	1								
Boulder	C221	Boulder	0								
King	C224	Ace	7	1	2				1	1	
Queen	C225	Ace	3		4				4		
Jack	C226	Ace	6	1	1	1			1	1	
Joker	C227	Ace	5		5			1		2	
Ace	C228	Ace	1		1				2		
Canela	C009	Alta Vista	1		1						

Part 2 of 2

Plazuela nickname	Op.	Neighborhood nickname	#LC SDs	dental inlays	dental filing	paint pots	medicine bottles	mini. vessels	barrel / urn	face cache	lip-to-lip cache
Rag	C006	Machete	4		1			1			
Castle	C015	Rebel	1								
Machete	C019	Machete	7	4	3						3
Tabanos	C022	Machete	3	1	2					1	
Estrellas	C029	Machete	2			1					
Ultimo	C049	Machete	14	4	6				1		16
Pech	C051	Dos Aguadas	4								1
Frog (&C7)	C079	Alta Vista	4	1	2						
Alta	C101	Ace	2				1			1	
Sage	C106	Sage	2								2
Midget	C107	Sage	5						1		1
Tenedor	C111	Sage	1								
Centro	C116	Rebel	4							5	27
Monterey	C118	Boulder	6	1	1				2		8
Ramon	C121	Alta Vista	3	2	4						4
London	C123	Chak	1								
Madrid	C124	Chak	1								
Berlin	C125	Chak	7							5	3
Rome	C127	Chak	0								
Incensario	C145	Alta Vista	1								
Mono	C158	Machete	6								2
B42 Group	C171	Rebel	9	1	2				7	1	2
Gateway	C174	Rebel	0								
Baja Vista	C184	Alta Vista	7	2			1		1	7	5

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Plazuela nickname	Op.	Neighborhood nickname	#LC SDs	dental inlays	dental filing	paint pots	medicine bottles	mini. vessels	barrel / urn	face cache	lip-to-lip cache
Alta Vista	C185	Alta Vista	13	1					2	4	6
Chalpat	C186	Alta Vista	4	2			1		1		3
Dos Aguadas	C188	Dos Aguadas	8	3	5			1	1	2	5
Zumba	C189	Dos Aguadas	14	3	3			2	12	7	15
Terraza	C190	Dos Aguadas	4	3	2		1			1	1
Tango	C191	Dos Aguadas	1								
Salsa	C192	Dos Aguadas	0								
Bimbo	C193	Machete	3	3	1			2			
Dulce	C194	Dos Aguadas	10	1					1	3	6
Pan	C195	Dos Aguadas	8							3	3
Galletas	C196	Dos Aguadas	1								
Tortilla	C197	Machete	0								
Migas	C198	Dos Aguadas	5							2	2
Alegre	C199	Dos Aguadas	3	1	1			1			3
Dormir	C200	Dos Aguadas	1							1	
Sonrisa	C201	Dos Aguadas	6	1	2					2	6
Renegon	C203	Machete	16	6				2	2	5	92
Vergonsoso	C204	Machete	4							4	5
Cheech	C209	Sage	1								
Rebel	C210	Rebel	13	3		5			2	3	10
Rogue	C211	Rebel	6	2	4						
Risk	C212	Rebel	0								

Part 2 of 2

Plazuela nickname	Op.	Neighborhood nickname	#LC SDs	dental inlays	dental filing	paint pots	medicine bottles	mini. vessels	barrel / urn	face cache	lip-to-lip cache
Chon	C213	Chak	3							1	
Chak	C214	Chak	6				1			1	
Barracuda	C216	Sage	7						1	3	5
Tuna	C217	Ace	12	4	2					5	4
Snapper	C218	Ace	0								
Pebble	C219	Boulder	1								
Public Arch.	C220	Boulder	1						1		1
Boulder	C221	Boulder	0								
King	C224	Ace	7				1			4	
Queen	C225	Ace	3		1						
Jack	C226	Ace	6				2		1	3	1
Joker	C227	Ace	5		2						2
Ace	C228	Ace	1								
Canela	C009	Alta Vista	1		1		1				

Table 7.4: Aggregated summary of 60 *plazuela* group data
Includes dental inlays, dental filing, and fourteen distinctive but broadly defined ceramic forms. This data only represents the specified materials from these special deposits (caches and burials) focusing on eastern mortuary buildings. Smaller artifacts often indicative of wealth or socio-economic status are not included. Excavation data generally comes from two-meter-wide trenches of eastern structures, often excavated to bedrock.

7.4.3 Similarity and Dissimilarity.

The relatively "sparse" (in the computer science sense of including many empty cells) nature of this dataset has an impact on the statistical analyses selected. While many archaeological datasets may look similar, biologists and ecologists studying the population dynamics of rare species encountered and solved this issue nearly sixty years ago (Horn 1966; Morisita 1959; Wolda 1981). The issue at hand, in those situations, revolved around measuring environmental similarity and dissimilarity when looking at species population dynamics and diversity. While artifacts differ from animal species, the idea of rare and common forms and a desire to understand the similarity or dissimilarity of groupings of identifiable entities remains the same in both fields. In fact, Watts and Ossa (2016:638-639) have already successfully used this style of analysis within archaeology to investigate potential market distributions through residential ceramics.

Given the nature of the data in Table 7.4, the Morisita-Horn index provides a means to deal with both the sparseness of the data and the secondary issue of a few overrepresented types (i.e., the 92 lip-to-lip caches from operation C203 while most other data fields have only single digit numbers). In addition, the Morisita index (Morisita 1959) and its modification the Morisita-Horn index (Horn 1966) provide robust indices within this problem space (Wolda 1981:302). In a similarity index, values near one represent nearly identical samples while values near zero represent a complete lack of overlap. Reversing this, a dissimilarity index provides the opposite relationship where 1 represents a complete lack of overlap and 0 represents two nearly identical samples. As such, the dissimilarity between neighborhoods should be higher than the one within neighborhoods, which R's vegdist method demonstrates with an intra-neighborhood dissimilarity of 0.5638 and an inter-neighborhood dissimilarity of 0.6003. While these two values might appear similar at first glance, this pattern represents a statistically significant difference.

In terms of testing the significance of these values, a few preconditions need to be addressed. First, the data in Table 7.4 do not possess normal distributions, which many statistical tests implicitly assume. Second, this requires a one-sided statistical test because this distribution only exhibits one tail. Put another way, this statistical test only needs to show if *plazuelas* show more dissimilarity between neighborhoods than within neighborhoods. As such, I use the non-parametric wilcox test to evaluate differences in terms of rank order (using R's wilcox.test method; see also Bauer 1972; Shennan 1997:87). Running the wilcox test on the two neighborhood values above yields a very low p-value of 0.03785. In other words, this represents a strong finding because we would not expect much difference between inter- and intra-neighborhood comparisons if both sets of data came from the same distribution (i.e., if all neighborhoods shared the same materials). It indicates that *plazuelas* have more similar special deposit materials with other *plazuelas* in their own neighborhoods than with *plazuelas* in other households located in other neighborhoods.

7.4.4 Statistically Significant Neighborhoods.

The archaeological data and results above would be unlikely if the artifact category distributions were the same between and within different neighborhoods. Future research will expand this analysis to use the reconstructed neighborhoods to investigate specific similarities and differences in materials, include items not analyzed in this subset of sampled eastern ritual deposits, and enlarge the dataset to include additional residences. These neighborhoods exist in three separate market districts, yet market forces do not appear to have impacted the availability of purchasable items for burials, tombs, and caches in these neighborhoods given the intra-neighborhood diversity. A better understanding of market distributions within them would focus on additional ritual, floor, and fill contexts and include a greater variety of materials and artifact classes including ear-flares, labrets, marine shells, other ceramic materials, and groundstone. However, the general similarities among the indices for this subset of ritual material indicates the similarity among available goods regardless of market, a worthwhile finding of its own.

While many similarities in practices exist at the citywide level through their eastern shrine focus on caching and burial practices, neighborhoods display a level of local uniqueness in their special deposits. For example, Boulder, Chak, and Sage all lack any dental modifications. Additionally, neighborhood-level variations in the vessel parings with cylinders provides another area for future investigation. In both cases, these and other small differences in the materials selected for deposit appear to represent intentional categorical identity. In particular, variations in dental modification would have been readily apparent in any social interactions among residents of different neighborhood groups.

Not only does the archaeological data support these reconstructed neighborhoods as useful spatial and analytical units, but this identification of significant within-neighborhood similarity also bolsters the argument for higher collective action potential among neighbors outlined in the introduction. While the extent of citywide similarities in categorical identity exhibited at Caracol already would have lowered the threshold for more collective action among residents in the past, the neighborhoods had their own unique categorical identities in ritual practices that further reduced any inherent friction to potential collective action. Both of these sets of similar practices acted to facilitate collective action among neighbors in the past, and they have strong implications for the foundational social structures that enabled and bolstered both the more collective nature of urban services (Chapter 5) and higher degree of household architectural autonomy (Chapter 6) exhibited at Caracol.

7.5 Collective Action Potential at Caracol

This chapter provides a model for ancient neighborhoods, a method for reconstructing archaeological neighborhoods, and tested the cohesion of a sample of those neighborhoods against the archaeological record using both excavations and legacy datasets. The material data analysis provides some statistically significant support for the algorithmically reconstructed neighborhoods. This, in turn, provides insight that Caracol possessed relatively high collective action potential with a union of relational and categorical identity at these reconstructed neighborhoods through similarities in household level eastern ritual shrine deposits. While previous research had identified a citywide categorical identity around these residential eastern shrines (AF Chase and Chase 2009; AF Chase, et al. 2020b:357), this analysis shows that neighborhoods exhibited even stronger similarities among their burial and caching behaviors. In other words, the citywide pattern does not subsume the more local neighborhood patterns, and, again, these similarities in ritual practices provided shared local practices between neighbors and would have lowered the threshold for collective action at the neighborhood level.

While some scholars expect the existence of neighborhoods within urban contexts as a given, I lay out a model of neighborhoods based on multiple bodies of theory based on the social interactions among residents. First, spatial autocorrelation, whereby closer things are more related, suggests that neighborhoods should consist of spatially co-located households where closer *plazuelas* due to their proximity interacted more often and became more similar over time. Second, triadic closure, whereby social networks prefer triangular sets of reciprocal strong relationships, suggest that neighborhood boundaries should form along weak ties between adjacent neighborhoods while intra-neighborhood bonds should represent primarily strong ties among triads of more similar neighbors. And third, cognitive limits, whereby limits on the number of social interactions human beings exhibit have emerged in multiple disciplines, suggests that neighborhoods built around repeated, face-to-face interaction should consist of under 500 people (based on reanalysis of Dunbar's original data by Lindenfors, et al. 2021). Taken together, these three separate disciplinary ideas provide a foundation for why neighborhoods should exist built on the spatial and social connotations of individuals within those neighborhoods.

In contrast to the size of neighborhoods, the reconstruction of neighborhood boundaries focused on GIS analysis and the clustering of residences using their walking distance (as time) from locations of energized crowding (e.g., the formal plazas of district nodes). However, the twenty-two district nodes contained within the Caracol lidar (AF Chase, et al. 2014b; AF Chase, et al. 2011a) created a 22-dimensional clustering problem that was based on the sample of *plazuelas* manually digitized within the Belizean lidar (with additional residences and districts in modern Guatemala excluded from this analysis). Using a combination of f' analysis of multiple k-means runs, the k value of 373 provided the only kink in this dataset that could represent neighborhoods based on the model of social interaction built to identify frequent, repeated face-to-face interaction. The stochasticity of the k-means clustering algorithm means that this process can be replicated, but that it may produce slightly different results. As such, future research will investigate other clustering algorithms to identify a better long-term algorithm that works well with large datasets of over 128,744 unique values.

A sample of eight neighborhoods in three different districts allowed for archaeological testing of the algorithmically reconstructed neighborhoods. The results demonstrate statistically significant similarities within neighborhoods in contrast to those between neighborhoods. This material data focused on special deposits (caches and burials) using similar excavation methodologies over four decades. This sample of 60 *plazuela* groups also included both excavation for this dissertation and legacy data use. Importantly, these results whereby neighborhoods in the same market district exhibit diversity from each other suggest that marketplace access alone did not determine the distribution of these ritual materials. However, this will require future testing with data selected to test for market distribution. While additional research with other material from additional contexts will be necessary to tease out the patterns among Caracol's markets and their material distributions among residences, these preliminary results suggest that residents selected (or produced) different sets of goods to some degree based on the identified ritual trends in their own neighborhoods. Fundamentally, these results show that neither the effects of market distributions nor widespread citywide practices among residents prevented the identification of unique, local neighborhood similarities in ritual practices built around eastern household shrines. The union of relational and categorical identity shown through these similarities would also have resulted in a higher collective action potential among neighbors.

Taken together, this data shows not only the presence of neighborhoods at ancient Caracol, but also highlights similar material practices indicating a higher collective action potential at the neighborhood level. While no specific architectural or built environmental feature appears to be indicative of neighborhoods, archaeological excavation evinced shared practices around ritualized special deposits. Caracol's neighborhoods – at least with the current sample of plazuelas – show a mean population of 157 and a median population of 150 people at ten residents per plazuela (ignoring size differences of plazuelas and number of structures) suggesting that these values, based around frequent, repeated face-to-face interactions may prove useful in other neighborhood studies. Future research will investigate specific material indicators of neighborhoods to see if ritual categorical identity is mirrored in other material deposition patterns, test market distributions of additional domestic artifactual remains, and expand the sample of materials recorded from intentionally deposited contexts with material from fill or other contexts.

This analysis represents a first pass neighborhood study to create and test neighborhood boundaries at Caracol. It successfully reconstructed neighborhoods that held up to testing with archaeological material selected to match likely categorical identity based on a citywide shared eastern shrine ritual practices. Those contexts provided a likely candidate for a shared relational identity that transitioned to a shared categorical identity over time. As such, this demonstrates that the etic GIS analysis can not only identify but also test the cohesiveness of neighborhoods. With the material evidence behind it, this neighborhood reconstruction now provides a unit for future analysis at Caracol but does not transition them into a fully emic category. In either case, these factors demonstrate that the strong relational identity inherent to interacting neighbors exists coequally with a strong categorical identity of shared neighborhood practices. Both types of identity may have facilitated collective action among neighbors in the past.

8 URBAN LIFE AT CARACOL

The previous chapters use multiple methods to operationalize archaeological lidar and excavation data to investigate governance within the ancient Maya city of Caracol in modern Belize. Taken together, these analyses provide varied perspectives on the shape and form of this city during its apogee in CE 650, while helping provide a deeper understanding of its civic administration at four urban levels. Independently, any one of these results may have provided an inaccurate conclusion, but, when conjoined, these analyses interdigitate into a more accurate and comprehensive perspective on the city as a whole.

This dissertation combines traditional archaeological research with lidar data in a novel way to investigate infrastructure, independent residences, and neighborhoods. These results shed new light on governance at Caracol by highlighting a higher degree of collective behavior in contrast to the autocratic expectations based on the hieroglyphic record and the complex nature of shared practices by the city's inhabitants.

8.1 Using Lidar Data

This research could not exist in its current form without the advent and use of lidar data within archaeology. This technology provides fundamentally new avenues and types of research in heavily forested environments and has had the impact of a paradigm shift in Maya archaeology (see AF Chase, et al. 2012; AF Chase, et al. 2016; McCoy 2021). However, this geospatial revolution has been uneven. Denuded landscapes already saw aspects of these changes in research techniques with aerial photography, photogrammetry, satellite imagery, and GIS technology (e.g., Bewley 2003; Ur 2003; TJ

Wilkinson 2003); yet, only lidar has allowed for the detailed analysis of built environments beneath heavy forest canopies. At the same time, lidar permits analyses at an unprecedented scale eclipsing decades of ground survey, but that initial work provided the foundation for the interpretation of this virtual landscape.

In this dissertation, lidar aided in the creation of new datasets that went beyond just feature identification. The reconstruction of intra-urban districts and neighborhoods required lidar data. Similarly, analyses of standardization, inequality, accessibility, and scaling permitted new uses of lidar data. Each of these analyses is replicable in other urban contexts. However, perhaps most importantly, this lidar analysis occurred at a very large scale covering over 200 square kilometers – an order of magnitude larger than most other archaeological investigations of urban systems.

Yet, lidar survey does not remove the need for additional archaeological data. The palimpsest nature of these landscapes were largely avoided on the Vaca Plateau but cause issues elsewhere through low-lying vegetation and modern land use (Cap, et al. 2018; Prufer, et al. 2015) and the difficulties that exist in dating features without excavation provide an imperative for more traditional archaeological research and excavation. (See Klassen, et al. 2018 for one example of how these difficulties may be overcome). In addition, lidar datasets require more general computational knowledge to use well; this will continue to lead to structural changes in archaeological practice, especially as the field proceeds with its shift toward computational archaeology (Grosman 2016; Huggett 2020; White 2016). Finally, lidar data provide a different set of ethical issues for archaeologists to face when appeasing and interacting with multiple stakeholders – including local communities, regional governments, and colleagues (ASZ Chase, et al.

2020a; Cohen, et al. 2020) – that do not differ too much from earlier ethical issues involving remote sensing.

8.2 Urban Level and Governance

The framework of urban levels (*plazuela*/residential, neighborhood, district, and city) provided a means for investigating ancient infrastructure and governance in a new way. The approach lends itself well to identifying governance processes (top-down to bottom-up) that range in form from collective to autocratic. Investigations of the smaller-scale, more zoomed-out levels (e.g., citywide and district) tend to elucidate top-down processes, while considerations of the smaller-scale, more zoomed-in levels (e.g., neighborhood and *plazuela*/residential) tend to provide information on bottom-up processes. Importantly, top-down and bottom-up processes can be relative; a bottom-up process at the district level will still be seen as top-down at the residential level. As a whole, this framework permitted a more detailed understanding of ancient urban governance. These levels must not be considered hierarchically. They simply represent different spatial scales that focus on separate units of urban aggregation; they are more akin to the focal lenses of a microscope that permit different levels of magnification for studying an object with a more zoomed-in or zoomed-out perspective, as necessary.

These urban levels still leave two unspoken, but influential, levels of analysis beyond of the analytical scope of the settlement – and this dissertation. Above the city level exists the polity, the political stratum that incorporates multiple settlements into a single cohesive organizational system, but that does not necessarily line up with a single unit of settlement (i.e., the political capital of a polity is not always the economic capital and not all polities were single city-states). In addition, beneath the residential level sits the level of individuals and their actions in the past. Archaeology often has difficulty reconstructing and identifying the role of individuals as opposed to the accumulation of individual actions over generations; however, it is the people and their actions that provide the impetus for all the urban levels of settlement in which those people once lived.

8.3 Physical Infrastructural Power at the District and City Levels

It is at the district and city levels at Caracol that the role of its urban services are most evident. The district nodes exhibited physical infrastructural power with tiered sets of urban services and widespread distribution of these services across the landscape. However, specific services like the causeway system and the plaza scaling analyses demonstrate centralization of some services at the city level into the downtown of Caracol. The findings of the primary analyses from Chapter 5 follow below.

8.3.1 Tiered Urban Services.

The urban service facility features of formal plazas, ballcourts, and E Groups at Caracol occur in a Gutmann-like scale among district nodes, whereby all E Groups co-occur with ballcourts, all ballcourts co-occur with formal plazas, and the reverse of the prior two statements remain false (ASZ Chase 2016b). The formal reservoirs do not easily fit into this relationship likely due to their earlier construction. Only the initial three districts that conurbated to form the city of Caracol contain monumental reservoirs; the other districts only contain large reservoirs, if any. In general, the greater accessibility and widespread distribution of some urban service features suggests that some services (i.e., those associated with formal plazas) remained more pertinent to daily life in ancient Caracol than others (i.e., those associated with E Groups).

At the same time, these urban service facility features co-occur in nodes of monumental architecture that are often interconnected by the dendritic causeway system (AF Chase and Chase 2001). The causeway system centers on downtown Caracol. In conjunction, more centrally located (and older) districts tend to have not only additional but larger features. This highlights the unique primacy of downtown Caracol as the city center beyond its association with rulership on Caana (see also AF Chase and Chase 2017a).

This nature of Downtown Caracol as the center of the city and of a larger polity, which incorporated multiple settlements, shows up repeatedly in these analyses. Downtown Caracol has an abnormally large formal plaza and a much higher population, both of which appear as outliers contrasted with other district nodes. While analysis of Caracol the polity sits beyond the scope of this dissertation, this data supports the notion of Caracol serving the administrative needs of a larger territorial system incorporating multiple settlements previously identified in the epigraphic and archaeological records (AF Chase and Chase 1998a, 2020b; AF Chase, et al. 2009). In terms of the city of Caracol, this analysis demonstrates both widespread services and the centralization of some services into specific nodes.

8.3.2 Distributed Accessibility.

The 22 district nodes for Caracol in Belize not only show widespread distribution of services, but their distribution throughout the city's landscape also meant that residents could easily reach them on foot. Within this landscape walking to a formal plaza required an average of 25-minutes of travel time, a ballcourt required an average of 30-minutes of travel time, and an E Group required an average of 45-minutes of travel time. Each of these would have been quite reasonable distances to traverse for the inhabitants of this city, especially since the trade-off meant having agricultural fields adjacent to their households (in contrast to outfield cities where the bulk of agriculture was carried out beyond the urban boundaries).

The ancient Maya "urban planners" built these monumental nodes across the city in order to facilitate movement, while at the same time preserving the garden and agricultural aspects of their city (Barthel and Isendahl 2013; AF Chase and Chase 1998b; Graham 1999). As a result, these analyses demonstrate that even in this large and sprawling city residents could both easily access urban services and maintain their own local terraced fields and kitchen gardens. This accessibility of formal plazas provides additional insight into the market system at Caracol. These locations, in addition to their other roles, served as marketplaces and their widespread nature corresponds with the prevalence of specialized household production at Caracol (see AF Chase and Chase 2015; AF Chase, et al. 2019; AF Chase, et al. 2015; DZ Chase and Chase 2014b, 2020c). Easily accessible marketplace locations in formal plazas provided centralized spaces for households to exchange their local production and interact with each other (e.g., energized crowding).

8.3.3 Formal Plaza Size Scaling

In addition to the use and accessibility of services like markets in the formal plazas, these plazas would also have facilitated other interactions involving social, political, and ritual events (see Inomata 2006; Tsukamoto and Inomata 2014). Based on both local population and formal plazas sizes, they were all sufficiently large to facilitate interactions among district residents. However, plazas were far larger than required. The plaza in downtown Caracol could have held the entire population of the city and half again (almost 156,000 at 0.46 m^2 per person) at the smallest density provided by Inomata (2006).

Beyond simply being larger than required, these formal plazas exhibit unique scaling patterns of area to population. While additional research needs to be done to increase the comparative sample, the only other Maya case study by Ossa, et al. (2017) identified a scaling coefficient of 0.4 with the Palenque dataset from Liendo's survey research (Ossa and Smith 2017; Stuardo 2002). This is quite different from the 2.1 scaling coefficient identified at Caracol. While the Palenque region saw economies of scale in its plaza construction efforts, the city of Caracol's larger plazas were not just able to accommodate a larger population but had more area per person.

Taken together, this large scaling factor and the ability for even the smallest plazas to accommodate their local populations emphasizes the importance of these formalized open spaces as loci of energized crowding (as defined by ME Smith 2019). They also demonstrate that higher tiered districts could hold more than just their local populations (possibly to use the less common service features like formal reservoirs, ballcourts, or E groups). Finally, these results suggest that while the districts had widespread services, there was a hierarchical centralization of power in specific district nodes.

8.3.4 District Service Area Scaling.

While the formal plazas within district nodes exhibit scaling, the district areas themselves (centered on their infrastructure) also exhibit scaling patterns. This scaling analysis represents a different relationship from the one described above. District service area scaling looks at the relationship between a district's population and the landscape area within the city situated closer to that service than another one. In other words, these scaling values test the types of social interactions within that services' local areas and provide insight into the nature of these districts.

Traditional urban scaling analysis of area and population distinguishes between two models of social interaction. Idealized social interaction in a circular settlement zone should be closer to 2/3rds, while interaction determined by infrastructure and transit networks should be closer to 5/6ths (Ortman, et al. 2014:2-3). While this model generally applies to settlements as a whole, recent research has demonstrated intra-urban district scaling (Xu, et al. 2020), and this analysis provides the second such example worldwide (with Codd 2020 providing the first intra-urban neighborhood analysis with the sian otot at Copan). Interpreting the results, service districts that scale closer to 2/3rds (~0.67) indicate more social interactions in that district area and those that scale closer to 5/6ths (~0.83) indicate more infrastructurally conditioned social interaction in that district area. Since these areas are generated from urban service facility feature locations, and all infrastructure at Caracol is co-located in nodes of monumental architecture, these values provide insight into whether interactions in these districts were more social or more infrastructural in nature.

Both E Groups and ballcourt service areas provided scaling relationships near but slightly above 5/6ths, supporting the idea that social interaction associated with these districts permitted infrastructural benefits to their local populations. Formal reservoirs provided a variant case where these districts scale near the 5/6ths value, but the removal of a single reservoir district (Round Hole Bank) – changes that scaling relationship to 0.49. This may indicate a separate process or issue at hand such as change in use over time. However, only the formal reservoir districts had such a significant change from a simple sensitivity analysis, and as a whole they follow the same pattern as E Groups and ballcourts. Finally, the formal plaza districts uniquely exhibit an interesting intermediate scaling value between social and infrastructural interactions in their service areas, which lines up with the many potential uses of these formalized open spaces (see Inomata 2006; Tsukamoto and Inomata 2014).

Importantly, each of these analyses includes agricultural land in the area calculations; agricultural land, a crucial service area for sustaining any ancient Maya city's population, is not accounted for by design in most modern scaling exercises as agriculture in these contexts occurs outside the city (Bettencourt, et al. 2007; Cesaretti, et al. 2016; Lobo, et al. 2020; Ortman, et al. 2014; Ortman and Coffey 2017; Ortman, et al. 2016; ME Smith, et al. 2021b). While the intra-urban scaling of district areas at Caracol aligns with these expected scaling results, the inclusion of agricultural area within the city makes it an outlier. In general, large ancient Maya cities contain many agricultural areas interspersed within their settlements, while smaller, and denser, ancient Maya cities tended to practice outfield agriculture (AF Chase and Chase 2016a; Fisher 2014). This means that urban scaling analyses of both types of Maya cities will show divergent results from general expectations because scaling theory expects larger cities to be denser than smaller ones following either a 2/3rds or 5/6ths scaling coefficient.

In terms of urbanism and physical infrastructural power, the intra-urban scaling results provided a means of testing these reconstructed districts. Prior research had assumed that these areas functioned as districts with service areas, but settlement scaling theory provides a means to test the relationship of district service areas and populations. Formal plaza districts exhibit patterns indicative of both social and infrastructurally conditioned interactions by residents, as expected based on the myriad of potential interactions within formal plazas. In conjunction, the ballcourt, formal reservoir, and E Group districts all exhibit infrastructurally conditioned scaling factors that align with the assumed role of those features in provisioning infrastructure. Additionally, this type of intra-urban scaling analysis, along with the modern results from Xu, et al. (2020), suggests that the social interactions investigated by settlement scaling theory are fractally exhibited by city districts.

8.3.5 Physical Infrastructural Power Summarized.

As a whole, this aspect of governance indicates the presence of a reasonably large infrastructural apparatus in this ancient city during the Late Classic Period with wide reaching impacts at the citywide and district levels; in addition, these services also have implications on potential restrictions on despotic power if the presence of these services and their distribution resulted from increased internal taxation (sensu Blanton and Fargher 2008). These data indirectly demonstrate the role that ancient bureaucracy at Caracol through its built environment. The distribution of these urban service facility features across the landscape and their district area scaling results both provide evidence for residential interaction with this infrastructure. However, the specific presence/absence of features in a tiered system and the generally increasing sizes of those features at higher tiers also suggests centralization. While the districts provisioned services widely at Caracol, the city still managed to hierarchically centralize its infrastructure power.

8.4 Household Architectural Autonomy at the Plazuela level

Analysis of the plazuela (or residential) level at Caracol uses standardization as one means to investigate the autonomy maintained by households. This perspective assumes that the governing apparatus did not preoccupy itself with regulating the residences, which is reminiscent of more autocratic governance following Blanton and Fargher (2008). However, standardization can occur through multiple processes including both top-down infrastructural power to establish building codes (Guo 1998) and bottom-up collective action in construction processes (Carballo 2013; Marino, et al. n.d.). While this dissertation focuses on standardization in physical measurements of residential features from lidar data, other approaches to standardization include, but are not limited to, units of measure (Sugiyama 1993) and construction practices (Murakami 2010, 2016, 2019a). This dataset of garden city landscape features also has implications for ancient land tenure systems and provides even more evidence to continue overturning the prior bimodal elite-commoner dichotomy sometimes ascribed to the ancient Maya.

8.4.1 Lack of Architectural Standardization.

No clear standardization exists within the lengths, widths, areas, and orientations of garden city features – the *plazuela* housemound groups, agricultural terraces, and residential reservoirs –in this dataset. Instead, these results suggest that construction efforts focused on local building efforts by the residents without a specific outside authority determining standard residential forms. These observations are in accord with evidence from other Maya research (e.g., Ashmore 1981a), and, in particular, with the variety of plazuela forms previously identified by Bullard (1960:Figure 2).

This suggests that local construction efforts were equally bespoke; however, standardization in household practices such as the eastern placement of residential shrines in ~70% of residences indicates a different type of standardization potentially related to shared social interactions among residents (sensu Hall 1966; Rapoport 1988). Future investigation of other types of standardization may also provide a different perspective. Even so, the lidar data permitted for the comparison of 7709 residences and provides a very widespread perspective on architectural form at Caracol larger than that provided by excavations alone.

8.4.2 Questions of Land Ownership.

The lack of physical standardization in residential groups exists hand-in-hand with the difficulties in understanding agricultural terrace ownership. The terraces flowed into each other and exhibit dynamic flow patterns indicative of hydrologic engineering (ASZ Chase and Weishampel 2016). This pattern of flow suggests that, even if individuals or households owned terraces, those fields still existed in a larger system that required coordination and cooperation among households to organize, construct, and maintain. This highlights the potential for disputes over the terrace systems and their continued maintenance that had to have been handled at the neighborhood or even district scales, instead of the *plazuela* level.

Conjoined residential groups also provide information for conjectures about land tenure. Very few conjoined groups exist at Caracol despite over 1000 years of continuous occupation. While the terrace system could be managed through cooperative or individual ownership and requires more research to fully parse, the solitary individuality of most residential groups provides one insight. Fundamentally, the households at Caracol did not bud into adjacent residences as they developed or, if they did so, it was only done very infrequently (and perhaps only by a very limited number of long-established or higher-status families; sensu McAnany 1995).

In general, the settlement distribution at Caracol suggests a system whereby most of the children of an extended family household moved into other *plazuelas* at some distance from the original residential group. The *plazuelas* themselves are dispersed over the landscape with relatively wide, non-standardized spacing to permit sufficient agricultural fields to exist for each localized residential unit – and this spacing was maintained over time, either by tradition or through some other mechanism(s). In other words, it is highly likely that as households grew in size and then splintered, the derivative households moved to the outskirts of Caracol the city where agricultural land remained available. This would have facilitated the system of "urban sprawl" seen at the final two monumental nodes (Termini A & C) and explain the lack of conjoined *plazuelas* throughout Caracol in addition to the wide spacing between the city's *plazuelas*. While this remains a fundamental and important topic of future research, other data such as aDNA may be required to understand the multi-generational nature of households in this landscape and shed light on land tenure systems.

8.4.3 Mesoamerican Elites.

Archaeological data provides a check to ethnohistoric and hieroglyphic descriptions of socio-economic status. The distributions of residential sizes and district access show a fuzziness and overlaps that firmly reject any simple bimodal model of socio-economic statuses; these new findings support the previous research of other scholars that have suggested the existence of one or more middle status levels (AF Chase 1992a; AF Chase and Chase 1992a; DZ Chase 1992b; Elson and Covey 2006; Hutson 2020; Masson and Pereza Lope 2005; Murakami 2016; Walden, et al. 2019). These data also support interpretations of on-ground intermixing of residences of different sizes and economic means within neighborhoods and districts, lining up with expectations for what are termed "walking cities" more broadly (AF Chase and Chase 2016b:365; Hutson and Welch 2021a; Storey 2006:9-10).

The residential area Gini demonstrates a very slight potential inflection point below that of the largest residences; however, the nature of this inflection point distributes "elite" acropoleis on either side of that divide and lumps some larger *plazuelas* with other acropoleis. This strongly suggests that acropoleis are simply large plazuelas that grew incrementally over time. They may also demonstrate some potential for social mobility in the past. In other words, inequality at this ancient Maya city refutes any categorization of its residents as simply being "elite" and "non-elite" without respecting the multiple overlapping groups of people in the middle-levels of that society.

8.4.4 Household Architectural Autonomy Summarized.

The various analyses suggest that there was relative household architectural autonomy among residences at Caracol and that civic structures and organization did not seem to intrude on day-to-day life. Even with the physical infrastructural power present at the distributed district nodes, the foregoing analyses provide no evidence that this power penetrated into the *plazuela* or neighborhood levels at least in the measures used (e.g., standardization of residences, reservoirs, and agricultural terraces). However, these findings of non-standardized residential sizes also demonstrate the difficulty in identifying clear wealth classes.

8.5 Collective Action Potential at the Neighborhood and City levels

The neighborhood and citywide levels of Caracol shed light on shared cultural practices and perceived similarities (i.e., categorical identity) and interactions (i.e., relational identity) that led to a higher potential for collective action. While specific incidences of collective action can be difficult to observe in the archaeological record, collective action potential assesses the likelihood of collective action based on multiple, overlapping shared identities. In this dissertation, the neighborhood data provide a statistically significant argument for more in-neighborhood than between-neighborhood similarity in eastern mortuary shrine materials, which are very slow to change (see for example Tarlow 2015:9). At the same time, this overarching pattern of eastern mortuary constructions at a majority of residences within Caracol indicates shared *plazuela*-level ritual activities that provide indications of an overlapping citywide categorical identity (AF Chase and Chase 2009; DZ Chase and Chase 2004b). The overlaps in larger practices and those within neighborhoods show that Caracol exhibited high collective action potential during its apogee.

8.5.1 Neighborhood Model.

Many assume the existence of neighborhoods in urban environments; however, few have focused on defining, testing, and evaluating them. Neighborhoods consist of people who live in close spatial proximity that leads to frequent, repeated social interactions (sensu Hutson 2016:70-73; ME Smith 2010:139). The model of neighborhoods presented in Section 7.2 builds on ideas of people, space, and interaction in the past – and it also indicates how these neighborhoods could form and persist over time through these social interactions among residents.

I use principles established in geography, sociology, and cognitive science to reconstruct neighborhoods of spatially co-located residences with individuals who would have interacted frequently. Residences in the same neighborhoods had similar travel times to and from the same set of formal plazas. In addition, residents interacted near their houses, in their fields, on their ways to and from these formal plazas, and in the plazas themselves. The resulting analysis produced a set of 373 neighborhoods with a mean of 157 residents and a median of 150 residents per neighborhood; however, the full population may have varied from 639 expected neighborhoods with 157 people per neighborhood to 373 neighborhoods with 269 people per neighborhood.

A sample of 60 residences in 8 neighborhoods provided a means to test these reconstructed neighborhoods for shared ritual behaviors involving ceramic vessel selection and dental modification in each residence. The results show more similarity in intra-neighborhood materials than inter-neighborhood materials with statistical significance. This lines up with the expectations of interaction in the neighborhood social model and helps establish the coherence of these reconstructed neighborhoods.

8.5.2 Collective Action Potential Summarized.

The reconstructed neighborhoods show similarities in ritual materials indicating common, local practices. These would have entailed local interactions during deposition, but also exhibit unique, neighborhood-centric categorical identities (following Peeples 2018). Analysis shows that the sampled neighborhoods all exhibit greater intra-neighborhood similarity than inter-neighborhood.

In addition to this higher intra-neighborhood cohesion, citywide patterns of eastern shrine erection and ritual would have bolstered this potential to organize collectively. In fact, the citywide similarities in cultural practices related to eastern ritual shrines existed even at the largest multi-purpose residence at Caracol where the ruler lived – Caana (AF Chase and Chase 2017a, c). While additional data and information will be needed to test and tease apart the role of market distributions or social similarities at the district level, these initial results suggest that district level patterns did not negate intra-district neighborhood-level differences. Finally, these overlapping sets of shared practice would have facilitated a high collective action potential in the city as a whole.

8.6 Caracol and Tikal

To demonstrate the comparative power of this overall framework, a brief comparison of Caracol, Belize and Tikal, Guatemala follows. These two contemporaneous ancient Maya cities provide a striking contrast to each other. Despite a shared history (AF Chase and Chase 2020b), Caracol appears to have a very different urban morphology than Tikal. While the underlying landscape may account for some of these differences – especially in terms of agricultural intensification strategies used (ASZ Chase and Cesaretti 2019) – others are likely related to governance and historical processes (see AF Chase, et al. in press 2021a; DZ Chase, et al. 2020d).

Functionally, Tikal exhibits a much more centralized downtown with larger architecture, but also a more limited projection of physical infrastructural power into its periphery. In contrast, Caracol exhibits a decentralized settlement system that provided more physical infrastructural power at the district level. The monumental core at Tikal is larger and more expansive than the monumental architecture at downtown Caracol; however, Caracol incorporates more monumental architecture in its distributed district nodes. In addition, Caracol placed a greater emphasis on longer causeway routes connecting markets to the epicenter, while the much shorter causeways at Tikal connected temples to the city center with raised avenues for movement (see Figure 8.1). Taken together, these patterns likely demonstrate more autocratic governance at Tikal and more collective governance at Caracol (Blanton and Fargher 2008, 2011, 2012; M Mann 1984, 2008, 2019).

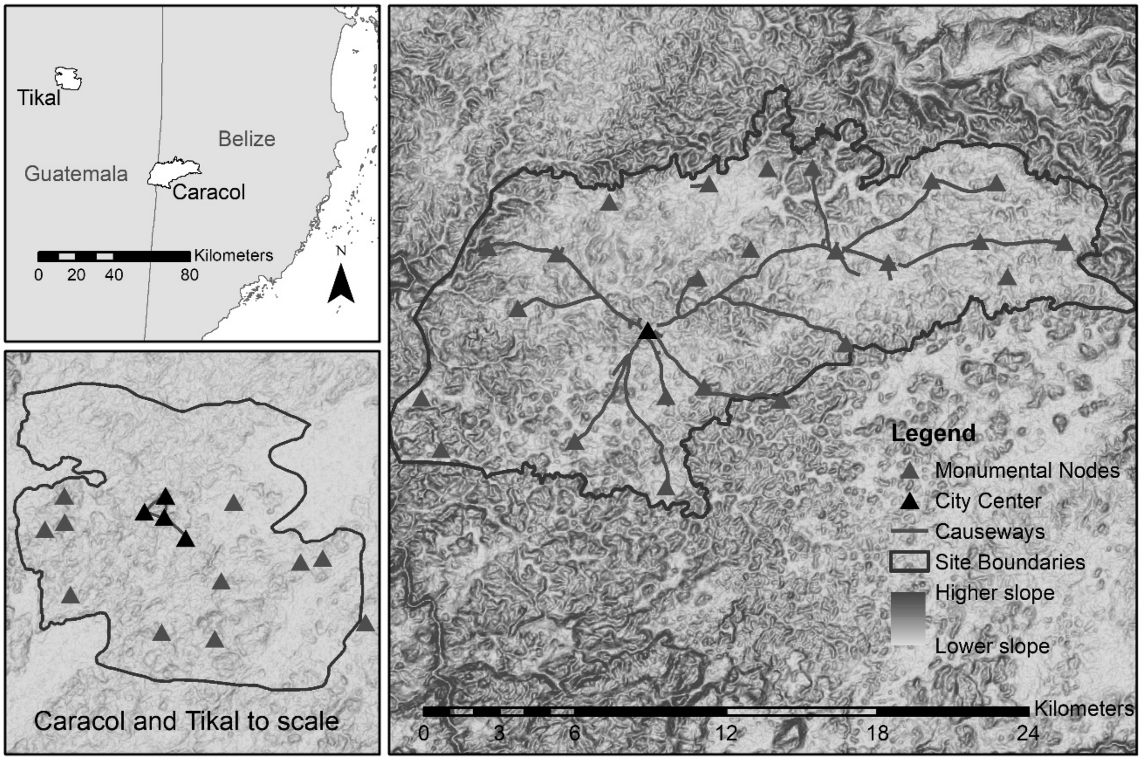

Figure 8.1: Caracol and Tikal comparison
The landscapes and urban forms of Tikal and Caracol shown at the same scale based on the maps and research from ASZ Chase and Cesaretti (2019)

In contrast, the variations and similarities in residential groups between the two cities remains more difficult to identify without the results of Tikal's lidar survey (Canuto, et al. 2018); however, despite the order of magnitude difference in sample size – 5852 or 7709 at Caracol (Chapter 6) versus 762 at Tikal (Kohler, et al. 2017:Supplementary Table 2) – the current Gini values for residential area of 0.34 for Caracol (Chapter 6; ASZ Chase 2017) and of 0.62 for Tikal (Kohler, et al. 2017; ME Smith and Kohler 2018) provide for very different settlement forms. Yet, settlement in both cities diverges from a more formally gridded pattern like that found at Teotihuacan (see AF Chase, et al. 2009:Figure 3).

These Gini values demonstrate more equality at Caracol and greater inequality at Tikal, or perhaps more standardization at Tikal in specific residential “classes”. At a higher level, these results may also suggest more autocratic governance at Tikal and more collective governance at Caracol (see both Boix 2015:64-65,85-87; and Kohler, et al. 2018:Figure 11.5). However, more (and future) investigation in this relationship between Gini values and governance is needed.

To more fully understand the differences in collective action potential would require an ability to compare and contrast the material remains from neighborhoods in both cities. However, the sharing of cultural traits in a pan-Caracol categorical identity has been described in detail (AF Chase and Chase 2009; DZ Chase and Chase 2017d:213-217), while a complementary system at Tikal does not seem to appear in the published literature. In fact, the burial and caching systems at Tikal exhibit different patterns from Caracol (DZ Chase and Chase 2017d:229); in particular Tikal has far fewer recovered burials (Coe 1990) and a markedly lesser focus on eastern shrines in residences (Becker 2004:129). This quick comparison suggests that Caracol exhibited more collective action potential through shared neighborhood and citywide categorical identities than was exhibited at Tikal in term of these mortuary practices.

This first look at all of these aspects of urbanism – physical infrastructural power, household architectural autonomy, and collective action potential – for both Caracol and Tikal highlights the potential use of the framework presented in this dissertation. It also suggests that Tikal exhibited more autocratic civic governance in the past in contrast to Caracol’s more collective governance, although both cities had known rulers. During the short period where the polity of Caracol governed both cities, scholars have identified two rulers (both from Caracol) as stranger kings (AF Chase and Chase 2020b). This identification rests on earlier interpretations made based on recovered archaeological remains that also highlighted the relative “poverty” of the grave goods in the two Tikal tombs (Coe 1990:39-540; Coggins 1975:372-380), according well with elite patterns noted for Caracol (DZ Chase and Chase 2017d:220-222). It also suggests that these two rulers may have broken from the traditions of the previous rulers in other ways.

This section provides only a very cursory view of using this framework to explore one additional Maya city. However, future work can provide a more detailed comparison between Caracol and other Maya centers through future collaborations with archaeologists working in Guatemala (e.g, Canuto, et al. 2018), expansion of the settlement archaeology documented in the Vaca Plateau (e.g., Iannone 2005; Iannone 2010; Iannone, et al. 2004) collaborations with other archaeologists in Belize (e.g., AF Chase, et al. 2014b), and comparisons with other regions and urban systems (e.g., Carballo 2020; LF Fargher, et al. 2020; ME Smith 2021).

8.7 Valediction

The urban analyses in this dissertation provide insights into the urban form and function of civic administration at the ancient city of Caracol, Belize. The framework created for these analyses provides a method for viewing governance from multiple urban levels and perspectives. Initial results indicate the physical infrastructural power of this city at the district and citywide levels through the widespread distribution and nature of its physical infrastructure; this may also suggest a limitation on despotic power. Initial results also reinforce the idea of household architectural autonomy through the lack of standardization in the physical measurements of the garden city's built environment, including the relative equality of residences indicating a lack of clear breaks between residential sizes. Finally, these initial results emphasize both citywide and neighborhood-based similarities in ritual practices (e.g., categorical identities) that would have facilitated collective action among individuals in the past by reducing the friction to initiate collective endeavors.

In sum, each of these analyses provides a more detailed and comprehensive view of ancient urbanism within this city. Despite the autocratic assumptions from the hieroglyphic record and presence of a known ruler, these results suggest both collective and autocratic elements of governance at ancient Caracol. They provide an example of using lidar data for urban analysis in conjunction with archaeological excavation, and they have the potential to help shed light on other governance practices through future comparative urban research on archaeological, historical, and modern cities.

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