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The Low-Density Urban Systems of the Classic Period Maya and Izapa: Insights from Settlement Scaling Theory

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The peoples of southern Mesoamerica, including the Classic period Maya, are often claimed to exhibit a distinct type of spatial organization relative to contemporary urban systems. Here, we use the settlement scaling framework and properties of settlements recorded in systematic, full-coverage surveys to examine ways in which southern Mesoamerican settlement systems were both similar to and different from contemporary systems. We find that the population-area relationship in these settlements differs greatly from that reported for other agrarian settlement systems, but that more typical patterns emerge when one considers a site epicenter as the relevant social interaction area, and the population administered from a given center as the relevant interacting population. Our results imply that southern Mesoamerican populations mixed socially at a slower temporal rhythm than is typical of contemporary systems. Residential locations reflected the need to balance energetic and transport costs of farming with lower-frequency costs of commuting to central places. Nevertheless, increasing returns in activities such as civic construction were still realized through lower-frequency social mixing. These findings suggest that the primary difference between low-density urbanism and contemporary urban systems lies in the spatial and temporal rhythms of social mixing.

Keywords: cities, urbanism, settlement scaling, population density, Maya, settlement patterns

A menudo se afirma que los asentamientos del sur de Mesoamérica representan un tipo de organización espacial distinto al de otros sistemas urbanos contemporáneos. Utilizando el marco analítico "escalado de asentamientos" investigamos las maneras específicas en las que los sistemas de asentamientos de Mesoamérica del Sur se asemejan, o no, a sistemas contemporáneos. Utilizamos la información registrada en sondeos de asentamientos Mayas y encontramos que la relación entre población y área difiere marcadamente de lo reportado para otros sistemas de asentamientos de carácter agrario. Notamos patrones más típicos cuando consideramos el epicentro de una zona arqueológica como el área de principal interacción social. Nuestros resultados implican que las poblaciones del sur de Mesoamérica poseían ritmos de interacción más lentos que la de otros sistemas urbanos contemporáneos. Las unidades familiares ubicaban sus residencias con el fin de equilibrar los costos de transporte ligados a la actividad agrícola y al desplazamiento a lugares centrales. El aumento de los rendimientos en actividades colectivas fueron realizadas a través de mezclas sociales de menor frecuencia. Concluimos que la principal diferencia entre el urbanismo Maya de baja densidad y otras experiencias urbanas contemporáneas tienen su origen en los patrones de movimiento asociados a las interacciónes sociales.

Palabres claves: ciudades, urbanismo, escalamiento de asentamientos, densidad de población, Maya, patrones de asentamiento

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Archaeologists have argued for decades about the urban status of Classic period Maya settlements. For some, the low populations and densities of these sites disqualify them as "urban" settlements (Sanders and Webster 1988), whereas others focus on their political and religious roles as (urban) organizing nodes for a larger landscape (Smith 1989). Even if one accepts the characterization of these settlements as "urban," there is little agreement concerning their similarity to or difference from cities in other urban traditions of the past and present.

Roland Fletcher (2012) includes the Classic Maya in his category of low-density, agrarian-based urbanism; other examples include Angkor and other early urban systems of Africa and Asia. He claims that these low-density urban centers had distinctive social, political, and agricultural systems—very different from cities in other urban traditions—making them fragile and prone to collapse. For Fletcher (1995), the low densities of these cities created patterns of social interaction and communication quite different from those in most urban systems known from both ancient and modern times.

In this article we use the analytical framework known as settlement scaling theory (SST) to quantitatively evaluate the similarities and differences between southern Mesoamerican settlement systems and other urban systems known from history and contemporary scholarship. SST, as an integrated approach to the study of settlements across eras, cultures, and geography, developed over the last decade initially by researchers investigating contemporary urban systems. It builds on extant traditions in urban economics, economic geography, and urban sociology, but is grounded in an alternative perspective that views settlements as social networks embedded in built environments (Bettencourt 2013, 2014; Lobo et al. 2013, 2020). The many and varied social interactions that occur when individuals meet and mix—which fundamentally involve the sharing and exchange of information—are the drivers of the quantitative patterns identified and explained by SST. We refer to these interactions, ranging from interplays mediated by ritual to chance encounters in a plaza, as "social mixing." Here, we examine data from five full-coverage surveys from the Maya Lowlands and the Pacific coast of Chiapas, Mexico, to determine how several aggregate properties of settlements (total area, epicenter area, civic architecture volume) relate to their populations as estimated by domestic dwelling counts.

We focus on two key expectations of SST. The first builds from the long-observed property of contemporary urban systems in which larger cities have higher densities than smaller ones (Bettencourt 2013). SST makes a specific quantitative prediction concerning the average rate at which cities densify as their populations increase, and this prediction has been borne out in numerous systems of a variety of scales, cultures, and time periods (Lobo et al. 2020). A recent study by Chase and Chase (2016), however, suggests that this densification process did not characterize Classic Maya cities. Specifically, they find that for nine large excavated Maya cities, larger cities had *lower* densities than smaller ones; Drennan (1988) made a similar observation. We expand on this work here using larger and more systematic regional datasets. We confirm that, indeed, residential density generally does decrease even as the number of residences in southern Mesoamerican sites increases, because the area over which the houses are spread grows more rapidly than the number of houses. This result, which is not consistent with SST, implies that in southern Mesoamerica the social units encapsulated within archaeological site boundaries did not mix socially across the site area on a daily basis, as is typical of villages, towns, and cities in many settings. Nevertheless, we do find evidence for an alternative, lower-frequency form of social mixing in these societies, which we explain later.

The second prediction involves the effect of population size on socioeconomic rates. In many urban systems, larger cities are more productive and innovative per capita but also exhibit more crime and disease per capita than smaller cities. This characteristic of cities today has led to their description as social reactors, or places of energized crowding (Smith 2019), that generate outputs proportionally greater than their population alone might suggest (Bettencourt 2013). We examine this possibility here using civic architecture volumes and find that the expected relation between civic construction rates and the contributing population becomes apparent when civic architecture volumes are compared against their relevant administered populations. Based on these results, we argue that people of southern Mesoamerica and other low-density urban systems *did* take advantage of the social reactor process, but they did so in a distinctive way that is not reflected in contemporary systems: they mixed socially with a less-than-daily rhythm.

The discussion is organized as follows. The next section presents SST and the specific predictions we investigate. The data are discussed in the third section, and the results are presented in the fourth section. The final section discusses the results and draws implications for understanding Maya and other southeastern Mesoamerican settlements, as well as urban systems in general.

The Social Reactor Process

SST builds from first principles, which is to say, basic statements about human behavior that apply to any culture or society. For these claims to be empirically valid, they must be rather modest in content while remaining useful for the construction of a theory and derivation of hypotheses. Anthropologists who focus on variation in human societies and cultures tend to be skeptical of such statements. Our view is that, at the most fundamental level, every society consists of human beings whose psychological and behavioral predispositions have been shaped through evolution. This ultimately means they have been shaped by the net effects of behavior for reproduction in the physical world. Anthropology shows us that there is much room for social and cultural variation within the constraints imposed by the physical world and the behavioral predispositions that have arisen in dialogue with that world. SST does not discount this variation. It merely seeks to capture the effects of these dispositions for human social behavior. In the process, it seeks to account for some of the variation in human behavior, thus bringing the remaining variation and its sources into greater focus.

The first principles and assumptions of SST, and the basic models derived from the theory, have been discussed in several publications (Bettencourt 2013, 2014; Lobo et al. 2020; Ortman and Coffey 2017; Ortman et al. 2014, 2015). Here, we provide a brief overview of the models in this framework, focusing on the relationship between population and area. The emphasis here is on the mathematical relationships themselves. A more extensive discussion in Supplemental Text 1 provides lengthier justifications for the assumptions, notes the links between SST and existing research traditions, and provides responses to concerns raised by archaeologists in previous studies. It is recommended that readers who are unfamiliar with the approach read the Supplemental Text 1 first and then return to this section (also see Supplemental Table S1 for a list of mathematical symbols used in the following discussion).

The most fundamental assumption of SST is that settlements are areas where people have arranged themselves in physical space in a way that balances the costs of movement with the benefits that accrue from the resulting social interactions. In the simplest case, the average energetic cost to the individual engaged in a social mixing process is given by the distance across the area encompassed by the group:

$$c = \varepsilon L = \varepsilon A^{\frac{1}{2}}, \tag{1}$$

where ε is the is the energetic cost of movement, L is the transverse dimension of the area, A is the circumscribing area within which most movement and interaction take place, and the one-half power relates the area to its transverse dimension. The energetic benefit of the resulting interactions experienced by that individual is then given by

$$y = \hat{g} a_0 l \frac{N}{A}, \tag{2}$$

where y is the average per capita result, $\hat{g}$ denotes the average "productivity" of an interaction (across all types that can occur), a_0 is the interaction distance, l refers to the average path length traveled by an individual per unit time, and $\frac{N}{A}$ is the average population density of the area.

By setting $c = y$ (i.e., balancing the benefits of social interactions with the costs of engaging in such interactions; see Supplemental Text 1), we can derive the following expression for the circumscribing area required for a population to engage in a social mixing process:

$$A(N) = \left(\frac{G}{\varepsilon}\right)^{\frac{2}{3}} N^{\frac{2}{3}}, \tag{3}$$

where $G = \hat{g}a_0 l$ represents the net "social attraction" of an individual's movements and interaction. The area required for social mixing grows proportionately to the population raised to the $\alpha = 2/3$ power: the required area thus grows more slowly than the population, becoming progressively denser. This is called the *amorphous settlement model.* Note also that the quantity $(G/\varepsilon)^{2/3} = a$ varies in accordance with the productivity of interactions, G, and transportation (movement) costs, ε, but is independent of population.

This very simple model can be adjusted in several ways. For example, as the population (and density of the required area) grows, social interaction must become increasingly structured in space by setting aside specific areas for movement and mixing: roads, paths, plazas, and other public spaces. The space needed for this "access network," d, can be added in accordance with the current population density (meaning that movement-related infrastructure is added as the population increases), so that the space embedded in such a network per capita is

$$d = (N/A)^{-1/2}, \tag{4}$$

and the total area of the network area (A_n) thus becomes

$$A_n \sim Nd = A^{1/2}N^{1/2}. \tag{5}$$

Substituting $aN^{2/3}$ for A in Equation (5), based on the relationship derived previously, leads to the following expression for the interaction area (which is different from, and smaller than, the circumscribing area):

$$A_n \sim a^{1/2}N^{5/6}. \tag{6}$$

As a population that mixes regularly across an area grows, interactions become increasingly structured by the interaction space. As a result, the area taken up by this group grows proportionately to the population raised to the *5/6* power; this alternative is referred to as the *structured* or *networked* settlement model. In both the "amorphous" and "networked" cases there is a clear economy of scale, in that larger groups arrange themselves more densely, but the densification rate declines slightly, from *2/3 to 5/6*, as space becomes increasingly structured.

Finally, the socioeconomic output (Y) generated by a spatially embedded mixing population is viewed as being proportional to the total number of social interactions that occur among its inhabitants per unit time (see Supplemental Text 1). Given the assumption that human networks support as much mixing as is possible given spatial constraints, we can write as an expression for aggregate output,

$$Y(N) = GN(N-1)/A_n \approx GN^2/A_n, \tag{7}$$

where G once again represents the net social attraction of an individual's movements and interactions. The number of interactions per unit time is assumed to be undirected and as large as possible, given the frictional effects of distance and the average benefit of an interaction, and thus $\approx N^2$ over the area within which interactions occur.

We can then compute the expected scaling of outputs relative to population by substituting the expression for A_n in equation (6) into equation (7). This leads to

$$Y(N) \propto N^{7/6}, \tag{8}$$

which in turn implies an average per capita output of

$$y = Y/N = GN/A_n \propto N^{1/6}. \tag{9}$$

Equation (9) states that, as a spatially localized mixing population grows, its average per capita socioeconomic outputs grow proportionately to population raised to the 1/6 power, and its total aggregate outputs grow proportionately to population raised to the 7/6 power. In other words, there are increasing returns to scale, such that larger groups are more productive on a collective and per capita basis.

It is important to emphasize that all these mathematical formalisms concern the average effect of population for other properties of settlements in a system. These relationships are relative to transport costs and a variety of institutions and technologies that affect the productivity of interactions, all of which are system specific. As a result, the only thing these models predict is the average effect of scale, given all these other factors, for the settlements in a particular system. In addition, there are numerous social, cultural, ecological, and cosmological factors that archaeologists are well aware of that are *not* included in these models but that obviously do affect the properties of individual settlements. SST proposes that the effects of these factors can be seen in the deviations of individual settlements from the average expectation value defined by the models (see Supplemental Text 1). So, for example, one could not use equation (3) to exactly predict the actual past population of Tikal based on its circumscribing area. All equation (3) provides is a point estimate for this population, given a circumscribing area, in the context of other settlements in the Tikal region (see Supplemental Text 1).

In these formulations we de-emphasized the terms "settlement" and "city" when describing the area over which social mixing occurs. This is because at the most fundamental level SST concerns a process of social mixing, and the relevant space involved does not necessarily need to correspond to the boundary of a settlement, city, or, indeed, an archaeological site. In many past societies, mixing populations were actually localized within settlements, making it convenient to measure both the interacting population and the corresponding interaction area using the settlement as the relevant unit (Cesaretti et al. 2016; Hanson and Ortman 2017; Ortman and Coffey 2017; Ortman et al. 2014, 2015, 2016). In such cases, the social reactor process described earlier is revealed by measuring the aggregate properties of settlements across a system. But there are other possibilities.

In modern cities, for example, the populations that reveal the social reactor process are defined on the basis of daily commuter flows, not the actual distribution of residences on the landscape (Arcaute et al. 2015; Bettencourt 2013; Bettencourt and Lobo 2016). Disjunctions between a population and its relevant area of social mixing can also arise when residences are interspersed with farmland. In such cases, the social mixing area may be much smaller than the settled area, perhaps being centered on civic buildings and plazas. One would still expect there to be a relationship between the social mixing space and the population, but the social mixing space would be much smaller than the total area of the dispersed settlement. In addition, the total area taken up by the settlement will reflect land in production, as well as residential and interaction space.

It is also important to note that interacting populations and their associated mixing spaces can vary across systems, especially when the frequency of social mixing occurs less than daily. As an example, late prehispanic pueblos in the U.S. Southwest were built with enough plaza space to hold a portion of the entire social network of the community, not just the residents of the pueblo, in public dances that occurred periodically and asynchronously across villages (Ortman and Coffey 2019). A single individual participated in several different mixing populations in several different spaces over the course of a year, with the frequency of such participation being far less than daily. Previous work in the prehispanic Basin of Mexico has similarly found evidence that individuals contributed corvée labor in different locations, and obviously at different times, based on their position within a nested political hierarchy and their associated administrative centers (Ortman et al. 2015). So, over time, a single individual would have participated in mixing populations in the public areas of his or her home community, district capital, regional capital, and other locations. We believe these considerations are important for making sense of low-density urbanism, especially in situations where residence groups outside of urban cores were interspersed with farmland (Barthel and Isendahl 2013), where polity- or settlement-level administrative hierarchies were important (Ashmore 1981; Chase 2016; Marcus 1993), and where the temporal rhythms of social mixing likely varied across different scales in the hierarchy (Chase and Chase 2017). In such situations, relationships between the populations and areas of sites and/or settlements may be quite different from the relationships between mixing populations, mixing spaces, and socioeconomic outputs in systems where settlements reflect actual mixing areas.

Southern Mesoamerican Settlement Data

To match the settlement scaling framework with archaeological data, several criteria must be met. First, individual settlements must belong to the same socioeconomic system (but not necessarily the same polity), meaning that they share attributes of settlement form, economy, technology, and society. Second, there must be a method to estimate population size that is not derived directly from site area. In the lowland regions of Mesoamerica, the typical means of estimating population involves counting residences, which are generally visible as stone foundations or earthen platforms on the modern ground surface (Culbert and Rice 1990; Rice 2006). Third, the collection of sites to be analyzed needs to encompass the range of size variation among settlements in a region and needs to be large enough for reasonable statistical evaluation of relationships between population and other quantities. All the data analyzed here conform to these requirements. Each of the five surveys we consider documented settlements across a settlement hierarchy, defined site boundaries in similar ways, and used domestic residences as the basis for estimating population. Four of the surveys (Palenque, Rosario Valley, Belize Valley, and Uxbenká/Ix Kuku'il) also include information on settlement hierarchies and civic-ceremonial precincts that allow additional types of analysis.

In this section we present the fieldwork projects that provided the data analyzed in this article. A discussion of each project, with citations and information on how field results were converted into data for analyses, is included in Supplemental Text 2. The locations of the five projects are shown in Figure 1.

Palenque

Our first dataset is the published results from the Proyecto Regional Palenque, carried out by Liendo Stuardo (2011). This full-coverage survey identified 413 sites within an area of 450 km^2. The sites included here date to the Balunté period, AD 750–850, which was the demographic peak in this area.

Rosario Valley

This dataset was compiled by Olivier de Montmollin (1989, 1995) for the Grijalva River Upper Tributaries, several hundred kilometers south of Palenque, in what can be called the southwest periphery of the Maya area. Advantages of this area include the fact that Maya occupation was essentially limited to the Terminal Classic period and that surface architectural visibility is excellent because the semi-arid local climate. As a result, it is reasonable to view the results as a synchronic snapshot of the settlement system.

Belize Valley

The upper Belize Valley encompasses an area of approximately 125 km^2, extending 25 km eastward and downriver from the Maya centers of Cahal Pech to Blackman Eddy. From 1988 to 2017, the Belize Valley Archaeological Reconnaissance (BVAR) Project extended Gordon Willey's initial study area through a block survey program designed for total coverage of the region (Hoggarth et al. 2010; Walden et al. 2019). An airborne lidar survey for the BVAR study area was conducted in 2013 as part of the West-Central Belize lidar Survey to supplement the pedestrian survey (Chase et al. 2014).

Uxbenká and Ix Kuku'il

Uxbenká and Ix Kuku'il are two neighboring polities located on the calcareous sandstone foothills of the southern Maya Mountains in Belize. The Uxbenká Archaeological Project (UAP) conducted a decade of pedestrian settlement survey and excavations including ground-truthing sites detected with aerial lidar data and high-resolution satellite imagery (Prufer et al. 2015). Combined survey and excavations produced a comprehensive diachronic settlement history of both polities. Both have origins earlier than the Early Classic and their maximum populations occurred during the Late Classic (Prufer et al. 2017; Thompson et al. 2018).

Figure 1. Locator map showing the locations of the five survey projects analyzed in this article. (Color online)

Izapa

The site of Izapa is famous for its large mounds and elaborate sculpture, but nothing was known of the regional structure of the polity until Rosenswig initiated the Izapa Regional Settlement Project (IRSP) in 2011. Two 60 km^2 survey zones were documented with lidar, and more than 1,000 mounds were surface-collected and the periods of their occupation determined on a phase-by-phase basis (Rosenswig et al. 2013, 2015). Then, a larger area was mapped, bringing the total to just under 600 km^2 and 40 political centers documented forming a three-tiered settlement hierarchy (Rosenswig and López-Torrijos 2018).

Results

We examine relationships between population size and other aggregate measures (settlement area, epicenter area, civic architecture volume) using a general form of equations (3) and (6):

$$Y = aX^{\beta}e^{\xi}, \qquad (10)$$

where Y denotes the dependent variable, X refers to the independent variable (a population), the power β captures the scaling relationship between area and population, and e^{ξ} are fluctuations of each settlement from the expected scaling relationship due to the combination of sampling error, measurement error, and other social, cultural, and technological factors that are not included in the model. The constant a captures how system-wide socioeconomic development modulates the effect of population size for other properties. The choice of a power-law functional form can be justified independently of the derivations in the previous section: the form assumes that the effect on the dependent variable of increasing population size is not additive but multiplicative, which is to say that the increase in Y is driven by the interaction of many factors observationally summarized by the increase in population size (Coffey 1979).

Taking the natural logarithm of equation (10) we obtain the estimation equation:

$$\ln(Y_i) = \ln a + \beta \ln(X_i) + \xi_i, \qquad (11)$$

where i indexes individual settlements or associated mixing populations and areas, and the scaling exponent β is the slope of the linear regression of lnY_i on lnX_i. The distributional properties of ξ are an approximate Gaussian random variable with zero mean, reflected in the residuals to this linear fit line. Depending on whether the estimated value of β is smaller than, equal to, or greater than 1, the relationship between an area and a population can be characterized as sublinear, linear, or superlinear, respectively.

To examine patterns across surveys we include results for each survey region, but we also provide pooled analyses to maximize sample sizes. There are differences in the baseline areas and civic architecture construction rates across survey areas. These differences represent interesting avenues for further investigation, but they also preclude us from pooling the data from multiple surveys in estimating the scaling exponent β. We control for these effects by centering the data from each region before analysis. Centering involves subtracting the mean value of a variable across cases in a survey from each case value, after log-transformation. This has the effect of rescaling the data so that their mean coordinate of each group is at the origin. This allows one to control for variation in the intercepts of scaling relations across surveys to better estimate the slope of the overall scaling relationship.

Population and Site Area

The overall relationship between the domestic structure count and the site area across the five survey datasets is not scale-invariant (Figure 2). Instead, there is a shift in the slope of the relationship, with a steep initial slope that gradually flattens out as site population increases. The transition point in this relationship appears to coincide with a settlement size of about 40 houses. Figure 2A presents regression lines that were fitted separately for two subpopulations—one with fewer than 40 domestic structures per settlement and the other one with 40 or more structures (see Table 1). The estimation results show that the area encompassed by these settlements initially exhibits a superlinear relationship such that the area grows faster than population, but it eventually transitions to a roughly linear relationship such that the site area grows proportionately to population (in the largest settlements).

However, as alluded to earlier, it appears that differences in the baseline area per person across surveys (perhaps because of differences in local agricultural productivity), in combination with differences in the size distributions of settlements across surveys, are responsible for this feature of the data. This is made clear by centering the data by survey and then replotting the results, shown in Figure 2B. After centering, the domestic structure versus area relationship is much more consistent and is well described by a fit line with a slope substantially greater than one. Table 1 presents regression results for each survey dataset, almost all of which suggest a superlinear relationship between house count and area. The only sublinear relationship observed in these data is for Uxbenká/Ix Kuku'il, the survey dataset for which the relationship has the lowest r-squared value (Table 1). Taken together, these results confirm that the scaling of population size (as proxied by domestic structures) and settlement area for southern Mesoamerican sites exhibits a markedly different pattern than is typical of both past and present urban systems, where $2/3 \leq \beta \leq 5/6$. This in turn implies that southern Mesoamerican archaeological sites do not represent areas within which households arranged themselves to facilitate daily social mixing. Instead, social mixing may have occurred less frequently, within central areas, by groups that are not necessarily coterminous with site boundaries. This result is in keeping with previous studies (Lobo et al. 2020; Ortman et al. 2020).

Although this result indicates that households in southern Mesoamerica did not mix across site areas on a regular basis, it does not rule out the possibility that individuals moved in a more directed way, gathering and mixing in epicenter

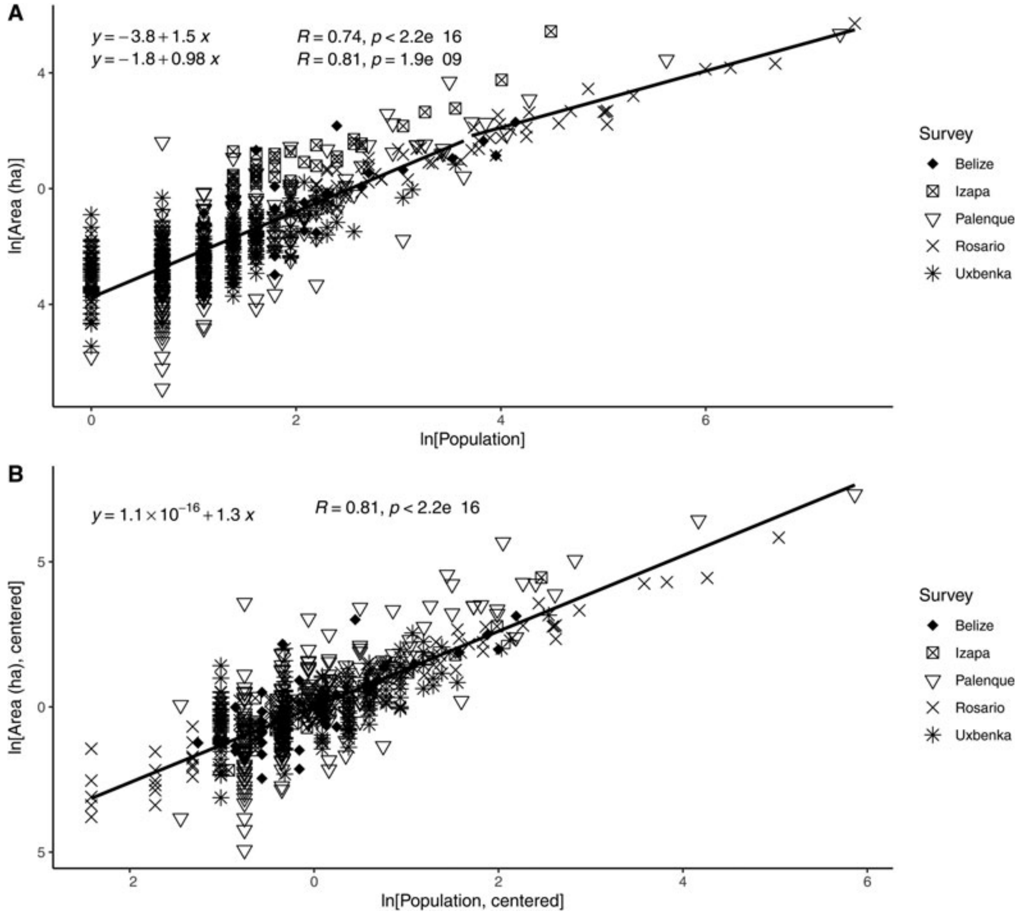

Figure 2. Relationship between population (domestic structure count) and area in six settlement pattern surveys from southern Mesoamerica. (A) All data included, with a breakpoint at 40 houses; (B) after centering the data for each survey, with no breakpoint. Note that there appears to be a transition from superlinearity to linearity when the raw data are considered, but after controlling for the baseline area in each region all data are well summarized by a single fit line.

Table 1. Relationships between Settlement Area and Population (House Count).

Survey	Sample Size	Intercept	Coefficient	R^2
Belize Valley	36	−3.397 (0.040)	1.312 (0.189)	0.587
Izapa	39	−1.883 (0.203)	1.414 (0.094)	0.861
Palenque	201	−4.453 (0.163)	1.711 (0.095)	0.621
Rosario	112	−3.110 (0.091)	1.237 (0.032)	0.933
Uxbenká/Ix Kuku'il	218	−3.151 (0.090)	0.820 (0.072)	0.376
All (<40 houses)	570	−3.761 (0.090)	1.487 (0.057)	0.546
All (>40 houses)	36	−1.802 (0.572)	0.978 (0.121)	0.659
All (centered)	606	0.000 (0.040)	1.304 (0.039)	0.648

Notes: In all cases the independent variable is the house count. All regressions are ordinary least-squares fits following natural log transformation. All results are significant ($p < 0.0001$) and standard errors are in parentheses. Note that the only case of sublinear scaling (Ix Kuku'il) has a low *r*-squared value. Thus, results show that households in southeast Mesoamerica did not arrange themselves to balance costs and benefits of daily social mixing.

Table 2. Relationships between Interacting of Mixing Populations and Epicenter Properties.

Survey	Dependent Variable	Sample Size	Intercept	Coefficient	R^2
Belize Valley	Epicenter area (ha)	33	−1.830 (0.117)	0.847 (0.103)	0.687
Palenque	Epicenter area (ha)	18	−1.940 (0.072)	0.631 (0.072)	0.830
Rosario	Epicenter area (ha)	26	−2.263 (0.271)	0.817 (0.111)	0.691
Uxbenká*	Epicenter area (ha)	9	−2.142 (0.288)	0.749 (0.128)	0.831
All (centered)	Epicenter area (ha)	86	0.014 (0.033)	0.776 (0.054)	0.701
Belize Valley	Civic architecture m^3/year	34	2.247 (0.145)	1.172 (0.126)	0.731
Palenque	Civic architecture m^3/year	18	2.267 (0.172)	1.144 (0.106)	0.879
Rosario	Civic architecture m^3/year	27	0.452 (0.243)	1.184 (0.100)	0.849
Uxbenká*	Civic architecture m^3/year	9	2.117 (0.509)	1.136 (0.225)	0.784
All (centered)	Civic architecture m^3/year	88	0.012 (0.037)	1.167 (0.062)	0.805

Notes: In all cases the independent variable is the contributing population. All regressions are ordinary least-squares fits following natural log transformation. All results are significant ($p < 0.0001$) unless otherwise noted, and standard errors are in parentheses. Note that the relationships for epicenter/plaza area are all strongly sublinear, and the relationships for civic architecture construction rates are all superlinear. In combination with Table 1, these results suggest that polities in southeast Mesoamerica took advantage of social mixing with a temporal rhythm that was much slower than daily.
$^*p < 0.0001$.

areas on a less frequent basis. To test this possibility, we first use information on the position of each site in the settlement hierarchy to associate specific centers with their administered populations. These administrative relationships were likely hierarchical and nested in at least three levels, with the span of control of local centers being limited to the settlement itself, of district capitals to the residents of all sites in that district, and of polity capitals to all residents of the polity. These relationships among settlements, as defined by the surveyors in the Palenque and Rosario surveys and applied to the Belize Valley and Uxbenká/Ix Kuku'il surveys here, were used to estimate the populations that gathered periodically in specific sites. These are referred to as "mixing" or "contributing" populations in Table 2 and Supplemental Data Appendix 2. These mixing populations can then be compared to the epicenters and civic architectural volumes of the associated centers.

Although the definitions of epicenter and civic architecture are relatively standardized in Maya archaeology (Houston 1998), the measurements of epicenter areas are not identical between the surveys included in this analysis. In the Rosario case, de Montmollin traced the outlines of areas within settlements that contained concentrations of epicenter architecture and calculated the areas within these outlines to estimate the area of the epicenter of each local, district, or regional center. In the Palenque case, in contrast, Liendo Stuardo (2011: Table 4.4) used Turner and colleagues' (1981) method to determine the epicenter ranking of tier 1–3 settlements; as a step in this process one calculates a measure of the epicenter area within these settlements (Code AB^2, which is the square of the product of the linear dimension of all plazas and the linear dimension of all temples). Finally, in the Belize Valley and Uxbenká/Ix Kuku'il surveys, epicenter areas were calculated from polygons representing the extent of landscape modifications and constructed plazas derived from GPS mapping and lidar data. Despite this variation, all are measures of the epicenter area within settlements that can be compared to the size of the populations that likely gathered there periodically for civic-ceremonial events and activities.

With these details in mind, Figure 3 illustrates the relationship between mixing populations and epicenter areas for the centers in four of the five surveys, and Table 2 presents the estimation results. In this case, all relationships are clearly sublinear, with an exponent approaching 2/3 in the Palenque case and 5/6 in the other three cases. (The lower exponent for Palenque may be due to the exclusion of streets and paths from the AB^2 calculation versus their inclusion in the epicenter area calculation for the other three surveys.) This relationship conforms to the prediction of SST regarding the average relationship between a mixing or interacting population and the mixing area, but in this case the

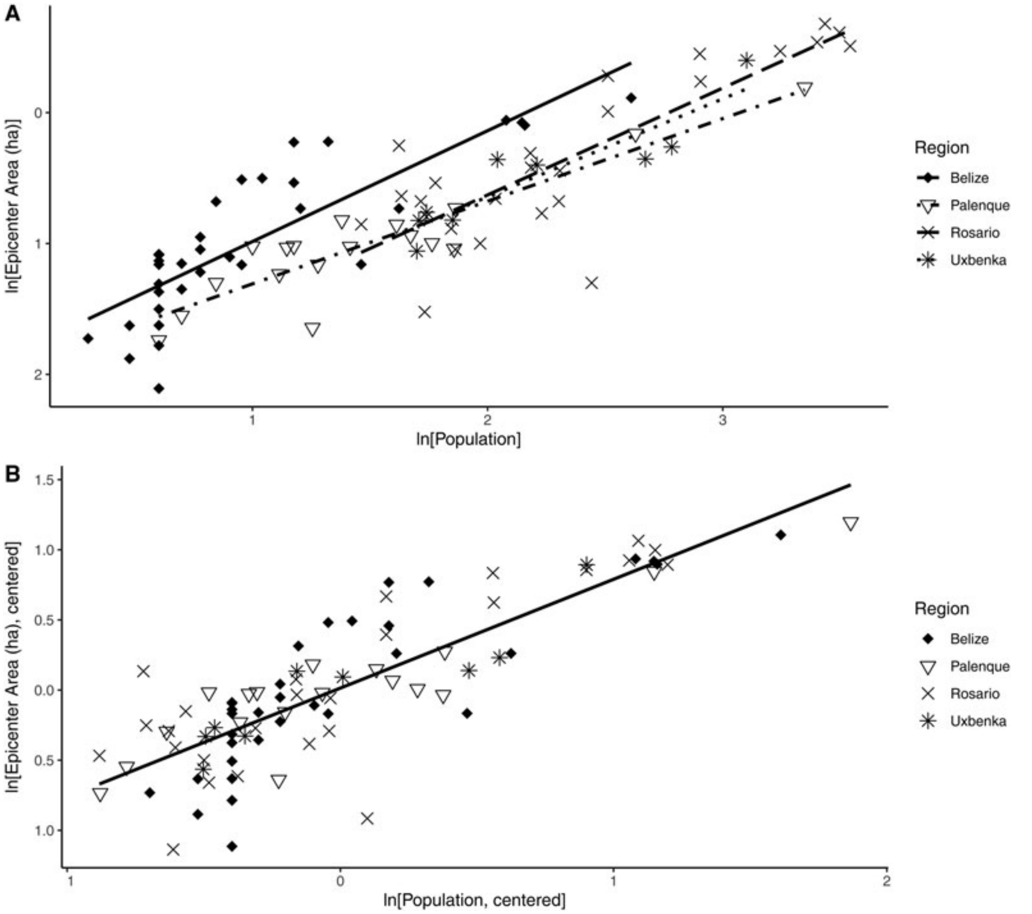

Figure 3. Relationship between contributing population and civic/epicenter area (ha) in four survey regions, taking the political/settlement hierarchy into account. (A) Raw data; (B) centered data. Note that after controlling for the baseline investment in civic area across regions the data are well summarized by a single fit line.

relevant mixing area is not the area over which people lived, but the area within which they gathered. Presumably in this case, this mixing social network came into being relatively infrequently, such that the energetic benefits of social mixing were not the dominant factor in determining the spatial distribution of residences. Also notice that the implied patterns of movement involved residents commuting to different locations, for gatherings of different scales, over some calendrically based period. This is quite different from the pattern of daily commuting in contemporary cities.

Population and Civic Architecture

Additional evidence for the periodic social mixing of groups defined by the settlement hierarchy is also apparent in the relationship between mixing populations and civic architecture construction rates (Table 2; Figure 4). Once again, the measures of civic architecture volumes are not identical across cases. In the Palenque survey, Liendo multiplied the epicenter area mentioned earlier by a third dimensional measure derived from both the summed heights of civic buildings and aspects of the quality of construction (Code X; Turner et al. 1981). In the Rosario survey, de Montmollin estimated the total volume of all civic-ceremonial architecture within each epicenter based on dimensions recorded in the field. And in the Belize Valley and Uxbenká/Ix Kuku'il surveys, civic architecture volumes were computed directly from a DEM derived from lidar survey. Thus, one might expect the measure for

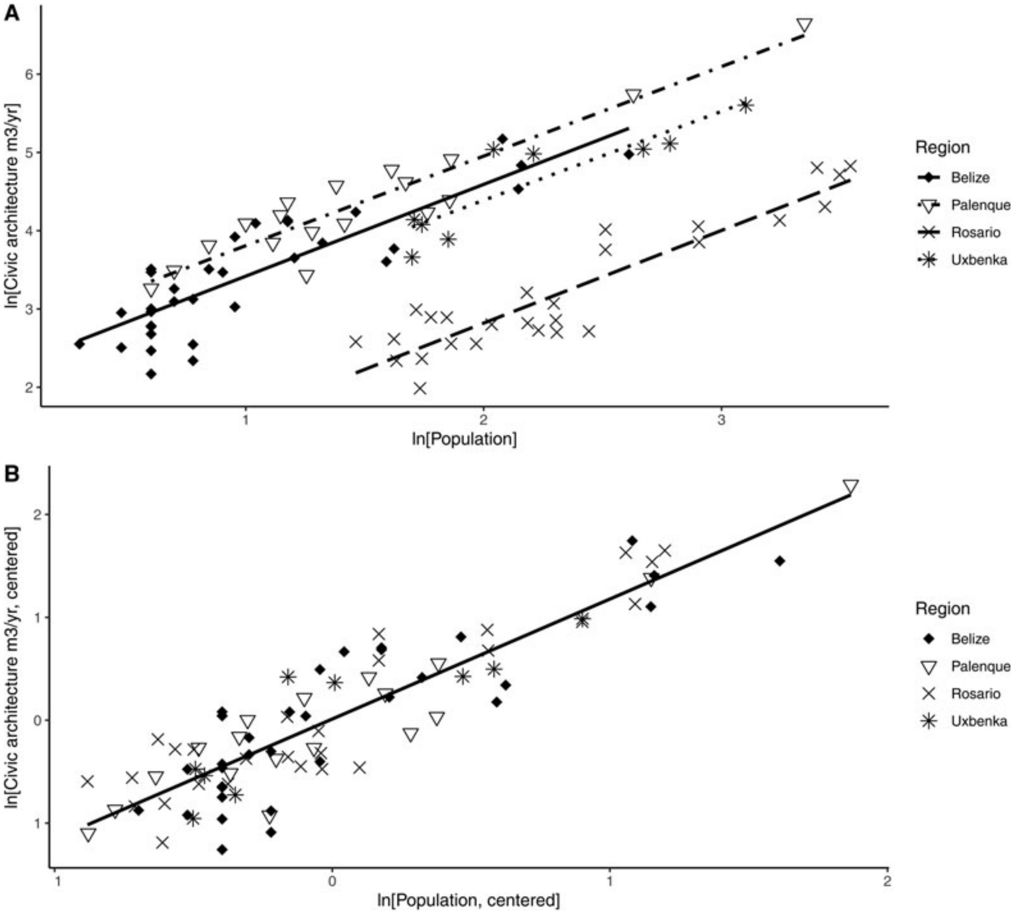

Figure 4. Relationship between contributing population and civic architecture construction rates (m^3/years in period) in four survey regions, taking the political/settlement hierarchy into account. A) Raw data; (B) centered data. Note that after controlling for the baseline investment in civic area across regions the data are well summarized by a single fit line.

the Palenque survey to be somewhat larger than, but still proportional to, the volume measures from the other surveys. One might also expect the volume estimates to be more precise for the Belize Valley and Uxbenká/Ix Kuku'il surveys compared to the Rosario survey.

It is also important to note that all the sites in the Palenque and Rosario surveys date from a single archaeological phase, but the Belize Valley and Uxbenká/Ix Kuku'il sites date to one or more phases. To control for this variation to some extent, we divided the civic architecture volumes at centers in the Belize Valley and Uxbenká survey by the number of phases of occupation at that center to estimate the amount of construction during the Late Classic (AD 600–900) period to which the other settlement data pertain. As a result, the amount of civic architecture at a center can be viewed as an average construction rate over one phase of occupation. This is obviously not ideal, because civic architecture construction rates likely varied over time; yet, improving on this approach would require extensive excavations within public buildings to determine construction volumes during each archaeological phase. With these details in mind, Table 2 shows that the slope of the fit line for all four surveys is very close to 7/6, the value predicted by SST for the relationship between a mixing population and a socioeconomic rate. These results suggest that southern Mesoamerican populations did in fact mix socially within epicenters, at least for the purpose of construction. This result, combined with the fact that the overall relationship between population and site area is not consistent with daily social mixing, coincides with other research in suggesting that southern Mesoamerican populations gathered and mixed in civic-ceremonial centers on only a periodic or episodic basis (Inomata 2006; Ossa et al. 2017). It also suggests that site boundaries by themselves do not capture these mixing populations. This phenomenon—where expected scaling relationships are apparent with respect to administered populations but not with respect to archaeological site populations—may explain the atypical results of previous scaling analyses. For example, Ossa and coauthors (2017) found that epicenter areas do not scale with site populations as predicted by SST, but they were only able to examine individual settlement populations, not contributing populations (because such data were not available for their samples).

Discussion: Low-Density Urbanism in Southern Mesoamerica

The results presented in this article illustrate ways in which Classic period Maya and Izapan settlement systems were both similar to and different from other systems. Before discussing our results, we should address two background issues: the urban status of these settlements and the reasons why their population density was so low. Although much ink has been spilled arguing about whether Maya settlements were cities or not (Hutson 2016; Sanders and Webster 1988; Willey 1982), our results suggest this may not be a particularly important question. There are many definitions of urbanism, and these low-density settlements conform to some definitions but not others (Smith 2020). SST focuses on spatially embedded human networks and argues that the social reactor process is the fundamental generative force driving change and growth (Glaeser 2011; Lobo et al. 2020; Smith 2019; Storper and Venables 2004). Our results indicate that southern Mesoamerican archaeological sites do not represent containers for social mixing, but that Maya and Izapan people still took advantage of the social reactor process in a distinctive way by congregating periodically in central places for ceremonialism, exchange, and corvée labor projects.

A central finding of settlement scaling research is that the effects of social network sizes for other properties of those networks are consistent across a wide range of societies, from contemporary urban systems to past urban systems—such as the Basin of Mexico, the Roman Empire, or medieval Europe (Cesaretti et al. 2016; Hanson et al. 2017, 2019; Ortman et al. 2014, 2015)—and even non-urban settlement systems of small-scale societies (Ortman and Coffey 2017; Ortman and Davis 2019). In this context, southern Mesoamerican centers clearly facilitated the same social reactor process that characterizes a wide range of societies. The results of this process are most evident in contemporary cities, but the process itself is common to societies of all scales, regardless of how one labels them. From the perspective of SST, then, determining whether southern Mesoamerican centers were cities is secondary to understanding exactly how they facilitated the social processes that characterize human networks of all scales.

Although our research was not designed to answer the question of *why* the densities of southern Mesoamerican cities were so low, our results do shed some light on this issue. We would first mention that recent lidar surveys have confirmed the generally low-population densities of Maya centers. For example, based on lidar survey of 2,144 km^2 across 10 survey blocks that included such major centers as Tikal, Uaxactun, Xultun, and Naachtun, Canuto and colleagues (2018) defined *urban cores* as regions containing more than 300 structures per square kilometer. Based on their population index this works out to a minimal population density of 10–20 persons per hectare. These urban cores are denser than surrounding *urban* (5–10 persons/ha), *periurban* (2–5 persons/ha), and *rural* (<2 persons/ha) areas, but they are still strikingly low. Hanson and Ortman (2017) documented population densities for ancient Roman cities ranging from 50–500 persons/ha. Even if the cores of Maya centers had elevated residential densities and concentrations of civic architecture, they still had comparatively low densities and were surrounded by much larger areas of even lower-density settlement (Rice 2006; Webster 2018). Our findings (see Figure 2B) suggest that the larger the center, the larger the surrounding sprawl, and the lower the average residential density—a pattern that is likely to be even more marked when one considers the areas over which mixing populations of district and polity capitals were drawn.

Barthel and Isendahl (2013) have discussed four possible explanations for the relatively low density of Maya cities. The first is that incomplete recognition of subsurface evidence (Johnston 2004) may result in erroneous low-density estimates. We doubt, however, that such biases would lead to the consistent patterns reported in this article. The second is that weak sociopolitical control was unable to offset centrifugal tendencies in occupation patterns (Inomata 2006). This notion is based on the assumption that, left to their own devices, agriculturalists prefer dispersion over agglomeration. This suggestion is weakened by the finding that settlement aggregation has often occurred in the absence of centralized control (Bandy and Fox 2010; Birch 2013; Gyucha 2019) and that the same scaling patterns are apparent in such societies (Ortman and Coffey 2017; Ortman and Davis 2019). Clearly agglomeration can happen with or without centralized control.

The third possibility is that southern Mesoamerican settlement patterning was an adaptive response to the tropics' high ecological diversity and low individual species density (Scarborough and Burnside 2010). Even if tropical environments have this character, the idea that intensive agriculture was not possible in such an environment is contradicted by the extensive landesque capital documented in recent lidar surveys (Canuto et al. 2018). Finally, Barthel and Isendahl's (2013:327) favored explanation is that substantial agricultural production took place within the areas that archaeologists define as settlements (Isendahl 2002). Although this is undoubtedly true, it does not explain why this was the preferred arrangement. We suggest that such an explanation will require consideration of regional demography, soils, labor productivity, land tenure systems, and economic organization (Dunning and Beach 2010; Prufer et al. 2017). What we add to the conversation here is evidence that Maya and Izapan populations nevertheless did take advantage of the social reactor process by congregating periodically in local communities, district capitals, and polity capitals.

Our results also have a bearing on the concept of low-density urbanism developed by Roland Fletcher (2012). In Fletcher's (1995) initial model, settlements grow in both population and density until they reach a size limit based on their communications and transport technology. Settlements can only cross certain size thresholds and continue to grow if they develop or borrow techniques and institutions to handle the scalar stress caused by population size and density. As part of this investigation, Fletcher observed that settlements in some ancient societies had very low densities yet grew to cover a large area. He hypothesized that these low-density cities had found an alternative pathway to growth (Fletcher 1995:93). Fletcher subsequently developed the concept of "low-density agrarian-based urbanism" through a comparative analysis of settlements of the Maya, Angkor, Bagan, and Anuradhapura (Fletcher 2012). In Fletcher's model, low densities, distinctive growth trajectories, and a suite of distinctive social, political, and agricultural systems made ancient low-density urban systems fragile and prone to collapse.

For the Maya, some have argued there may be occasional outliers to the low-density urban model based on actual settlement densities, such as Chunchucmil (Hutson 2016). Nevertheless, for Fletcher (1995), the low density of these cities overall reflects patterns of social interaction and communication that are quite different from those in most urban systems of the past and present. Although we acknowledge these differences, our results suggest that large-scale, low-density systems still took advantage of energized crowding, albeit at a slower temporal rhythm than is characteristic of urban systems today. It would be useful to follow up our study with scaling analyses of the internal structure of some of the large mapped Maya cities.

Most past and present settlement systems show an empirical pattern of increasing density with settlement size. In those cases where quantitative analysis is possible, the specific rates of densification are consistent with the SST model of settlements as containers for social mixing

(Lobo et al. 2020). Chase and Chase (2016) published preliminary data suggesting that this model is not appropriate for Classic Maya settlements, and we have reinforced and expanded on this finding through the analyses described in this article. Our results make clear that the large sites defined by archaeologists in southern Mesoamerica should not be thought of as areas that contained populations that mixed socially across that area on a regular basis. Instead, southern Mesoamerican populations seem to have congregated periodically in nested centers for political, ceremonial, construction, and economic activities.

Archaeologists have long known that Classic lowland Maya people *did* aggregate periodically for at least ceremonial activities, and perhaps economic activities as well (Inomata 2006; Ossa et al. 2017; Rice 2009). The built environments of the epicenters where these activities took place provide evidence that their outcomes exhibit the same scalar effects noted for other forms of settlement. However, because these activities took place at a lower frequency than daily, their outcomes were comparatively less than those emanating from daily social mixing in other societies. In addition, the fact that the Izapa data predate the Late Classic Maya by a millennium and that they derive from a non-Maya region strongly suggests that the distinctive settlement pattern identified in this article was part of a deep tradition in southern Mesoamerica, perhaps related to minimizing the costs of particular forms of intensive farming. The Izapa case also shows that distinctive Maya cultural characteristics or institutions cannot account for this pattern (see the Supplemental Text 1 for an initial attempt to account for the de-densification pattern observed in this study).

In this article we have shown that, although settlement densities were low, and the relevant social units do not correspond to the boundaries of individual sites, southern Mesoamerican populations nevertheless did generate economies of scale and increasing returns to scale through periodic gathering and social interaction in political centers. This means that, on a very basic level, these populations interacted with one another as in other urban traditions, and those interactions had discernible outcomes in the quantitative properties of civic architecture and infrastructure. In this sense, these urban systems operated the way other urban systems operate: they were not radically different. Our results show the importance of face-to-face social interactions within the built environment—energized crowding (Smith 2019)—as a generative force in ancient Mesoamerican societies. At the same time, periodic energized crowding was not associated with a settlement densification process. Indeed, from a functional and energetic perspective, it is not all that clear what the settlements apparent to archaeologists working in the region represent. We do not doubt their reality; several different research teams defined the settlements examined in this study, and they show consistent scaling patterns. Still, in the repertoire of settlement systems investigated through scaling analysis thus far, southern Mesoamerican societies present a distinctive pattern. Whether it can be generalized to other low-density urban systems is an open question.

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Data Availability Statement. Tables containing the data analyzed in this paper are posted with the Supplemental Materials.

Supplemental Materials. To view supplemental material for this article, please visit https://doi.org/10.1017/laq.2020.80.

Supplemental Text 1. A Model for Agglomeration Effects (Introduction to Settlement Scaling Theory).

Supplemental Table S1. List of Mathematical Symbols.

Supplemental Text 2. Descriptions of Survey Projects.

Supplemental Data Appendix 1. Site data from five settlement pattern surveys in southern Mesoamerica.

Supplemental Data Appendix 2. Mixing populations, epicenter areas, and civic architecture volumes for political units in four regional surveys.

References Cited

Arcaute, Elsa, Erez Hatna, Peter Ferguson, Hyejin Youn, Anders Johansson, and Michael Batty
2015 Constructing Cities, Deconstructing Scaling Laws. *Journal of the Royal Society Interface* 12:20140745. DOI:10.1098/rsif.2014.0745.

Ashmore, Wendy (editor)
1981 *Lowland Maya Settlement Patterns*. University of New Mexico Press, Albuquerque.

Bandy, Matthew S., and Jake R. Fox (editors)
2010 *Becoming Villagers: Comparing Early Village Societies*. Amerind Studies in Archaeology. University of Arizona Press, Tucson.

Barthel, Stephan, and Christian Isendahl
2013 Urban Gardens, Agriculture, and Water Management: Sources of Resilience for Long-Term Food Security in Cities. *Ecological Economics* 86:224–234.

Bettencourt, Luís M. A.
2013 The Origins of Scaling in Cities. *Science* 340:1438–1441.
2014 Impact of Changing Technology on the Evolution of Complex Informational Networks. *Proceedings of the IEEE* 102:1878–1891.

Bettencourt, Luís M. A., and José Lobo
2016 Urban Scaling in Europe. *Journal of the Royal Society Interface* 13:20160005. DOI:10.1098/rsif.2016.0005.

Birch, Jennifer (editor)
2013 *From Prehistoric Villages to Cities: Settlement Aggregation and Community Transformation*. Routledge, New York.

Canuto, Marcello A., Francisco Estrada-Belli, Thomas G. Garrison, Stephen D. Houston, Mary Jane Acuña, Milan Kováč, Damien Marken, Philippe Nondédéo, Luke Auld-Thomas, Cyril Castanet, David Chatelain, Carlos R. Chiriboga, Tomáš Drápela, Tibor Lieskovský, Alexandre Tokovinine, Antolín Velasquez, Juan C. Fernández-Díaz, and Ramesh Shrestha
2018 Ancient Lowland Maya Complexity as Revealed by Airborne Laser Scanning of Northern Guatemala. *Science* 361:eaau0137.

Cesaretti, Rudolf, Luís M. A. Bettencourt, José Lobo, Scott Ortman, and Michael E. Smith
2016 Population-Area Relationship in Medieval European Cities. *PLoS ONE* 11(10):e162678.

Chase, Adrian S. Z.
2016 Districting and Urban Services at Caracol, Belize: Intra-Site Boundaries in an Evolving Maya Cityscape. *Research Reports in Belizean Archaeology* 13:15–28.

Chase, Arlen F., and Diane Z. Chase
2016 The Ancient Maya City: Anthropogenic Landscapes, Settlement Archaeology, and Caracol, Belize. *Research Reports in Belizean Archaeology* 13:3–14.

Chase, Arlen F., Diane Z. Chase, Jaime J. Awe, John F. Weishampel, Gyles Iannone, Holly Moyes, Jason Yaeger, Kathryn Brown, Ramesh L. Shrestha, William E. Carter, and Juan Fernandez Diaz
2014 Ancient Maya Regional Settlement and Inter-Site Analysis: The 2013 West-Central Belize LiDAR Survey. *Remote Sensing* 6:8671–8695.

Chase, Diane Z., and Arlen F. Chase
2017 Caracol, Belize, and Changing Perceptions of Ancient Maya Society. *Journal of Archaeological Research* 25:185–249.

Coffey, William J.
1979 Allometric Growth in Urban and Regional Social-Economic Systems. *Canadian Journal of Regional Science* 2:49–62.

Culbert, T. Patrick, and Don S. Rice (editors)
1990 *Precolombian Population History in the Maya Lowlands*. University of New Mexico Press, Albuquerque.

de Montmollin, Olivier
1989 *Settlement Survey in the Rosario Valley, Chiapas, Mexico*. Papers No. 57. New World Archaeological Foundation, Provo, Utah.
1995 *Settlement and Politics in Three Classic Maya Polities*. Monographs in World Archaeology 24. Prehistory Press, Madison, Wisconsin.

Drennan, Robert D.
1988 Household Location and Compact versus Dispersed Settlement in Prehispanic Mesoamerica. In *Household and Community in the Mesoamerican Past*, edited by Richard R. Wilk and Wendy Ashmore, pp. 273–293. University of New Mexico Press, Albuquerque.

Dunning, Nicholas P., and Timothy Beach
2010 Farms and Forests: Spatial and Temporal Perspectives on Ancient Maya Landscapes. In *Landscapes and Societies: Selected Cases*, edited by I. Peter Martini and Ward Chesworth, pp. 369–389. Springer, Berlin.

Fletcher, Roland
1995 *The Limits of Settlement Growth: A Theoretical Outline*. Cambridge University Press, New York.
2012 Low-Density, Agrarian-Based Urbanism: Scale, Power and Ecology. In *The Comparative Archaeology of Complex Societies*, edited by Michael E. Smith, pp. 285–320. Cambridge University Press, New York.

Glaeser, Edward L.
2011 *The Triumph of the City: How Our Greatest Invention Makes Us Richer, Smarter, Greener, Healthier, and Happier*. Penguin, New York.

Gyucha, Attila (editor)
2019 *Coming Together: Comparative Approaches to Population Aggregation and Early Urbanization*. State University of New York Press, Albany.

Hanson, John W., and Scott G. Ortman
2017 A Systematic Method for Estimating the Populations of Greek and Roman Settlements. *Journal of Roman Archaeology* 30:301–324.

Hanson, John W., Scott G. Ortman, Luís M. B. Bettencourt, and Liam C. Mazur
2019 Urban Form, Infrastructure and Spatial Organization in the Roman Empire. *Antiquity* 93:702–718

Hanson, John W., Scott G. Ortman, and José Lobo
2017 Urbanim and the Division of Labour in the Roman Empire. *Journal of the Royal Society Interface* 14:20170367.

Hoggarth, Julie A., Jaime J. Awe, Evga Jobbová, and Christopher Sims
2010 Beyond the Baking Pot Polity: Continuing

Settlement Research in the Upper Belize River Valley. *Research Reports in Belizean Archaeology* 7:171–182.

Houston, Stephen D. (editor)
1998 *Function and Meaning in Classic Maya Architecture: A Symposium at Dumbarton Oaks, 7th and 8th October 1994*. Dumbarton Oaks, Washington, DC.

Hutson, Scott R.
2016 *The Ancient Urban Maya: Neighborhoods, Inequality, and Built Form*. University Press of Florida, Gainesville.

Inomata, Takeshi
2006 Plazas, Performers, and Spectators: Political Theaters of the Classic Maya. *Current Anthropology* 47:805–842.

Isendahl, Christian
2002 *Common Knowledge: Lowland Maya Urban Farming at Xuch*. Studies in Global Archaeology. University of Uppsala, Department of Archaeology and Ancient History, Uppsala, Sweden.

Johnston, Kevin J.
2004 The "Invisible" Maya: Minimally Mounded Residential Settlement at Itzán, Petén, Guatemala. *Latin American Antiquity* 15:145–175.

Liendo Stuardo, Rodrigo (editor)
2011 *B'aakal: Arqueología de la región de Palenque, Chiapas, México, temporadas 1996–2006*. Paris Monographs in American Archaeology Vol. 26. BAR International Series Vol. 2203. British Archaeological Reports, Oxford.

Lobo, José, Luís M. A. Bettencourt, Scott G. Ortman, and Michael E. Smith
2020 Settlement Scaling Theory: Bridging the Study of Ancient and Contemporary Urban Systems *Urban Studies* 57:731–747.

Lobo, José, Luís M. A. Bettencourt, Deborah Strumsky, and Geoffrey B. West
2013 Urban Scaling and the Production Function for Cities. *PLoS ONE* 8(3):e58407.

Marcus, Joyce
1993 Ancient Maya Political Organization. In *Lowland Maya Civilization in the Eighth Century A.D.*, edited by Jeremy A. Sabloff and John S. Henderson, pp. 111–184. Dumbarton Oaks, Washington, DC.

Ortman, Scott G., Andrew H. F. Cabaniss, Jennie O. Sturm, and Luís M. A. Bettencourt
2014 The Pre-History of Urban Scaling. *PLoS ONE* 9(2): e87902.
2015 Settlement Scaling and Increasing Returns in an Ancient Society. *Science Advances* 1(1):e1400066.

Ortman, Scott G., and Grant D. Coffey
2017 Settlement Scaling in Middle-Range Societies. *American Antiquity* 82:662–682.
2019 The Network Effects of Public Rituals. In *Reframing the Northern Rio Grande Pueblo Economy*, edited by Scott G. Ortman, pp. 75–85. Anthropological Papers of the University of Arizona Vol. 80. University of Arizona Press, Tucson.

Ortman, Scott G., and Kaitlyn E. Davis
2019 Economic Growth in the Pueblos? In *Reframing the Northern Río Grande Pueblo Economy*, edited by Scott Ortman, pp. 1–16. Anthropological Papers of the University or Arizona Vol. 80. University of Arizona Press, Tucson.

Ortman, Scott G., Kaitlyn E. Davis, José Lobo, Michael E. Smith, Luís M. A. Bettencourt, and Aaron Trumbo
2016 Settlement Scaling and Economic Change in the Central Andes. *Journal of Archaeological Science* 73:94–106.

Ortman, Scott G., Michael E. Smith, José Lobo, and Luís M. A. Bettencourt
2020 Why Archaeology Is Necessary for a Theory of Urbanization. *Journal of Urban Archaeology* 1:152–167.

Ossa, Alanna, Michael E. Smith, and José Lobo
2017 The Size of Plazas in Mesoamerican Cities: A Quantitative Analysis and Social Interpretation. *Latin American Antiquity* 28:457–475.

Prufer, Keith M., Amy E. Thompson, and Douglas J. Kennett
2015 Evaluating Airborne LiDAR for Detecting Settlements and Modified Landscapes in Disturbed Tropical Environments at Uxbenká, Belize. *Journal of Archaeological Science* 57:1–13.

Prufer, Keith M., Amy E. Thompson, Clayton R. Meredith, Brendan J. Culleton, Jillian M. Jordan, Claire E. Ebert, Bruce Winterhalder, and Douglas J. Kennett
2017 The Classic Period Maya Transition from an Ideal Free to an Ideal Despotic Settlement System at the Polity of Uxbenká. *Journal of Anthropological Archaeology* 45:53–68.

Rice, Don S.
2006 Late Classic Maya Population: Characteristics and Implications. In *Urbanism in the Preindustrial World: Cross-Cultural Approaches*, edited by Glenn R. Storey, pp. 252–276. University of Alabama Press, Tuscaloosa.

Rice, Prudence M.
2009 On Classic Maya Political Economies. *Journal of Anthropological Archaeology* 28:70–84.

Rosenswig, Robert M., and Ricardo López-Torrijos
2018 Lidar Reveals the Entire Kingdom of Izapa during the First Millennium BC. *Antiquity* 92:1292–1309.

Rosenswig, Robert M., Ricardo López-Torrijos, and Caroline E. Antonelli
2015 Lidar Data and the Izapa Polity: New Results and Methodological Issues from Tropical Mesoamerica. *Archaeological and Anthropological Sciences* 7:487–504.

Rosenswig, Robert M., Ricardo López-Torrijos, Caroline E. Antonelli, and Rebecca Mendelsohn
2013 Lidar Mapping and Surface Survey of the Izapa State in the Tropical Piedmont. *Journal of Archaeological Science* 40:1493–1507.

Sanders, William T., and David Webster
1988 The Mesoamerican Urban Tradition. *American Anthropologist* 90:521–546.

Scarborough, Vernon L., and William R. Burnside
2010 Complexity and Sustainability: Perspectives from the Ancient Maya and the Modern Balinese. *American Antiquity* 75:327–363.

Smith, Michael E.
1989 Cities, Towns, and Urbanism: Comment on Sanders and Webster. *American Anthropologist* 91:454–461.
2019 Energized Crowding and the Generative Role of Settlement Aggregation and Urbanization. In *Coming Together: Comparative Approaches to Population Aggregation and Early Urbanization*, edited by Attila Gyucha, pp. 37–58. State University of New York Press, Albany.
2020 Definitions and Comparisons in Urban Archaeology. *Journal of Urban Archaeology* 1:15–30.

Storper, Michael, and Anthony J. Venables
2004 Buzz: Face-to-Face Contact and the Urban Economy. *Journal of Economic Geography* 4:351–370.

Thompson, Amy E., Clayton R. Meredith, and Keith M. Prufer
2018 Comparing Geostatistical Analyses for the Identification of Neighborhoods, Districts, and Social Communities in Archaeological Contexts: A Case Study from Two Ancient Maya Centers in Southern Belize. *Journal of Archaeological Science* 97:1–13.

Turner, Ellen Sue, Norman I. Turner, and R. E. W. Adams
1981 Volumetric Assessment, Rank Ordering, and Maya Civic Centers. In *Lowland Maya Settlement Patterns*, edited by Wendy Ashmore, pp. 71–88. University of New Mexico Press, Albuquerque.

Walden, John P., Claire E. Ebert, Julie A. Hoggarth, Shane M. Montgomery, and Jaime J. Awe
2019 Modeling Variability in Classic Maya Intermediate Elite Political Strategies through Multivariate Analysis of Settlement Patterns. *Journal of Anthropological Archaeology* 55:101074.

Webster, David
2018 *The Population of Tikal: Implications for Maya Demography*. Archaeopress, Oxford.

Willey, Gordon R.
1982 Maya Archaeology. *Science* 215:260–267.

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Supplemental Materials to:

THE LOW-DENSITY URBAN SYSTEMS OF THE CLASSIC PERIOD MAYA AND IZAPA: INSIGHTS FROM SETTLEMENT SCALING THEORY

by

Michael E. Smith, Scott G. Ortman, José Lobo, Claire Ebert, Amy E. Thompson, Keith M. Prufer, Rodrigo Liendo Stuardo, and Robert M. Rosenswig

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Supplemental Text 1: A Model for Agglomeration Effects (Introduction to Settlement Scaling Theory)

The main text utilizes settlement scaling theory (SST) to suggest that the primary reason Classic Maya and Izapan settlements do not exhibit the densification effect that characterizes many other urban systems is that the spatial units archaeologists define as settlements represent zones over which social mixing occurred with a less-than-daily temporal rhythm. Space limitations precluded a thorough introduction to SST in the main text, and we recognize that this creates opportunities for misunderstanding regarding the assumptions of the approach, how it relates to existing research traditions in archaeology, economics and behavioral ecology, and what the approach does and does not attempt to do. To address these issues, we provide an introduction to SST that is tailored to the interests and backgrounds of archaeologists in the following pages.

Insights from anthropology, economics and sociology provide a strong foundation for viewing population aggregation as a process that emerges from the interplay of centripetal and centrifugal forces; specifically, the socio-economic advantages of concentrating human populations in space vs. the associated costs of doing so. The changes in average socio-economic properties, land-use patterns, and infrastructure characteristics that accompany this process have come to be known as “agglomeration effects”, and such effects have been a focus of research in archaeology (Birch 2013; Gyucha 2019; Ucko et al. 1972) and in economics (Brucker 2011, Fujita et al. 1999, Henderson 1988) for many decades. Our framework provides articulating arguments for this long-standing recognition that population is a key determinant of many socio-economic features of human settlements and their associated communities (Boserup 1981, Carneiro 2000, Dumond 1965, Ember 1963, Johnson and Earle 2000, Naroll 1956).

As is the case with any formal theory, SST is constructed on the basis of a few foundational assumptions. Although there is strong empirical support for these assumptions, they are not intended, nor expected, to be universally true of every group of humans everywhere and all times. Rather these assumptions identify what many research traditions consider to be the most basic processes behind the formation of human settlements. Importantly, these assumptions also facilitate the specification of *variables* and the formulation of precise statements (equations) concerning expected relationships among these variables. The equations in turn make it possible to seek evidence that either supports or invalidates the model. The goal of the model is to answer questions and provide explanations. If the results for a particular situation do not conform to the model, it could mean that the model is inadequate or inappropriate for the situation at hand, that the underlying assumptions are incorrect, or that the dynamics on the ground were systematically different from cases where the model has been applied previously. When a batch of new evidence does not conform to expectations of the model, it provides a basis for interrogating the details to see what is missing, what must be improved, or if the framework can be adjusted so as to take the new evidence into account.

With this background in mind, the first principles behind SST are that (a) human interactions are exchanges of material goods and information that take place in physical space; (b) the intensity, productivity and quality of individual-level efforts are mediated and enhanced through interaction with others (social networks); (c) any human activity can be thought of as generating benefits and incurring costs (especially the costs of moving people and things in physical space); (d) human effort is energetically bounded; and (e) the size (scale) of a human agglomeration is both a consequence and a determinant of the agglomeration's productivity. These principles provide the micro-foundations for predicting aggregate scaling phenomena in terms of the behavior of individual agents and their (economic and non-economic) interactions (Janssen 2008). Note especially that the economic concept of utility and its maximization is not part of the theory, nor are capitalist markets or specific types of political organization. In this approach, spatially concentrated social networks and associated costs, which can take different institutional and cultural forms, are sufficient for generating agglomeration effects. Most fundamentally, the social networks embedded in physical space provide the channels and relationships through which settlement dwellers generate and share information (Meier 1962).

Costs and benefits of interaction

The settlement scaling framework has been presented in several previous publications (e.g. Bettencourt 2013, 2014, Lobo et al. 2020; Ortman et al. 2014). Here, we focus on the relationships that are most central to this paper. We begin by positing that when individuals arrange themselves socially in physical space, they do so in a way that balances the benefits of interacting with others with the costs of moving around to do so. When settlements are small and unstructured, the cost of such movement is given by $c = \varepsilon L$, where ε is the energetic cost of movement and L is the transverse distance (a generalization of a diameter) across the area over which people have settled. In this circumstance the distance is proportional to the square root of the circumscribed area containing the settlement, $L \sim A^{1/2}$. The social benefits resulting from such movement, on the other hand, derive from the number of interactions a person has per unit time. This number of interactions is given by:

$$i = a_0 l N/A, \tag{S1}$$

where l is the average length of the path traveled by an individual over that period, a_0 is the distance at which interaction occurs, and N/A is the population density within this circumscribing area. These interactions are mostly intentional so that they can be translated into net benefits, y, by considering that there is some average net energetic consequence of an interaction, across all types of interactions that can occur $\hat{g}$, such that:

$$y = \hat{g} a_0 l N/A. \tag{S2}$$

Of course, each individual experiences a different set of interactions, the energetic benefits of different types of interaction vary substantially, and population densities are rarely homogeneous across an interaction area. But so long as the goal is to characterize the aggregate results of all the interactions in a network, the average outcome for the representative individual is sufficient.

Balancing costs and benefits

The key next step in constructing the model is the assumption that individuals, on average, seek to balance the costs and benefits of their interactions. Once again, not every individual achieves this balance, the time horizon over which the balance is achieved varies, and people can put energy into interactions that do not yield direct or immediate physical benefits, as in the case of gift-giving, ritual activity, and so forth. The effort of individuals to balance costs and benefits should also not be confused with the idea of maximizing or optimizing benefits or fitness. This latter idea is central to neoclassical economics and behavioral ecology (Charnov 1976; Dixit 1990; Kelly 2013; Parker and Smith 1990; Samuelson 1947), but it plays no role in SST. What SST does assert is that a balance of interaction benefits and costs emerges as an average result over a relatively short period of time, such that this balance can be viewed as a characteristic of the behavior of the representative individual. Ultimately, this view is grounded in an evolutionary perspective on human behavioral predispositions. But rather than focusing on the idea of maximizing reproductive fitness at an inter-generational time scale, SST focuses on the idea of homeostasis over shorter time scales. In all complex organisms, evolution has generated basic emotional drives that motivate individuals to seek to maintain homeostasis. Research in cognitive neuroscience suggests that humans recruit these evolutionarily ancient mechanisms to plan and strategize in ways that seek to maintain homeostasis over longer (but shorter than generational) time horizons (Damasio 1994; Kahneman 2011). At this scale, such efforts translate into a balancing of costs and benefits. Note also that this balance need not be direct or immediate or even conscious to individuals in context, as cultural and political concepts can motivate people to expend time and energy on activities that yield indirect benefits over time, in addition to immediate and direct benefits. Thus SST does not make any grand pronouncement about human nature, other that humans are satisficing entities—choosing among the best of available alternatives in the context of their preferences, constrains they operate under and limited information at their disposal (Simon 1957).

This homeostatic view of the representative individual is also embedded in urban economics via the notion of a spatial equilibrium. In any social network embedded in space, individuals experience different landscapes of interaction costs and benefits due to variation in the distribution of people, resources, infrastructure, goods, and services across their local area, and the travel and time (opportunity) costs of moving to access them. Models of urban land use in the tradition of central place theory generally assume that these costs and benefits balance at each location. The representative agent in these models has a budget which includes an income, transport costs, housing costs, and other-than-housing costs, and a budget constraint which specifies that costs and benefits must equilibrate. As a result, demand for specific locations, and thus land values and uses, adjust to take variation in travel costs into account, thus maintaining a balance of costs and benefits across the city (Alonso 1964; Von Thünen 1966; O'Sullivan 2011). Importantly, these models end up factoring the concept of utility out of the equation by assuming that it is constant across space, which is to say, the balance of costs and benefits holds at each location. These models have been celebrated for their ability to capture spatial patterns in cities (Brueckner 1987) and although they are typically presented using a different language, it turns out that they also incorporate the notion of a homeostatic balance of movement costs and interaction benefits.

Given this view of a spatial equilibrium, one can assume that, for the representative individual, movement costs and interaction benefits balance over a reasonably short time period, $c = y$. One can then substitute the relations previously derived for c and y above to yield $\varepsilon A^{1/2} = \hat{g} a_0 l N / A$, and this simplifies to:

$$A(N) = a N^{2/3}, \tag{S3}$$

where $a = (\hat{g} a_0 l / \varepsilon)^{2/3}$. One can think of a as the net attractive "force" (resources per unit time per unit area, or the power density) that an individual exerts on others through his/her interactions.

Equation (S3) expresses the way in which a salient feature of a settlement, areal extent, depends non-linearly on population size. It hypothesizes that as the number of people who mix socially on a regular basis increases, the total area taken up by these people will grow more slowly than the number of people, such that the area taken up by each person will decrease. In addition, it makes a prediction regarding the rate at which area will increase, relative to population, in this case, with an exponent of two-thirds. Notice, however, that in order to see this process empirically one must be able to define the circumscribing area A over which the social mixing of N people occurs on a regular basis, and indeed, a circumscribing area needs to be a reasonable way of characterizing the area over which people are distributed. The pre-factor a in Equation (S3) varies in accordance with the strength of social interaction and transport costs (ε) and can change over time with changes in transport and social institutions, but it is independent of population.

Defining the interaction area

Equation (S3) applies to small and spatially unstructured settlements, but as settlements grow larger the inhabitants must increasingly set aside some of the land area, A_n, for roads, paths, public spaces and public infrastructure so that residents can continue to move around and mix socially. This is the area over which the spatial equilibrium of interaction costs and benefits actually occurs, and as a result it is necessary to specify the relationship between people and the "network" area, and also to actually measure the network area if possible. We assume that on average the distance b between people is set in accordance with the current population density, such that $b \sim (A/N)^{1/2}$. This can be justified by the observation that historically infrastructure has been built or expanded in urban areas *mainly* in response to population expansion (Angel 2012, Bertaud 2018, Glaeser and Xiong 2017, Southall 1998). Thus, one can think of b as the length and width of street-frontage per resident in a city. Under this model, the total area of the access network is:

$$A_n = Nb = A^{1/2}N^{1/2}. \tag{S4}$$

From here, one can substitute $aN^{2/3}$ for A and simplify, leading to:

$$A_n = a^{1/2}N^{5/6}. \tag{S5}$$

Equation (S5) implies that, as settlements in a society grow, movement and interaction become increasingly structured by the access network and its associated public spaces, and that the area of this network grows with population more rapidly than the circumscribing area, leading the exponent of the population-area relationship to transition from 2/3 to 5/6. There is still an economy of scale in space use per capita, but the exponent of the growth rate of the built area with population is slightly higher than it is with respect to a circumscribing area.

It is important to emphasize once again that Equations (S3) and (S5) are "mean-field" models that predict the average rate of increase in the circumscribing or network area, respectively, relative to population, as specified by the exponent of N. Another way of saying this is that they yield expectation values for the area of a settlement, given its population. This means that, if one examines the relationship between population and area across many settlements in a system, the average area of a settlement of a given size will be given by Equation (S3) or (S5), depending on how the type of area that is being measured.

From interactions to socio-economic rates

The final element of SST that we consider in the main text is the relationship between population, area, frequency of interaction, and socio-economic rates. The key assumption underlying this relationship is that per capita productivity is proportional to the number of interactions (the degree of an individual's undirected socio-economic network) that an individual experiences per unit time. This notion, that increasing productivity derives from the concentration and intensification of social interaction, is the basic idea in economics models of agglomeration effects (Glaeser, et al. 1992; Glaeser, et al. 1995; Hausmann and Hidalgo 2011; Jones and Romer 2010). The notion that individual productivity is enhanced through an expansion in group size is also captured in Adam Smith's famous dictum "That the Division of

Labour is Limited by the Extent of the Market". Smith argued than an expanding division and coordination of labor, tied to an expanding population, stimulates increases in the efficiency and thus the productivity of each worker through increased skill in performing specific tasks, and a reduction in the number of times individuals have to switch between tasks (Arrow 1994; Kelly 1997; Mokyr 2006). This basic idea has been augmented by other economists who note that the concentration and specialization of producers facilitates—through copying, imitation and social learning—the transmission and accumulation of improvements in production procedures and techniques (Arrow 1962; Auerswald, et al. 2000; Young 1928).

Within archaeology, the connection between specialization, exchange, and community size has played an important role with respect to the concept of craft specialization, where it is generally assumed that the empirical marker of increasing specialization is enhanced efficiency in production, reflected in increased standardization of products, which in turn implies increased individual productivity (Brumfiel and Earle 1987; Costin 1991; Costin and Hagstrum 1995). Given this, a broader and more sociologically rich interpretation of Smith's dictum is that the productivity of an individual is systematically related to the number of people who regularly interact with each other, either directly or indirectly, in production processes (Ortman and Lobo 2020). From this perspective, the division of labor is not simply about the vertical integration of specialized tasks but about the distribution of tasks in networks that facilitate learning, knowledge flow and the integration (recombination) of information (Bettencourt 2014). These phenomena are of long-standing interest to anthropologists, archaeologists, sociologists and economists (Arrow 1994; Blau 1975; Boserup 1981; Carneiro 2000; Durkheim 1984; Johnson and Earle 2000; Naroll 1956), and SST builds on this assumption.

The assumption that individual productivity is most fundamentally driven by the number of interactions an individual experiences per unit time allows one to specify how the productivity of an individual worker changes with the size of the social group in which they work. From Equations (S1) and (S3), above, we can write:

$$y(N) = \hat{g} a_0 l \frac{N}{A_n}, \tag{S6}$$

where $y(N)$ is the output of an individual worker per unit time. Again, notice that this output is the product of the outcome of each interaction $\hat{g}$, a person's daily movement given by the path length l, the distance at which interaction occurs a_0, and the distribution of people across the network area A_n. From here, one can substitute Equation (S5) for A_n in Equation (S6) and simplify, leading to:

$$y(N) = Y_0 N^{1/6}, \tag{S7}$$

where $Y_0 = \hat{g} a_0 l a^{-1/2}$ reflects the baseline productivity of an individual working alone, and $y(N)$ is the productivity of that individual when working in a social group of size N. This relation predicts that, on average, the productivity of a worker will increase with the population size of the socio-economic network within which that person is ensconced raised to the one-sixth power. Although gains from the coordination of labor are modest for each individual, they nevertheless accumulate exponentially as the group size increases. Finally, the total output of the group $Y(N)$ is simply the product of per capita productivity and the population:

$$Y(N) = Ny = Y_0 N^{7/6}. \quad \text{(S8)}$$

Notice that this model simply captures the effects of social mixing in space, and this process is sufficiently general that one might expect such effects to occur in any context where people concentrate themselves in space for productive activities. Indeed, the network area in Equation (S5) could be defined for forms of social mixing that take place less frequently, and even in varying locations. In such cases, one may be able to observe increasing returns to population scale, as specified by Equation (S8), for forms of social mixing that involve lower-frequency movement. This is the possibility explored with respect to Classic Maya and Izapan settlements in the main text.

In the models discussed above many parameters, including $a, a_0, l, \hat{g}, y_0,$ and ε, are scale-invariant, meaning that their values are independent of N. However, the values of these parameters need not be constant across systems or over time. Indeed, it is typically observed that baseline areas and socio-economic rates vary from year to year and across systems in contemporary societies (Bettencourt 2019). In addition, there are a range of additional factors one would expect to be involved in determining the properties of any specific settlement that are not included in SST models. Given these additional considerations, a more exact way of writing scaling relationships, using Equation (S5) as an example, is:

$$A_{n_i}(N_i, t) = a_0(t) N_i(t)^{5/6} * e^{\xi_i(t)}, \quad \text{(S9)}$$

where $a_0(t)$ is standing in for $a^{1/2}$. This notation indicates that the pre-factor of the scaling relationship $a_0(t)$ is specific to a particular system at a particular time, and $e^{\xi_i(t)}$ captures the range of contextual factors unique to each city that lead to a deviation of the network area in that settlement from the average expectation. This deviation is represented as an exponential so that it will take the form of a Gaussian random variable following natural log transformation. To see this, one can take the natural logarithm of Equation (S9):

$$\ln\left[A_{n_i}(N_i, t)\right] = \ln[a_0(t)] + (5/6) * \ln[N_i(t)] + \xi_i(t), \quad \text{(S10)}$$

and then express Equation (S10) as the ensemble average. Since by definition $\langle \xi_i(t) \rangle = 0$, it can be dropped from the ensemble average, leaving the following result:

$$\langle \ln\left[A_{n_i}(N_i, t)\right] \rangle = \ln[a_0(t)] + (5/6) * \langle \ln[N_i(t)] \rangle. \quad \text{(S11)}$$

This linear function is an exact expression that relates the mean of the log of the network area across settlements in a system at time t to the mean of the log of population across those same settlements at that time. Equation (S11) helps to clarify what can and cannot be predicted using SST. One cannot exactly predict the properties of any given settlement based on its population, or vise-versa, but one can predict the average relationship and the relationship of the averages. Also, the average of the deviation of a particular property from the expectation value across cities should sum to zero, which is to say, the deviations should follow a standard normal distribution in log-transformed variables (and thus a log-normal distribution in the original variables). Finally, there is a concrete general prediction regarding the numerical value of the coefficient that relates population to network area for the log-transformed variables (and thus the exponent of the relationship for the original variables), but the numerical value of the intercept for the log-transformed variables (and the pre-factor for the original variables) is a system-specific and time-specific property that is independent of population and area. The same can be said for the relationship between population and socio-economic rates, although the value of the predicted coefficient (exponent) is given by Equation (S8) in that case. In the main text we focus on these predictions with respect to settlement systems in southern Mesoamerica.

The relationships between settlement population and area discussed above presuppose the ability to define areas over which daily interactions took place. For small and amorphous settlements, this is the area circumscribing the interacting population; and for larger cities, it is the area of residences, workplaces, shops, and transport infrastructure within which daily social mixing occurs. Given this, a key question is the extent to which the spatial units that are defined and measured in a given archaeological context correspond to the networks of interaction in space envisioned in these models. This question is addressed in the main text with respect to Classic Maya and Izapan settlements.

Accounting for the southern Mesoamerican results

In the main text we argue that Classic Maya and Izapan sites represent areas of interspersed residential and agricultural use, and that the residents within these areas congregated periodically in the site epicenter rather than mixing across the area on a daily basis. We can begin to account for this distinctive settlement pattern by illustrating how de-densifying settlement can emerge from periodic congregation for social mixing. In this situation, Equation (S2) can be re-written to reflect the fact that the mixing area is not the same as the settled area, and that perhaps only a fraction of the total population p actually travels to the center for any given occasion:

$$y = ga_0 lp \frac{N}{A_m}. \tag{S12}$$

The cost of mixing will remain $c = \varepsilon L$ because the distance to be traversed for mixing remains the overall area from which the population is drawn, but one might expect individual paths l to traverse the mixing space as opposed to just a local portion of a larger city, such that $l = {A_m}^{1/2}$. Given this, the overall scaling of area with population will be set by the rate at which the interaction area grows with increasing population. If, for example, $A_m = m_0 N^{2/3}$, as is suggested by the results in the main text, then:

$$\varepsilon A^{1/2} = ga_0 pm_0 \frac{N^{4/3}}{N^{2/3}} \rightarrow A \propto N^{4/3}. \tag{S13}$$

The overall area from which people are drawn will increase faster than the number of people who periodically congregate in the mixing space, but because the relationship between population and the mixing space will be as in the amorphous settlement model, increasing returns will also emerge from increasing connectivity within the mixing space, for those activities that take place within that space, relative to the temporal duration of mixing. This is just one possibility, but hopefully it is sufficient to show that the patterns identified in this study can be incorporated into the SST framework with additional work.

Supplemental Table S1. List of mathematical symbols

Symbol	Interpretation
c	The energetic cost for an individual to mix socially per unit time.
ε	The energetic cost of movement (e.g. calories per km per hour).
L	The transverse dimension of the area over which social mixing occurs.
A	The circumscribing area over which social mixing occurs.
y	The per capita (intensive) outcome of social interactions per unit time.
a	The baseline area taken up by a person in a mixing area.
Y	The total (extensive) outcome of social interactions per unit time.
Y_0	The baseline productivity of an individual in the absence of network effects.
N	The population within an area of social mixing.
$\hat{g}$	The mean energetic benefit of an interaction, across all types that may occur.
a_0	The distance at which social interaction typically occurs within a mixing area.
l	The length of the path traveled by an individual for interaction, per unit time.
b	The infrastructural area per capita within a mixing area.
A_n	The network, or infrastructural, area within which people move to interact.
ξ	The deviation of an individual settlement from the expectation value.
t	Time.
A_m	The epi-center area of social mixing.
p	The fraction of the population that travels to the epi-center to mix socially.
m_0	The baseline area of an epi-center for social mixing.

Supplemental Text 2: Descriptions of Survey Projects

Palenque

The *Proyecto Regional Palenque* (PREP) was conducted by Liendo Stuardo (2011). The goal of this project was to delineate the spatial extent of the Palenque regional state, and the nature of political and economic integration of the hinterland into that state. This full-coverage survey resulted in the identification of a total of 413 sites within an area of 450 km^2. The sites included here date to the Balunté period, AD 750-850, which was the demographic peak in this area. The basic data are presented in Liendo Stuardo (2011); for additional context, see Liendo Stuardo (2005; 2014), and Barnhart (2008).

Sites were identified from the presence of mounds or other architectural remains, and then classified on the basis of their architecture and size. Two categories of architecture were recognized: dwellings and nonresidential structures. The dwelling category consists of small, low platforms and range structures (higher, elongate platforms with cut-stone facades). Non-residential structures include pyramids (identified from their square ground plan, a basal area usually larger than 120 m^2, height more than 5 m, and high-quality construction material) and other specialized civic structures (ball courts, plazas and public platforms). Site populations were estimated using domestic residence counts. Thus, our units of population are households, not individuals. Site areas were measured as amorphous shapes that include all of the structures of a site. *Rank 1* sites describe the two largest and most complex settlements, Palenque and Chinikiha. These are the largest sites in the survey (see Appendix) and are interpreted as capitals of their associated polities. *Rank 2* includes thirteen sites that, like Palenque and Chinikiha, have large civic architecture (plazas, temples, ballcourts). These sites are interpreted as district capitals and are differentiated from the remaining sites (Ranks 3 through 5) by their civic architecture and their size. They present clear evidence that elite residences were closely associated with features having ceremonial-civic functions. *Rank 3* sites have more than one architectural group, and lack evidence of civic-ceremonial functions. These were most likely commoner settlements of groups larger than a household. *Rank 4* sites have a single patio group; these were classified into patio groups and informal groups. *Rank 5* sites consist of isolated platforms.

Rosario

This dataset was compiled by Olivier de Montmollin for the Grijalva River Upper Tributaries, several hundred kilometers south of Palenque, in what can be called the southwest periphery of the Maya area (de Montmollin 1989, 1995). Much of this work was focused on the Greater Rosario Valley, and all sites were given Rosario Valley site numbers. Advantages of this area include the fact that Maya occupation was essentially limited to the Terminal Classic period, and that surface architectural visibility is excellent due to the local semi-arid climate. As a result, it is reasonable to view the results as a synchronic snap-shot of the settlement system (de Montmollin 1989). In addition, correspondence between remains of settlement and topographic boundaries suggest political boundaries between local polities, allowing one to group results into a variety of nested political units.

Survey methods for this work combined Central Mexican (Sanders et al. 1979) and lowland Maya (Ashmore 1981) approaches. Site data for the Rosario Valley itself are reported in de Montmollin (1989), and survey data from adjacent areas of the Grijalva Upper Tributaries are reported in de Montmollin (1995). In the latter source, the author also summarizes the information collected from civic-ceremonial epicenters of important sites, including counts of structures by structure type (pyramids, range buildings, high platforms, ballcourts, altars, acropolis platforms, long platforms, U-shaped platforms, raised and fully-enclosed plazas), the total volume of civic-ceremonial architecture (based on compass and tape mapping), and the area in hectares of the epicenter (based on outlines on aerial photos). Finally, de Montmollin groups settlements into a three-tiered settlement hierarchy consisting of individual settlements, districts with district capitals, and polities with polity capitals. As a result, it is possible to estimate the number of dwellings associated with each level of the hierarchy and to link these populations to their respective epicenters. These data are summarized in Appendix 2.

Belize Valley

The upper Belize River Valley encompasses an area of approximately 125 km^2, extending 25 km eastward and downriver from the Maya centers of Cahal Pech to Blackman Eddy. Gordon Willey and his colleagues initiated the earliest settlement studies in the region to examine the relationship between Classic period (AD 300-900/100) monumental centers and surrounding households (Willey et al. 1965). Beginning in 1988, the Belize Valley Archaeological Reconnaissance (BVAR) Project extended Willey's study area through a block survey program designed for total coverage of the region, primarily documenting Late and Terminal Classic house mounds (Hoggarth et al. 2010). Airborne lidar survey for the BVAR study area was conducted in 2013 as part of the West-Central Belize Lidar Survey to supplement pedestrian survey (Chase et al. 2014). Quantitative spatial analyses of lidar data and subsequent ground verification have documented over 2,300 mounds in the upper Belize Valley (see Ebert et al. 2016).

Multi-dimensional scaling of attributes calculated from features documented via lidar (e.g., number and volume of structures, distance to major centers, surrounding population density) indicate that the local settlement system was organized into six tiers (i.e., groups) focused on several large Classic epicenters (Walden et al. 2019). Group 1 includes polity capitals sometimes described as "major centers," such as Baking Pot, Cahal Pech and Lower Dover. They formed the civic-ceremonial epicenters of territorial polities during the Classic period. Intermediate elite centers are split into three categories, including multi-component centers (Group 2), medium-sized centers with a single plaza and an ancestral triadic shrine (Group 3), and small centers and high-status commoner households (Group 4). High-status commoner households without an overt ceremonial function characterized Group 5 sites (Walden et al. 2019). A sixth group includes lower status commoner settlements.

Uxbenká

Uxbenká and Ix Kuku'il are two neighboring polities located on the calcareous sandstone foothills of the southern Maya Mountains in Belize. Households in this region were primarily built on leveled hilltops or ridges near to arable land. These settlement choices were likely in response to high rainfall (>4000mm/year, flooding low lying areas), a steeply incised landscape, and the high agricultural productivity of hillslopes (Culleton 2012). Similarly, civic-ceremonial core plazas and district seats (sensu Smith 2010) were constructed on highly modified hilltops and ridgetops. The Uxbenká Archaeological Project (UAP) has conducted a decade of pedestrian settlement survey and excavations including ground-truthing sites detected with aerial lidar data and high-resolution satellite imagery (Prufer et al. 2015). Combined survey and excavations have produced a comprehensive diachronic settlement history of both polities. Both have their origins prior to the Early Classic and maximum populations during the Late Classic (Prufer et al. 2017; Thompson et al. 2018).

For Uxbenká and Ix Kuku'il, we define a domestic site as a discrete architectural cluster situated on a leveled hilltop or ridge. Household sites vary from single isolated domiciles to expansive residential clusters with multiple structures and plazas. Some outlying districts have small temples, hilltop shrines, and ballcourts, and extensive landscape modifications. The Uxbenká core is dispersed across several ridgetops and has 136 sites outside of the civic core while Ix Kuku'il has 106 sites outside of the single large civic core . The mean number of buildings per site at Uxbenká is 3.87 and the average area per site is 1730 m^2. At Ix Kuk'il mean building per site is 3.3 buildings with an average area of 1512 m^2. Civic core sites have the highest investments in landscape modification, primarily cut-and-fill to level and expand hilltops (Prufer and Thompson 2016), suggesting they were constructed to be the foci of group interactions. At Uxbenká the average core area contains 6.7 buildings each with a mean area of 6544 m^2. In comparison, Ix Kuku'il the single civic core site contains 8 buildings and has an area of 10,201 m^2.

Izapa

The site of Izapa is famous for its large mounds and elaborate sculpture, but nothing was known of the regional structure of the polity until Rosenswig initiated the Izapa Regional Settlement Project (IRSP) in 2011. Two 60 km^2 survey zones were documented with lidar, and over 1,000 mounds were surface-collected and the periods of their occupation determined on a phase-by-phase basis (Rosenswig et al. 2018; Rosenswig et al. 2013). A second campaign of lidar data collection in 2015 brought the total coverage to almost 600 km^2 and documented 40 lower-order monumental centers that were all occupied from 700-100 BC (Rosenswig and López-Torrijos 2018). Izapa was the capital city of this regionally-organized polity (Rosenswig 2019), and the dozens of lower-order centers all employed the same planning principles, defining a four-tiered settlement hierarchy based on site size and the range of architectural features (Rosenswig and López-Torrijos 2018). The Izapa kingdom centers encompassed an area of at least 450 km^2 with the largest centers defensively arranged around the perimeter of the polity's territory.

References Cited

Alonso, William
1964 *Location and Land Use: Toward a General Theory of Land Rent*. Harvard University Press, Cambridge, MA.

Arrow, Kenneth J.
1962 The Economic Implications of Learning by Doing. *The Review of Economic Studies* 29(3):155-173.

1994 The Division of Labor in the Economy, the Polity, and Society. In *The Return to Increasing Returns*, edited by J. M. Buchanan and Y. J. Yoon, pp. 69-84. The University of Michigan Press, Ann Arbor.

Ashmore, Wendy (editor)
1981 *Lowland Maya Settlement Patterns*. University of New Mexico Press, Albuquerque.

Auerswald, Philip, Kauffman, Stuart, Lobo, José, Shell, Karl (2000) The Production Recipes Approach to Modeling Technological Innovation: An Application to Learning-by-doing. *Journal of Economic Dynamics and Control*, 24: 389-450.

Barnhart, Edwin L.
2008 Palenque: Urban City of the Ancient Maya. In *El urbanismo en mesoamérica / Urbanism in Mesoamerica*, edited by Alba Guadalupe Mastache, Robert H. Cobean, Ángel García Cook, and Keneth G. Hirth, pp. 165-196. Proyecto Urbanismo en Mesoamérica / The Mesoamerican Urbanism Project, vol. 2. Pennsylvania State University and Instituto Nacional de Antropología e Historia, University Park and Mexico City.

Bettencourt, Luís M. A.
2013 The Origins of Scaling in Cities. *Science* 340:1438-1441.

2014 Impact of Changing Technology on the Evolution of Complex Informational Networks. *Proceedings of the IEEE* 102(12):1878-1891.

2019 Towards a Statistical Mechanics of Cities. *Comptes Rendus Physique* 20:308-318.

Birch, Jennifer (editor)
2013 *From Prehistoric Villages to Cities: Settlement Aggregation and Community Transformation*. Routledge, New York.

Blau, Peter M.
1975 Parameters of Social Structure. In *Approaches to the Study of Social Structure*, edited by P. M. Blau, pp. 220-253. Free Press, New York.

Boserup, E.
1981 *Population and technological change: a study of long-term trends*. Chicago: University of Chicago Press.

Bruckner, Jan K.
2011 *Lectures in Urban Economics*. Cambridge (MA): The MIT Press.

Brueckner, Jan K
1987 The structure of urban equilibria: A unified treatment of the Muth-Mills model. In *Handbook of regional and urban economics*, edited by E. S. Mills, pp. 821-845. vol. 2.

Brumfiel, Elizabeth M. and Timothy K. Earle (editors)
1987 *Specialization, Exchange, and Complex Societies*. Cambridge University Press, Cambridge.

Carneiro, R.L.
2000 The transition from quantity to quality: a neglected causal mechanism in accounting for social evolution. *Proceedings of the National Academy of Sciences of the United States of America*, 97: 12926-12931.

Charnov, Eric L.
1976 Optimal foraging, the Marginal Value Theorem. *Theoretical Population Biology* 9:129-136.

Chase, Arlen F., Diane Z. Chase, Jaime J. Awe, John F. Weishampel, Gyles Iannone, Holly Moyes, Jason Yaeger, Kathryn Brown, Ramesh L. Shrestha, William E. Carter, and Juan Fernandez Diaz
2014 Ancient Maya Regional Settlement and Inter-Site Analysis: The 2013 West-Central Belize LiDAR Survey. *Remote Sensing* 6: 8671-8695.

Costin, Cathy Lynne
1991 Craft Specialization: Issues in Defining, Documenting, and Explaining the Organization of Production. In *Archaeological Method and Theory, vol. 3*, edited by M. B. Schiffer, pp. 1-56. University of Arizona Press, Tucson.

Costin, Cathy Lynn and Melissa B. Hagstrum
1995 Standardization, Labor Investment, Skill, and the Organization of Ceramic Production in Late Prehispanic Highland Peru. *American Antiquity* 60(4):619-639.

Culleton, Brendan
2012 *Human Ecology, Agricultural Intensification and Landscape Transformation at the Ancient Maya Polity of Uxbenká, Southern Belize.* Ph.D. dissertation, Department of Anthropology, University of Oregon.

Damasio, Antonio
1994 *Descartes' Error: Emotion, Reason, and the Human Brain*. G. P. Putnam, New York.

de Montmollin, Olivier
1989 *Settlement Survey in the Rosario Valley, Chiapas, Mexico*. Papers of the New World Archaeological Foundation, vol. 57. New World Archaeological Foundation, Provo.

1995 *Settlement and Politics in Three Classic Maya Polities*. Monographs in World Archaeology, vol. 24. Prehistory Press, Madison.

Dixit, Avinash K. (1990) Optimization in Economic Theory. Oxford: oxford University Press.

Dumond, D.E.
1965 Population growth and cultural change. *Southwestern Journal of Anthropology*, 21: 302-324.

Durkheim, Emile
1984 *The division of labor in society*. The Free Press, New York.

Ebert, Claire E., Julie A. Hoggarth, and Jaime J. Awe
2016 Integrating Quantitative Lidar Analysis and Settlement Survey in the Belize River Valley. *Advances in Archaeological Practice* 4 (3): 284-300.

Ember, M.
1963 The relationship between economic and political development in nonindustrial societies. *Ethnology*, 2: 228-248.

Fujita, Masahisa, Krugman, Paul, Venables, Anthony J.
1999 *The Spatial Economy: Cities, Regions, and International Trade.* Cambridge (MA): The MIT Press.

Glaeser, Edward L., Hedi D. Kallal, Jose A. Scheinkman and Andrei Shleifer
1992 Growth in Cities. *Journal of Political Economy* 100(6):1126-1152.

Glaeser, Edward L., Jose A. Scheinkman and Andrei Shleifer
1995 Economic growth in a cross-section of cities. *Journal of Monetary Economics* 36(1):117-143.

Gyucha, Attila (editor)
2019 *Coming Together: Comparative Approaches to Population Aggregation and Early Urbanization*. State University Press of New York, Albany.

Hausmann, Ricardo and Cesar A. Hidalgo
2011 The Network Structure of Economic Output. *Journal of Economic Growth* 16:309-342.

Henderson, John Vernon
1988 *Urban Development: Theory, Fact and Illusion*. New York: Oxford University Press.

Hoggarth, Julie A., Jaime J. Awe, Evga Jobbová, and Christopher Sims
2010 Beyond the Baking Pot Polity: Continuing Settlement Research in the UPper Belize River Valley. *Research Reports in Belizean Archaeology* 7: 171-182.

Johnson, A.W., Earle, T.K.
2000 *The Evolution of Human Societies: From Foraging Group to Agrarian State*. Stanford: Stanford University Press.

Jones, Charles I. and Paul M. Romer
2010 The New Kaldor Facts: Ideas, Institutions, Population, and Human Capital. *American Economic Journal: Macroeconomics* 2(1):224-245.

Kahneman, Daniel
2011 *Thinking, Fast and Slow*. Farrar, Strauss and Giroux, New York.

Kelly, Morgan
1997 The Dynamics of Smithian Growth. *The Quarterly Journal of Economics* 112(3):939-964.

Kelly, Robert L.
2013 *The Lifeways of Hunter-Gatherers: The Foraging Spectrum*. Cambridge University Press, Cambridge.

Liendo Stuardo, Rodrigo
2005 An Archaeological Study of the Settlement Distribution in the Palenque Area, Chiapas, Mexico. *Anthropological Notebooks (Slovene Anthropological Society)* 11: 31-44.

2011 *B'aakal: Arqueología de la Región de Palenque, Chiapas, México, Temporadas 1996-2006*. Paris Monographs in American Archaeology, 26. BAR, International Series, vol. 2203. British Archaeological Reports, Oxford.

Liendo Stuardo, Rodrigo, Javier López Mejía, and Arianna Campisani
2014 The Social Construction of Public Spaces at Palenque and Chinikihá, Mexico. In *Mesoamerican Plazas: Arenas of Community and Power*, edited by Kenchiro Tsukamoto and Takeshi Inomata, pp. 108-120. University of Arizona Press, Tucson.

Lobo, Jose, Luis M. A. Bettencourt, Scott G. Ortman and Michael E. Smith
2020 Settlement Scaling Theory: Bridging the Study of Ancient and Contemporary Urban Systems *Urban Studies* 57(4):731-747.

Meier, R. L.
1962 *A Communications Theory of Urban Growth*. Cambridge (MA): The MIT Press.

Mokyr, Joel
2006 Long-term economic growth and the history of technology. In *Handbook of Economic Growth*, edited by P. Aghion and S. Durlauf. North Holland, London.

Naroll, R.
1956 A preliminary index of social development. *American Anthropologist*, 58: 687-715.

Ortman, Scott G., Andrew HF Cabaniss, Jennie O. Sturm and Luís MA Bettencourt
2014 The Pre-History of Urban Scaling. *PLOS ONE* 9(2):e87902.

Ortman, Scott and José Lobo
2020 Smithian growth in a nonindustrial society. *Science Advances* 6(25):eaba5694.

O'Sullivan, A.
2011 *Urban Economics*. McGraw Hill, New York.

Parker, Geoff A. and John Maynard Smith
1990 Optimality theory in evolutionary biology. *Nature* 348:27-33.

Prufer, Keith M. and Amy E. Thompson
2016 LiDAR Based Analyses Of Anthropogenic Landscape Alterations As A Component Of The Built Environment. *Advances in Archaeological Practice* 4 (3): 393-409.

Prufer, Keith M., Amy E. Thompson, and Douglas J. Kennett
2015 Evaluating Airborne LiDAR for Detecting Settlements and Modified Landscapes in Disturbed Tropical Environments at Uxbenká, Belize. *Journal of Archaeological Science* 57: 1-13.

Prufer, Keith M., Amy E. Thompson, Clayton R. Meredith, Brendan J. Culleton, Jillian M. Jordan, Claire E. Ebert, Bruce Winterhalder, and Douglas J. Kennett
2017 The Classic Period Maya Transition from an Ideal Free to an Ideal Despotic Settlement System at the Polity of Uxbenká. *Journal of Anthropological Archaeology* 45: 53-68.

Rosenswig, Robert M.
2019 The Izapa Kingdom's Capital: Formative-Period Settlement Patterns, Population and Dating Low-Relief Stelae. *Latin American Antiquity* 30 (1): 91-108.

Rosenswig, Robert M., Brendan J. Culleton, Douglas J. Kennett, Rosemary Lieske, Rebecca R. Mendelsohn, and Yahaira Núñez-Cortés
2018 The Early Izapa Kingdom: Recent Excavations, New Dating and Middle Formative Ceramic Analyses. *Ancient Mesoamerica* 29 (2): 373-393.

Rosenswig, Robert M. and Ricardo López-Torrijos
2018 Lidar Reveals the Entire Kingdom of Izapa During the First Millennium BC. *Antiquity* 92: 1292-1309.

Rosenswig, Robert M., Ricardo López-Torrijos, Caroline E. Antonelli, and Rebecca Mendelsohn
2013 LiDAR Mapping and Surface Survey of the Izapa State in the Tropical Piedmont. *Journal of Archaeological Science* 40: 1493-1507.

Samuelson, Paiul (1947) *Foundations of Economic Analysis*. Cambridge (MA): Harvard University Press.

Sanders, William T., Jeffrey R. Parsons, and Robert S. Santley
1979 *The Basin of Mexico: Ecological Processes in the Evolution of a Civilization*. Academic Press, New York.

Simon, Herbert A. (1956). Rational Choice and the Structure of the Environment. *Psychological Review*. 63: 129–138.

Smith, Michael E.
2010 The Archaeological Study of Neighborhoods and Districts in Ancient Cities. *Journal of Anthropological Archaeology* 29 (2): 137-154.

Thompson, Amy E., Clayton R. Meredith, and Keith M. Prufer
2018 Comparing Geostatistical Analyses for the Identification of Neighborhoods, Districts, and Social Communities in Archaeological Contexts: A Case Study from Two Ancient Maya Centers in Southern Belize. *Journal of Archaeological Science* 97: 1-13.

Ucko, Peter J., Ruth Tringham and George W. Dimbleby (editors)
1972 *Man, Settlement, and Urbanism*. Schenkman Publishing Company, Cambridge, Massachussetts.

von Thünen, Johann Heinrich
1966 *The Isolated State*. Pergamon Press, Oxford.

Walden, John P., Claire E. Ebert, Julie A. Hoggarth, Shane M. Montgomery, and Jaime J. Awe
2019 Modeling variability in Classic Maya intermediate elite political strategies through multivariate analysis of settlement patterns. *Journal of Anthropological Archaeology* 55.

Willey, Gordon R., William R. Bullard, John B. Glass, and James C. Gifford
1965 *Prehistoric Maya Settlements in the Belize Valley*. Papers, vol. 54. Peabody Museum of Archaeology and Ethnology, Harvard University, Cambridge, MA.

Young, Allyn (1928) Increasing retruns and economic progress. *The Economic Journal*, 38: 527-542.

Supplemental Data Appendix

Appendix 1. Site data from five settlement pattern surveys in southern Mesoamerica.

Survey	Site	Area (ha)	Domestic Structure Count
Belize Valley	Atalaya	0.0844	4
Belize Valley	Bacab Na	0.7169	4
Belize Valley	Baking Pot	5.1774	46
Belize Valley	Bedran	0.2542	4
Belize Valley	Blackman Eddy	1.9114	21
Belize Valley	BR-147	0.1871	4
Belize Valley	BR-180/168	1.0795	6
Belize Valley	BR-19	0.1254	2
Belize Valley	BR-260	0.1274	4
Belize Valley	BR-96	0.2601	4
Belize Valley	Cahal Pech	2.8374	34
Belize Valley	Cas Pek	0.051	6
Belize Valley	Ch'um Group	0.1768	4
Belize Valley	Ek Tzul	0.8601	10
Belize Valley	Esperanza	0.5	6
Belize Valley	Floral Park	0.6163	8
Belize Valley	Ixim Group	0.1268	4
Belize Valley	Lower Barton Creek	1.0749	14
Belize Valley	Lower Dover	3.1321	52
Belize Valley	Lubul Huh	0.0945	3
Belize Valley	Manbatty Site	0.1834	4
Belize Valley	Martinez Group	0.1069	5
Belize Valley	Melhado Site	3.7686	5
Belize Valley	Nohoch Ek	0.6553	9
Belize Valley	North Caracol Farm	8.7611	11
Belize Valley	Spanish Lookout	0.3671	4
Belize Valley	Tolok 1	0.0976	6
Belize Valley	Tutu Uitz Na	0.2409	5
Belize Valley	Tuztziiy K'in	0.4484	7
Belize Valley	Xualcanil (Cayo Y)	1.7158	15
Belize Valley	Xunantunich	9.9376	63
Belize Valley	Yaxtun	0.1128	3
Belize Valley	Zinic	0.2322	8
Belize Valley	Zopilote	0.4293	3
Belize Valley	Zotz	0.0369	4
Belize Valley	Zubin	0.2184	9
Ix Kuku'il	1	0.1369	1
Ix Kuku'il	2	0.2111	5
Ix Kuku'il	3	0.1436	3

Survey	Site	Area (ha)	Domestic Structure Count
Ix Kuku'il	4	0.1002	2
Ix Kuku'il	5	0.0297	2
Ix Kuku'il	6	0.0703	2
Ix Kuku'il	7	0.7298	2
Ix Kuku'il	8	0.0831	2
Ix Kuku'il	9	0.0336	2
Ix Kuku'il	10	0.1274	3
Ix Kuku'il	11	0.0562	3
Ix Kuku'il	12	0.0222	2
Ix Kuku'il	13	0.163	4
Ix Kuku'il	14	0.0241	1
Ix Kuku'il	15	0.117	6
Ix Kuku'il	16	0.1526	5
Ix Kuku'il	17	0.0774	3
Ix Kuku'il	18	0.0783	2
Ix Kuku'il	19	0.5782	10
Ix Kuku'il	20	0.2068	5
Ix Kuku'il	21	0.0339	1
Ix Kuku'il	22	0.1939	3
Ix Kuku'il	23	0.2318	2
Ix Kuku'il	24	0.2143	5
Ix Kuku'il	25	0.0897	1
Ix Kuku'il	26	0.0481	1
Ix Kuku'il	27	0.0682	3
Ix Kuku'il	28	0.0325	1
Ix Kuku'il	29	0.11	4
Ix Kuku'il	30	0.0914	1
Ix Kuku'il	31	0.0751	1
Ix Kuku'il	32	0.9274	9
Ix Kuku'il	33	0.3542	5
Ix Kuku'il	34	0.0331	3
Ix Kuku'il	35	0.1354	7
Ix Kuku'il	36	0.1797	3
Ix Kuku'il	37	0.0959	3
Ix Kuku'il	38	0.0231	3
Ix Kuku'il	39	0.0954	3
Ix Kuku'il	40	0.1157	3
Ix Kuku'il	41	0.1473	3
Ix Kuku'il	42	0.1736	2
Ix Kuku'il	43	0.1339	4
Ix Kuku'il	44	0.0429	4
Ix Kuku'il	46	0.0244	4
Ix Kuku'il	47	0.0447	4

Survey	Site	Area (ha)	Domestic Structure Count
Ix Kuku'il	48	0.058	4
Ix Kuku'il	49	0.0626	3
Ix Kuku'il	51	0.2036	10
Ix Kuku'il	52	0.0441	2
Ix Kuku'il	53	0.044	1
Ix Kuku'il	54	0.2638	1
Ix Kuku'il	55	0.148	3
Ix Kuku'il	56	0.0286	3
Ix Kuku'il	57	0.0329	4
Ix Kuku'il	58	0.1165	3
Ix Kuku'il	59	0.1843	9
Ix Kuku'il	60	0.4213	7
Ix Kuku'il	61	0.1625	5
Ix Kuku'il	62	0.0414	1
Ix Kuku'il	63	0.1625	5
Ix Kuku'il	64	0.1651	2
Ix Kuku'il	65	0.0338	1
Ix Kuku'il	66	0.121	4
Ix Kuku'il	67	0.1753	2
Ix Kuku'il	68	0.0455	4
Ix Kuku'il	71	0.0342	2
Ix Kuku'il	75	0.3313	2
Ix Kuku'il	76	0.0861	3
Ix Kuku'il	78	0.0667	1
Ix Kuku'il	79	0.27	3
Ix Kuku'il	80	0.0594	2
Ix Kuku'il	81	0.0917	3
Ix Kuku'il	82	0.063	1
Ix Kuku'il	83	0.1523	5
Ix Kuku'il	84	0.3663	4
Ix Kuku'il	85	0.0883	1
Ix Kuku'il	87	0.0299	2
Ix Kuku'il	88	0.1058	3
Ix Kuku'il	89	0.0516	1
Ix Kuku'il	90	0.1225	4
Ix Kuku'il	91	0.0438	2
Ix Kuku'il	92	0.0918	7
Ix Kuku'il	119	0.3107	5
Ix Kuku'il	120	0.1065	1
Ix Kuku'il	123	0.0484	2
Ix Kuku'il	124	0.0465	4
Ix Kuku'il	125	0.0236	2
Ix Kuku'il	126	0.236	2

Survey	Site	Area (ha)	Domestic Structure Count
Ix Kuku'il	127	0.9681	23
Ix Kuku'il	130	0.0535	5
Ix Kuku'il	131	0.0921	2
Ix Kuku'il	135	0.0583	2
Ix Kuku'il	136	0.1649	1
Izapa	in Guatemala	1.6	4
Izapa	in Guatemala	3.4	5
Izapa	in Guatemala	2.2	9
Izapa	in Guatemala	16	35
Izapa	Iz	229.0	89
Izapa	Tp 1001	5.5	13
Izapa	Tp 1082	8.7	21
Izapa	Tp 1224	0.9	4
Izapa	Tp 1231	3.6	7
Izapa	Tp 1270	1.3	7
Izapa	Tp 1367	1.6	5
Izapa	Tp 1501	0.7	4
Izapa	Tp 1502	1.8	5
Izapa	Tp 1504	0.3	3
Izapa	Tp 1505	1.4	4
Izapa	Tp 1506	0.6	4
Izapa	Tp 1507	2.9	6
Izapa	Tp 1508	4.7	13
Izapa	Tp 1509	3.0	11
Izapa	Tp 1510	3.6	4
Izapa	Tp 1511	2.6	11
Izapa	Tp 1512	1.3	5
Izapa	Tp 1513	2.2	5
Izapa	Tp 1514	1.5	6
Izapa	Tp 1515	1.2	4
Izapa	Tp 1516	4.3	14
Izapa	Tp 1517	1.5	5
Izapa	Tp 1518	2.1	6
Izapa	Tp 1519	4.5	9
Izapa	Tp 1521	4.7	14
Izapa	Tp 1521	14.1	26
Izapa	Tp 1522	0.8	4
Izapa	Tp 1523	1.1	4
Izapa	Tp 1525	1.9	5
Izapa	Tp 1527	1.2	5
Izapa	Tp 1530	42.8	55
Izapa	Tp 2013	3.3	6
Izapa	Tp 2192	1.5	4

Survey	Site	Area (ha)	Domestic Structure Count
Izapa	Tp 2241	2.5	8
Palenque	Belisario Domínguez Norte	3.872	10
Palenque	Chancalá	0.170	21
Palenque	Chinikiha	86.000	275
Palenque	Ejido Reforma	3.470	19
Palenque	El Barí	13.164	18
Palenque	El Jabalinero	2.900	4
Palenque	El Lacandon	21.800	72
Palenque	El Sacrificio	5.000	2
Palenque	La Cascada	4.439	24
Palenque	La Concepción	4.224	7
Palenque	La Providencia	4.500	15
Palenque	Lindavista	40.200	33
Palenque	N1E1-40	0.033	3
Palenque	N1E1-41	0.028	3
Palenque	N1E1-42	0.026	3
Palenque	N1E1-428	0.100	2
Palenque	N1E1-45	1.390	12
Palenque	N1E1-46	0.017	2
Palenque	N1E1-47	0.100	2
Palenque	N1E1-48	0.180	4
Palenque	N1E1-50	0.200	5
Palenque	N1E1-52	0.062	2
Palenque	N1E1-55	0.015	2
Palenque	N1E1-59	0.320	5
Palenque	N1E1-61	0.006	2
Palenque	N1E3-137	0.130	4
Palenque	N1E3-141	0.110	4
Palenque	N1E4-145	0.810	13
Palenque	N1E4-148	0.350	5
Palenque	N1E4-149	0.250	3
Palenque	N1E4-155	0.019	2
Palenque	N1E5-158	0.160	4
Palenque	N1-E5-159	0.030	2
Palenque	N1E6-380	0.044	2
Palenque	N1W1-10	0.033	2
Palenque	N1W1-15	1.520	38
Palenque	N1W1-17	0.190	2
Palenque	N1W1-18	0.400	8
Palenque	N1W1-19	0.160	7
Palenque	N1W1-21	0.015	2
Palenque	N1W1-22	0.088	3

Survey	Site	Area (ha)	Domestic Structure Count
Palenque	N1W1-23	0.022	5
Palenque	N1W1-24	0.031	2
Palenque	N1W1-25	0.025	2
Palenque	N1W1-26	0.050	3
Palenque	N1W1-29	0.210	3
Palenque	N1W1-30	0.270	4
Palenque	N1W1-31	0.043	6
Palenque	N1W1-32	0.270	2
Palenque	N1W1-36	0.002	2
Palenque	N1W1-39	0.003	2
Palenque	N1W1-4 (Michol Ridge)	1.140	7
Palenque	N1W1-402	0.040	3
Palenque	N1W1-5	0.170	7
Palenque	N1W1-6	0.003	1
Palenque	Nututun	4.600	26
Palenque	Palenque	210.000	1498
Palenque	Rancho 5 de Mayo	0.714	5
Palenque	Reforma de Ocampo	6.700	58
Palenque	S1E10-271	0.100	3
Palenque	S1E2-164	0.069	2
Palenque	S1E2-167	0.205	6
Palenque	S1E2-71	0.240	4
Palenque	S1E2-72	0.030	3
Palenque	S1E2-74	0.130	4
Palenque	S1E2-76	0.050	3
Palenque	S1E2-77	0.120	6
Palenque	S1E2-78	0.550	4
Palenque	S1E2-79	0.060	2
Palenque	S1E2-92	0.870	3
Palenque	S1E2-94	0.200	7
Palenque	S1E2-95	0.047	3
Palenque	S1E2-96	0.059	3
Palenque	S1E2-97	0.021	3
Palenque	S1E3-101	0.024	2
Palenque	S1E3-103	1.100	12
Palenque	S1E3-104	0.810	12
Palenque	S1E3-105	4.500	24
Palenque	S1E3-107	0.040	2
Palenque	S1E3-108	3.400	31
Palenque	S1E3-109	0.080	2
Palenque	S1E3-110	0.110	5
Palenque	S1E3-111	0.680	9

Survey	Site	Area (ha)	Domestic Structure Count
Palenque	S1E3-112	0.005	2
Palenque	S1E3-113	0.470	11
Palenque	S1E3-114 (El Porvenir)	3.960	31
Palenque	S1E3-115	0.110	5
Palenque	S1E3-116	0.330	7
Palenque	S1E3-117	0.059	2
Palenque	S1E3-121	0.043	3
Palenque	S1E3-171	0.025	2
Palenque	S1E3-98	0.084	7
Palenque	S1E3-99	0.084	4
Palenque	S1E4-122	0.300	4
Palenque	S1E4-123	0.130	5
Palenque	S1E4-124	0.370	8
Palenque	S1E4-125	0.100	2
Palenque	S1E4-127	0.180	5
Palenque	S1E4-128	0.360	5
Palenque	S1E4-129	0.570	6
Palenque	S1E4-130	0.929	7
Palenque	S1E4-131	0.561	10
Palenque	S1E4-133	0.269	4
Palenque	S1E4-134	0.016	5
Palenque	S1E4-135	0.026	6
Palenque	S1E4-136	0.180	9
Palenque	S1E4-152(Francisco Villa)	0.580	9
Palenque	S1E4-370	0.675	4
Palenque	S1E4-374	0.014	2
Palenque	S1E4-375	0.011	2
Palenque	S1E4-376	0.014	2
Palenque	S1E5-356	0.045	2
Palenque	S1E5-360	0.102	3
Palenque	S1E5-361	0.046	2
Palenque	S1E5-363	0.011	2
Palenque	S1E6-336	0.200	3
Palenque	S1E6-337	0.053	3
Palenque	S1E6-338	0.034	3
Palenque	S1E6-340	0.990	4
Palenque	S1E6-343	0.148	1
Palenque	S1E6-345	0.092	2
Palenque	S1E6-349	0.234	2
Palenque	S1E6-350	0.532	4
Palenque	S1E6-352	0.083	3
Palenque	S1E6-355	1.693	5

Survey	Site	Area (ha)	Domestic Structure Count
Palenque	S1E7-313	0.089	5
Palenque	S1E7-314	0.007	2
Palenque	S1E7-317	0.225	2
Palenque	S1E7-319	0.117	6
Palenque	S1E7-320	0.840	3
Palenque	S1E7-322	0.420	2
Palenque	S1E7-323	0.265	4
Palenque	S1E7-324	0.028	2
Palenque	S1E7-325	0.066	2
Palenque	S1E7-326	0.028	2
Palenque	S1E7-327	0.008	2
Palenque	S1E7-328	0.052	2
Palenque	S1E7-329 (El Chinal)	0.073	3
Palenque	S1E7-330	0.008	2
Palenque	S1E7-333	0.480	3
Palenque	S1E7-389	0.180	2
Palenque	S1E8-292	0.350	8
Palenque	S1E8-296	1.033	7
Palenque	S1E8-298	0.650	5
Palenque	S1E8-309	0.580	3
Palenque	S1E8-310	0.066	2
Palenque	S2E10-275	0.440	9
Palenque	S2E2-168	0.066	3
Palenque	S2E3-178	0.173	5
Palenque	S2E3-179	0.001	2
Palenque	S2E3-180	0.030	2
Palenque	S2E3-181	0.064	2
Palenque	S2E5-188	0.077	3
Palenque	S2E5-189	0.185	4
Palenque	S2E5-190	0.111	2
Palenque	S2E5-191	0.002	2
Palenque	S2E5-192	0.007	2
Palenque	S2E5-195	0.073	2
Palenque	S2E5-196	0.029	2
Palenque	S2E9-389	0.504	4
Palenque	S3E6-202	0.026	2
Palenque	S3E6-203	0.046	3
Palenque	S3E6-204	0.051	2
Palenque	S3E6-205	0.009	2
Palenque	S3E6-206	0.039	3
Palenque	S3E6-207	0.044	3
Palenque	S3E6-208	0.014	2
Palenque	S3E6-209	0.856	10

Survey	Site	Area (ha)	Domestic Structure Count
Palenque	S3E6-210	0.041	3
Palenque	S3E6-211	0.016	3
Palenque	S3E6-213	0.220	4
Palenque	S3E6-214	0.380	6
Palenque	S3E7-218	0.240	5
Palenque	S3E7-219	0.018	2
Palenque	S3E7-220	0.500	3
Palenque	S3E7-224	0.003	2
Palenque	S3E7-225	0.007	2
Palenque	S4E6-217	0.022	3
Palenque	S4E7-228	0.219	8
Palenque	S4E7-230	0.009	3
Palenque	S4E7-235	0.420	5
Palenque	S4E7-238	0.140	4
Palenque	S4E7-241	0.012	2
Palenque	S4E7-244	0.262	3
Palenque	S4E7-246	0.147	4
Palenque	S4E7-250	0.005	2
Palenque	S4E8-254	0.170	5
Palenque	S4E8-257	0.036	9
Palenque	S4E8-258	0.650	4
Palenque	S4E8-261	0.008	3
Palenque	S4E8-262	0.160	6
Palenque	S4E8-263	0.019	2
Palenque	S4E8-269	0.534	7
Palenque	S4E8-394	0.130	2
Palenque	S4E8-395	0.080	4
Palenque	S4E8-397	0.160	4
Palenque	S4E8-400	0.100	3
Palenque	San Juan Chancalaíto	9.700	47
Palenque	Santa Isabel	9.900	41
Palenque	Sulusum	9.500	19
Palenque	Xupa	2.182	14
Rosario	215	1.12	9
Rosario	216	0.21	1
Rosario	217	0.76	12
Rosario	218	0.07	1
Rosario	219	14.15	149
Rosario	220	0.11	4
Rosario	221	0.5	11
Rosario	222	0.06	2
Rosario	223	0.04	1
Rosario	224	0.03	2

Survey	Site	Area (ha)	Domestic Structure Count
Rosario	225	1.24	15
Rosario	226	0.29	6
Rosario	227	31.38	128
Rosario	228	0.11	3
Rosario	229	0.66	10
Rosario	230	3.23	21
Rosario	231	0.2	5
Rosario	232	24.65	199
Rosario	234	14.74	154
Rosario	235	0.05	2
Rosario	236	0.1	2
Rosario	237	0.03	1
Rosario	238	13.93	72
Rosario	239	4.14	25
Rosario	240	0.27	4
Rosario	241	14.23	152
Rosario	242	62	402
Rosario	243	0.03	1
Rosario	244	2.39	28
Rosario	245	1.05	12
Rosario	246	1.37	22
Rosario	247	0.19	2
Rosario	248	0.15	3
Rosario	249	0.32	6
Rosario	250	8.23	70
Rosario	251	0.83	9
Rosario	252	0.33	5
Rosario	253	14.56	108
Rosario	254	0.02	1
Rosario	255	0.03	1
Rosario	257	2.47	27
Rosario	258	3.16	52
Rosario	259	0.07	2
Rosario	260	3.97	44
Rosario	261	6.02	70
Rosario	262	2.62	37
Rosario	263	1.39	17
Rosario	264	65.36	514
Rosario	265	5.25	44
Rosario	266	0.02	1
Rosario	267	0.2	5
Rosario	268	0.45	3
Rosario	269	0.49	10

Survey	Site	Area (ha)	Domestic Structure Count
Rosario	270	0.02	1
Rosario	271	9.53	96
Rosario	272	0.02	1
Rosario	273	0.12	3
Rosario	274	0.54	8
Rosario	275	0.75	7
Rosario	276	0.93	10
Rosario	277	0.48	4
Rosario	278	9.2	154
Rosario	279	1.65	16
Rosario	280	5.76	49
Rosario	281	0.39	8
Rosario	282	0.88	12
Rosario	283	0.08	3
Rosario	284	1.1	11
Rosario	285	3.23	31
Rosario	286	0.68	10
Rosario	287	2.27	15
Rosario	288	0.49	5
Rosario	289	8.27	42
Rosario	290	0.45	8
Rosario	291	0.1	2
Rosario	292	0.56	5
Rosario	293	3.14	30
Rosario	294	9.36	54
Rosario	295	0.54	11
Rosario	296	0.86	12
Rosario	297	0.89	14
Rosario	298	0.67	7
Rosario	299	0.16	3
Rosario	300	0.26	3
Rosario	301	3.78	41
Rosario	302	75.2	796
Rosario	303	3.95	24
Rosario	304	1.1	5
Rosario	305	1.17	12
Rosario	306	1.17	9
Rosario	307	1.99	15
Rosario	308	7.69	60
Rosario	309	12.73	53
Rosario	310	0.69	5
Rosario	311	0.02	1
Rosario	312	5.77	55

Survey	Site	Area (ha)	Domestic Structure Count
Rosario	313	1.18	7
Rosario	314	0.47	7
Rosario	315	3.9	20
Rosario	317	1.07	7
Rosario	318	0.19	2
Rosario	319	2.88	15
Rosario	320	0.71	10
Rosario	321	0.33	4
Rosario	322	1.86	10
Rosario	323	1.37	17
Rosario	324	2.11	14
Rosario	325	1.91	11
Rosario	326	0.49	5
Rosario	327	0.02	1
Rosario	328	2	10
Rosario	329	302	1730
Uxbenka	3	0.2244	5
Uxbenka	4	0.0269	1
Uxbenka	5	0.17	5
Uxbenka	9	0.3116	11
Uxbenka	10	0.1824	7
Uxbenka	13	0.2836	3
Uxbenka	18	0.0562	1
Uxbenka	19	0.2627	6
Uxbenka	20	0.1226	2
Uxbenka	21	0.1525	3
Uxbenka	22	0.068	4
Uxbenka	23	0.1533	5
Uxbenka	24	0.4097	6
Uxbenka	25	2.3159	35
Uxbenka	26	0.2266	13
Uxbenka	27	0.064	3
Uxbenka	28	0.7301	21
Uxbenka	29	0.1385	6
Uxbenka	30	0.0305	1
Uxbenka	31	0.0106	1
Uxbenka	32	0.0096	1
Uxbenka	33	0.1356	4
Uxbenka	34	0.1714	3
Uxbenka	35	0.4149	9
Uxbenka	36	0.0821	3
Uxbenka	37	0.3926	7
Uxbenka	38	0.0441	2

Survey	Site	Area (ha)	Domestic Structure Count
Uxbenka	39	0.0545	2
Uxbenka	42	0.3857	8
Uxbenka	43	0.2615	10
Uxbenka	44	0.2741	7
Uxbenka	45	0.0796	4
Uxbenka	47	0.1694	5
Uxbenka	48	0.0324	2
Uxbenka	50	0.0316	1
Uxbenka	51	0.0332	4
Uxbenka	52	0.0469	2
Uxbenka	53	0.071	2
Uxbenka	54	0.1175	2
Uxbenka	60	0.0731	5
Uxbenka	62	0.0851	4
Uxbenka	63	0.0688	4
Uxbenka	64	0.227	6
Uxbenka	65	0.064	4
Uxbenka	66	0.0326	1
Uxbenka	67	0.0471	1
Uxbenka	68	0.0741	2
Uxbenka	69	0.1429	3
Uxbenka	70	0.1609	1
Uxbenka	71	0.052	2
Uxbenka	72	0.0093	1
Uxbenka	73	0.7177	7
Uxbenka	74	0.2337	4
Uxbenka	75	0.1071	3
Uxbenka	76	0.444	5
Uxbenka	77	0.0643	3
Uxbenka	78	0.1203	2
Uxbenka	79	0.6485	9
Uxbenka	80	0.0964	2
Uxbenka	81	0.1609	1
Uxbenka	83	0.1964	4
Uxbenka	84	0.0939	5
Uxbenka	87	0.5444	7
Uxbenka	88	0.4817	2
Uxbenka	89	0.1411	2
Uxbenka	90	0.1345	1
Uxbenka	91	0.0302	3
Uxbenka	92	0.0589	2
Uxbenka	93	0.023	2
Uxbenka	94	0.0929	3

Survey	Site	Area (ha)	Domestic Structure Count
Uxbenka	105	0.0541	2
Uxbenka	106	0.0163	1
Uxbenka	107	0.2734	2
Uxbenka	108	0.0043	1
Uxbenka	109	0.0988	7
Uxbenka	110	0.0519	4
Uxbenka	111	0.1698	2
Uxbenka	112	0.0288	1
Uxbenka	113	0.0131	1
Uxbenka	114	0.1006	3
Uxbenka	115	0.0722	1
Uxbenka	116	0.0389	4
Uxbenka	117	0.044	2
Uxbenka	118	0.021	1
Uxbenka	119	0.0597	1
Uxbenka	120	0.0685	2
Uxbenka	121	0.1097	6
Uxbenka	122	0.0133	1
Uxbenka	123	0.0425	2
Uxbenka	124	0.1031	5
Uxbenka	A	0.4493	6
Uxbenka	F	0.2828	4
Uxbenka	I	0.7722	11
Uxbenka	L	0.1134	5
Uxbenka	M	1.2489	8
Uxbenka	X100	0.1158	1
Uxbenka	X101	0.0709	1
Uxbenka	X102	0.0632	1
Uxbenka	X103	0.1035	2
Uxbenka	X104	0.0293	1
Uxbenka	X105	0.1032	2
Uxbenka	X106	0.1009	2
Uxbenka	X107	0.2137	7
Uxbenka	X108	0.1936	5
Uxbenka	X109	0.1205	4
Uxbenka	X110	0.0832	1
Uxbenka	X111	0.0824	2
Uxbenka	X112	0.0798	4
Uxbenka	X113	0.0281	1
Uxbenka	X114	0.1765	6
Uxbenka	X115	0.4064	1
Uxbenka	X116	0.0609	2
Uxbenka	X117	0.0936	7

Survey	Site	Area (ha)	Domestic Structure Count
Uxbenka	X118	0.1639	2
Uxbenka	X129	0.0616	1
Uxbenka	X133	0.0373	3
Uxbenka	X134	0.0097	2
Uxbenka	X93	0.0554	1
Uxbenka	X94	0.0887	5
Uxbenka	X95	0.3498	6
Uxbenka	X96	0.1102	1
Uxbenka	X97	0.1882	5
Uxbenka	X98	0.1167	5
Uxbenka	X99	0.1063	1

Supplemental Appendix 2. Mixing populations, epicenter areas, and civic architecture volumes for political units in four regional surveys. The Palenque data are from Liendo (2011:Table 4.4), the Rosario data are from de Montmollin (1995: Table 14, Table 10), and data for the other two regions were compiled from recent lidar surveys for this study. Mixing populations are the summed populations of all subject settlements based on the position of each center in the settlement hierarchy.

Epicenter Site	Region	Site Level	Civic area (ha)	Civic Architecture /phase (m3)	Site Dwellings	Mixing Population	Site Area (ha)	Notes
164	R	1	4.09	51879	260	3135		Rosario Polity Capital
217	R	3	0.36	502		203	0.76	Population adjacent to the Ojo de Agua polity
219	R	2	1.91	10331	149	325	14.15	Ojo de Agua E District Capital
227	R	2	4.77	20210	129	2722	31.38	Ojo de Agua W District Capital
230	R	2	1.02	5711	23	325	3.23	Ojo de Agua E population
232	R	3	0.21	718	201	201	24.65	
234	R	3	0.38	660	153	153	14.74	
238	R	3	0.09	360	73	73	13.93	
241	R	3	0.49	1617	152	152	14.23	
242	R	1	3.22	66939	435	3482	62	Ojo de Agua Polity Capital
244	R	3	0.14	381	29	29	2.39	
250	R	3	0.13	778	70	70	8.23	
253	R	3	0.22	634	108	108	14.56	
261	R	3	0.05	519	70	277	6.02	
264	R	1	1.73	7122	528	805	65.36	Los Encentuaros Polity Capital
278	R	1	3.45	63748	154	2520	9.2	Conception Polity Capital, subject population estimated based on polity area and 70 houses/km2
285	R	3	0.23	218	43	43	3.23	
286	R	3	0.1	360		93	0.68	
289	R	3	0.56	414	42	42	8.27	
294	R	3	0.03	97	54	54	9.36	
302	R	1	2.81	11315	799	799	75.2	Ontela Polity Capital
308	R	3	0.29	784	60	60	7.69	

Epicenter Site	Region	Site Level	Civic area (ha)	Civic Architecture /phase (m3)	Site Dwellings	Mixing Population	Site Area (ha)	Notes
309	R	3	0.21	977	52	52	12.73	
312	R	3	0.16	232	55	55	5.77	
320	R	3	0.2	197			0.71	Unclear associated population
328	R	3	0.08	467			2	Unclear associated population
330	R	2	2.95	13554	1756	1756	302	Ojo de Agua W District Capital
335	R	3	0.17	533		170	12	
339	R	3		1177		197	13	
Palenque	P	1	1.56	4452319	1498	2232	210	Palenque Polity Capital
Chinikiha	P	1	0.69	552449	275	426	86	Chinikiha Polity Capital
Lindavista	P	2	0.19	81849	33	73	40.2	District Capital
La Cascada	P	3	0.15	37617	24	24	4.44	
Nututun	P	3	0.09	12284	26	26	4.6	
San Juan Chancalaíto	P	3	0.12	41567	47	47	9.7	
El Lacandon	P	3	0.09	24625	72	72	21.8	
Xupa	P	3	0.09	15804	14	14	2.18	
Rancho 5 de Mayo	P	3	0.03	3086	5	5	0.71	
Reforma de Ocampo	P	3	0.1	17105	58	58	6.7	
Santa Isabel	P	3	0.14	59922	41	41	9.9	
La Providencia	P	3	0.1	22960	15	15	4.5	
S3E6-209	P	3	0.1	12363	10	10	0.86	

Epicenter Site	Region	Site Level	Civic area (ha)	Civic Architecture /phase (m3)	Site Dwellings	Mixing Population	Site Area (ha)	Notes
La Concepción	P	3	0.05	6500	7	7	4.22	
N1E4-145	P	3	0.06	6993	13	13	0.81	
Sulusum	P	3	0.07	9647	19	19	9.5	
El Barí	P	3	0.02	2718	18	18	13.16	
N1E3-141	P	3	0.02	1823	4	4	0.11	
Atalaya	B	3	0.02	607	4	4	0.08	High-status commoner household, Baking Pot
Bacab Na	B	2	0.32	12417	4	11	0.72	Small IE center/household; no associated polity
Baking Pot	B	1	1.3	94670	46	408	5.18	Polity Capital; Population from Hoggarth et al. 2010
Bedran	B	2	0.07	2967	4	4	0.25	Baking Pot Intermediate Elite Center
Blackman Eddy	B	1	0.8	68421	21	144	1.91	Polity Capital; primarily Preclassic-Early Classic
BR-147	B	3	0.08	596	4	4	0.19	Small IE center/household, Barton Ramie
BR-180/168	B	2	0.19	5881	6	42	1.08	Lower Dover Intermediate Elite Center
BR-19	B	3	0.02	356	2	2	0.13	High-status commoner household, Barton Ramie
BR-260	B	3	0.04	293	4	4	0.13	High-status commoner household, Barton Ramie
BR-96	B	3	0.07	1005	4	4	0.26	High-status commoner household, Barton Ramie
Cahal Pech	B	1	0.84	34046	34	140	2.84	Polity Capital; Population from Ebert et al. 2016
Cas Pek	B	3	0.09	218	6	6	0.05	Small IE center/household, Cahal Pech
Ch'um Group	B	2	0.05	479	4	4	0.18	Small IE center/household, Cahal Pech
Ek Tzul	B	1	0.29	13583	10	15	0.86	Polity Capital; not yet surveyed so numbers could be off; assume both periods
Esperanza	B	2	0.11	1333	6	6	0.5	Intermediate Elite Center; no associated polity (frontier site)
Floral Park	B	2	0.19	4490	8	16	0.62	Lower Dover Intermediate Elite Center
Ixim Group	B	3	0.03	923	4	4	0.13	High-status commoner household, Baking Pot

Epicenter Site	Region	Site Level	Civic area (ha)	Civic Architecture /phase (m3)	Site Dwellings	Mixing Population	Site Area (ha)	Notes
Lower Barton Creek	B	1	0.6	6973	14	21	1.07	Polity Capital; not yet surveyed so numbers could be off
Lower Dover	B	1	0.87	148751	52	120	3.13	Polity Capital; Late Classic Only, Population from Ebert et al. 2016
Lubul Huh	B	3	0.02	321	3	3	0.09	Small IE center/household, Baking Pot
Manbatty Site	B	2	0.01	2952	4	4	0.18	Small IE center/household, Blackman Eddy
Martinez Group	B	3	0.04	1813	5	5	0.11	Small IE center/household, Cahal Pech
Melhado Site	B	2			5	5	3.77	Small IE center/household, Cahal Pech
Nohoch Ek	B	2	0.31	8333	9	9	0.66	Intermediate Elite Center; no associated polity (frontier site)
North Caracol Farm	B	2		4027	11	39	8.76	Baking Pot Intermediate Elite Center
Spanish Lookout	B	2	0.08	3233	4	4	0.37	Intermediate Elite Center; no associated polity (frontier site)
Tolok 1	B	3	0.06	352	6	6	0.1	Small IE center/household, Cahal Pech
Tutu Uitz Na	B	2	0.07	1242	5	5	0.24	Lower Dover Intermediate Elite Center
Tuztziiy K'in	B	2	0.21	3224	7	7	0.45	Cahal Pech Intermediate Elite Center
Xualcanil	B	2	0.59	13000	15	15	1.72	Intermediate Elite Center, no associated polity, architecture mostly late classic
Yaxtun	B	3	0.01	894	3	3	0.11	High-status commoner household, Baking Pot
Zinic	B	2	0.08	2945	8	8	0.23	Cahal Pech Intermediate Elite Center; same catchment as Zopilote

Epicenter Site	Region	Site Level	Civic area (ha)	Civic Architecture /phase (m3)	Site Dwellings	Mixing Population	Site Area (ha)	Notes
Zopilote	B	2	0.07	17296	3	29	0.43	Cahal Pech Intermediate Elite Center; same catchment as Zinic, architecture mostly Late classic
Zotz	B	3	0.02	148	4	4	0.04	Small IE center/household, Cahal Pech
Zubin	B	2	0.07	1064	9	9	0.22	Cahal Pech Intermediate Elite Center
Uxbenka A-G, K (LC)	U	1	2.51	400600	11	1264	4.01	Late Polity Capital. Civic Architecture includes only B-G, K, M.
Ix Kuku'il	U	1	0.44	110115	12	469	0.44	Polity Capital . Only Group A counted as civic architecture.
UXB 25 & M	U	2	0.4	95933	2	162	1.83	District Seat of UXB District 2. Civic architecture includes the temple in SG 25 and Group M.
UXB I (EC)	U	2	0.44	108841	1	110	0.78	District Seat of UXB District 3. 1 ball court is present along with a temple.
IKK F & 35	U	2	0.17	11970	5	55	0.24	District Seat of IKK District 2. Group F is a receiving area and SG 35 has a ball court. Within this district, Group E is a hilltop shrine, Group D is a multi platform area not for residences, and a temple is present in SG 32.
IKK 19	U	2	0.15	7776	1	71	0.3	District Seat of IKK District 3. Civic architecture is limited to a plaza with a large temple.
IKK J & 61	U	2	0.15	13850	3	51	0.27	District Seat of IKK District 4. Group I is a hilltop shrine, Group J has a large temple, and SG 61 has a small eastern triadic building.
IKK K	U	2	0.09	4584	2	50	0.25	District Seat of IKK District 3. Group K has a large temple and is associated with the area of SG 92.
UXB A, L, Ramp (EC)	U	1	0.55	129875	6	607	0.82	Early Polity Capital. Includes the ramp between A and L.

Notes: 1) R=Rosario, P=Palenque, U=Uxbenká & Ix Kuku'il, B=Belize Valley; 2) 1=Polity capital, 2=District capital, 3=Local center.