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Evaluating Settlement Structures in the Ancient Near East using Spatial Interaction Entropy Maximization

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Abstract

We explore settlement structures and hierarchy found in different archaeological periods in northern, specifically the Khabur Triangle (KT), and southern Mesopotamia (SM) using a spatial interaction entropy maximization (SIEM) modeling and simulation method. Regional settlement patterns are investigated in order to understand what feedback levels for settlement benefits, or incentives, and abilities to move or disperse between sites in a landscape and period could have enabled observed settlement structures to emerge or be maintained. Archaeological and historical data are then used to interpret the best results. We suggest that in the Late Chalcolithic (LC) and first half of the Early Bronze Age (EBA), the KT and SM appear to have comparable urban patterns and development, where settlement advantage feedbacks and movement are similarly shaping the two regions for those periods. Within period variations, such as restrictions to population diffusion or movement in the EBA, are possible. In the KT during the Middle Bronze Age (MBA), multiple centers begin to emerge, suggesting a lack of social cohesion and/or political fragmentation. This is similar to SM in the MBA, but we also see the emergence of a single, dominant site. In the Iron Age (IA), movement in the KT likely becomes the least constrained in all assessed periods, as socio-political cohesion facilitates this process, with small sites now the norm and dominance by one state over the region is evident. For the same period in SM, a single site (Babylon) obtains significant settlement advantages relative to its neighbors and easy movement enables it to become far larger in size and likely socially, economically, and politically dominant. Overall, the results demonstrate that the method is useful for archaeologists and social theorists in allowing them to compare different archaeological survey results, with varied spatial dimensions and diachronically, while providing a level of explanation that addresses empirical settlement patterns observed.

1 Introduction

Settlement structures have long been evaluated by archaeologist and non-archaeologists interested in understanding past urbanism and social change across time (e.g., Johnson 1980; Falconer and Savage 1995; Ortman et al. 2014). While such interests persist and are not new, most techniques used by archaeologists are generally qualitative (Kowalewski 1990) or statistical (Drennan and Peterson 2004) approaches that describe characteristics of such structures, which include site sizes and hierarchy, and aspects of urban form. Such methods provide utility in delineating differences between structures; however, there are limitations to their theoretical capacity. Qualitative techniques are limited in not providing systematic metrics that make them easily comparable to multiple cases. Many statistical techniques are limited in that they often do not explain how underlying processes, such as choice of settlement due to site advantages, could lead to new forms of settlement structures and patterns (Wilson 2012; Altaweel 2013). What are needed are approaches that can better explain how settlement structures emerge and develop.

To address this issue, this paper presents a spatial interaction entropy maximization (SIEM) technique (Wilson 1970; Bevan and Wilson 2013; Davies et al. 2014) that provides a quantitative-based explanation used to study underlying dynamics that shape settlement formation. The intent is to demonstrate how this technique can be used to compare different regional and diachronic settlement patterns, providing plausible pathways as to how given structures emerged or were maintained. Additionally, quantitative results produced are interpreted with given social or historical understanding from the research literature, allowing outputs to be mapped to socio-political or economic events that shaped studied regions. The benefit of the approach is the use of relatively few variables, helping to address archaeological cases where uncertainty is common. The method provides an interpretation of settlement structures utilizing generalized concepts that focus on sites' capacity to attract people and populations' ability to move and migrate between settlements. This has the advantage of explaining how general causal factors (e.g. geographical location, political or religious prominence, trade contacts, transport and communication, etc.), that are difficult to isolate and quantify from the fragmentary nature of the archaeological and historical records, could have affected settlement expansion, contraction, and patterns in a given geographic setting. This method also allows survey regions of different spatial dimensions to be compared and evaluated. The main aim of this paper is to provide a diachronic and comparative picture of urban dynamics occurring in Northern and Southern Mesopotamia from the period of early urbanism, during the fourth millennium BC, the era of city- and small states in the Early and Middle Bronze Ages, and the rise of empires in the Iron Age (see Algaze 2008; Ur 2010 and 2012).

Hence, eight case studies integrating several surveys from Northern, specifically the Khabur Triangle (KT), and Southern Mesopotamia (SM) are presented. The results demonstrate how feedbacks to site settlement advantages/incentive and transport over different periods change or stay similar to each other. We begin the presentation by providing background materials on the case studies. An explanation of our methodology is then provided in detail. Next, results from the eight case studies are given in three different tests that demonstrate how settlement structures could emerge or develop under different circumstances, including if sites had relatively equal chances of becoming large, if they had distinct advantages, and with the third test focusing on the robustness and sensitivity of the results from the previous two tests. The implications of the results are discussed, including possible social and political reasons that may have shaped the given settlement size distributions and modeling outputs observed. We interpret that some comparable patterns of settlement benefit feedbacks and movement were occurring in the Late Chalcolithic (LC) and Early Bronze Age (EBA) in the KT and SM, with only slight variation between the regions. Within period variations, including restrictions to movement, are a possibility based on results. The Middle Bronze Age (MBA) represents a period of fractured political landscapes that appears to be directly affecting urban patterns through restricting movement and creating multiple centers, with a single center eventually emerging in SM. In the Iron Age (IA), we now see relatively easy movement in the KT and SM, low settlement advantages for sites in KT, and high incentive growth for living in a large settlement in SM, with results likely reflecting socio-political cohesion in both regions. Outputs demonstrate the comparative utility for analyzing surveys using the advanced method. We conclude with suggestions on how the approach could be applied to understanding settlement systems in different archaeological settings.

2 Background

2.1 Case Studies: Archaeological and Historical Backgrounds

The case studies and their data derive from settlement surveys in the KT (Meijer 1986; Eidem and Warburton 1996; Lyonnet 2000; Ristvet 2005; Wright et al. 2007; Brustolon and Rova 2008; Ur and Wilkinson 2008; Ur 2010; Ur et al. 2011) and SM (Adams 1965; Adams and Nissen 1972; Adams 1972; Gibson 1972; Adams 1981; Wright 1981). The advantage of comparing these regions is they have several surveys that are near or abutting each other, allowing a wider regional perspective (Figure 1). In fact, in Northern Mesopotamia, other nearby surveys (Algaze, 1989; Wilkinson and Tucker, 1995; Ball, 2003) have been left out of the analysis, as these are not as continuous with the others. The total area covered by the KT and SM surveys are 10,203 km^2 and 34,950 km^2 respectively. While the total area in SM is much larger, the methodology to be employed accommodates different spatial scales, allowing regional comparisons to be made. We have chosen four periods to assess in the tests conducted, which are the LC (c. 4000-3100 BC), the first half of the EBA (c. 3000-2400 BC), MBA (c. 2000-1600 BC), and IA (c. 1200-600 BC). Regional chronologies are found in the assessed areas, but for simplicity and to compare the regions diachronically the abbreviations for the periods are used.

We chose cases that provide, on the one hand, a way to demonstrate how settlement structure could emerge or be sustained, while also addressing important archaeological problems. Each case study provides the possibility to look at the long-standing problem of how social developments relate to settlement patterns. The LC is chosen as one case because it was a period of emerging urbanism in Mesopotamia (Algaze 2008), including in the KT and SM, which allows us to determine what structures characterize early urban settlement patterns and how the regions assessed compare. Although there is a general tendency among scholars to consider SM as the heartland of early social complexity and urbanism (Liverani 2006), in the KT during the LC 2 (around 4200 - 3800 BC), settlements such as Tell Brak and al-Andalus reached unprecedented sizes (respectively 55 and 64 hectares) with high population densities perhaps earlier than sites in SM (Ur et al. 2007; Oates et al. 2007; Wright et al. 2007; Brustolon and Rova 2008; Ur et al. 2011) and are comparable to contemporary settlements in SM. During the LC 3-4 (around 3800 - 3400 BC), Tell Brak reaches a size of 130 ha (Ur et al. 2007 and 2011), epitomizing north Mesopotamia's early urbanism. In SM, Uruk reaches perhaps 250 ha (Finkbeiner 1991) and is far larger than any other site.

In the EBA, several large towns arise by the mid 3rd millennium BC in the KT and SM. Across Mesopotamia, small states likely dominated much of the KT and SM regions and urbanism now spreads. At times, there may have been some political or even economic integration (Archi 1998; Buccellati and Kelly-Buccellati 1999; Sallaberger 1999; Akkermans and Schwartz 2003; Ur 2013) in the KT. In SM, and in this period, the region is often portrayed as politically fragmented with numerous competing small territorial polities (Van de Mieroop 2006) strung along large branches of the Tigris and Euphrates Rivers, with the cities of Uruk (Finkbeiner 1991) and Lagash (Carter 1989/90) reaching 400 ha.

During the MBA, there are documented small kingdoms in the KT and SM (Adams 1981; Frayne 1990; Dalley 2002; Eidem 2012; Charpin 2012; Ristvet 2008, 2012, and 2013; Palmisano 2015) that are sometimes aggregated into larger states or empires, but these kingdoms are often ephemeral. The rise of Babylon, which occurs in the later half of this period, changes SM by moving the focus of political power to the northern alluvium. Other large sites, such as Umma and Nippur, seem to be relatively important towns, with an integrated rural hinterland. In the IA, a transformative new pattern of long-lived empires emerges. These empires and large states dominate much of the Near East for many centuries starting from this period, and imperialism becomes the norm in political formation. Even larger political capitals in Assyria and Babylonia are now established (Joannés 2004; Radner 2011). In the KT, few large sites are present and the settlement pattern consists of small and dispersed sites (Wilkinson and Barbanes 2000). In SM, Babylon is one of the great capitals of this period (Oates 1986; Pedersén 2011) with no other site comparable in scale. All of these cases are examples of important or arising social developments that may have directly affected or influenced urban and settlement patterns, whereby early urbanism, city-states or kingdoms, short-lived large states and empires, and patterns of continuous empires and imperialism are observed. The analysis performed will be used to assess if these socio-political developments may have had any discernable effects that potentially affected settlement structures, including site size and distribution.

2.2 Archaeological Problems and Empirical Settlement Structure

Settlement sizes from surveys are estimated from a combination of general and more intensive surveys, where in some cases ranges of occupation area are provided for any given period. While some of the KT surveys applied intensive and systematic surface survey, relatively few such methods were done in SM. For the KT, we use size extent estimated for settlements. In the methodology to be described below, we randomly select a size from provided site size ranges or use satellite imagery (Hritz 2005) to estimate site sizes where full occupation is suggested. Additionally, more intense surface survey at SM sites, including Uruk (Finkbeiner 1991), Kish (Gibson 1972), Mashkan-shapir (Stone and Zimansky 2004), and Lagash (Carter 1989/90) supplement the general survey data provided. These estimated empirical sizes are used to measure how well simulated populations, used as the proxy to measure site sizes in the model to be described, replicate the empirical record within the period studied. Finally, we will use a random sampling method (called Test 3 below) to test how robust result are, allowing us to measure how different size hierarchies and settlement structures could affect our understanding of settlement in studied periods. Ideally, we would have chosen relatively shorter periods to evaluate than what is presented here. While some surveys provide sub-chronologies within chosen periods, others do not, resulting in longer periods assessed for cases. This implies that the survey results may show many sites that are contemporary, while in reality they may have not been.

Figure 2 shows natural log rank-size distributions of the investigated regions. Table 1 summarizes statistical comparisons between settlement distributions using a Mann-Whitney-Wilcoxon test and applying a Holm-Bonferroni method for statistical significance (Holm 1979). Results indicate significant differences between the KT and SM's LC, MBA, and IA periods. Results also show the MBA and IA are significantly different when comparing to other periods within SM.

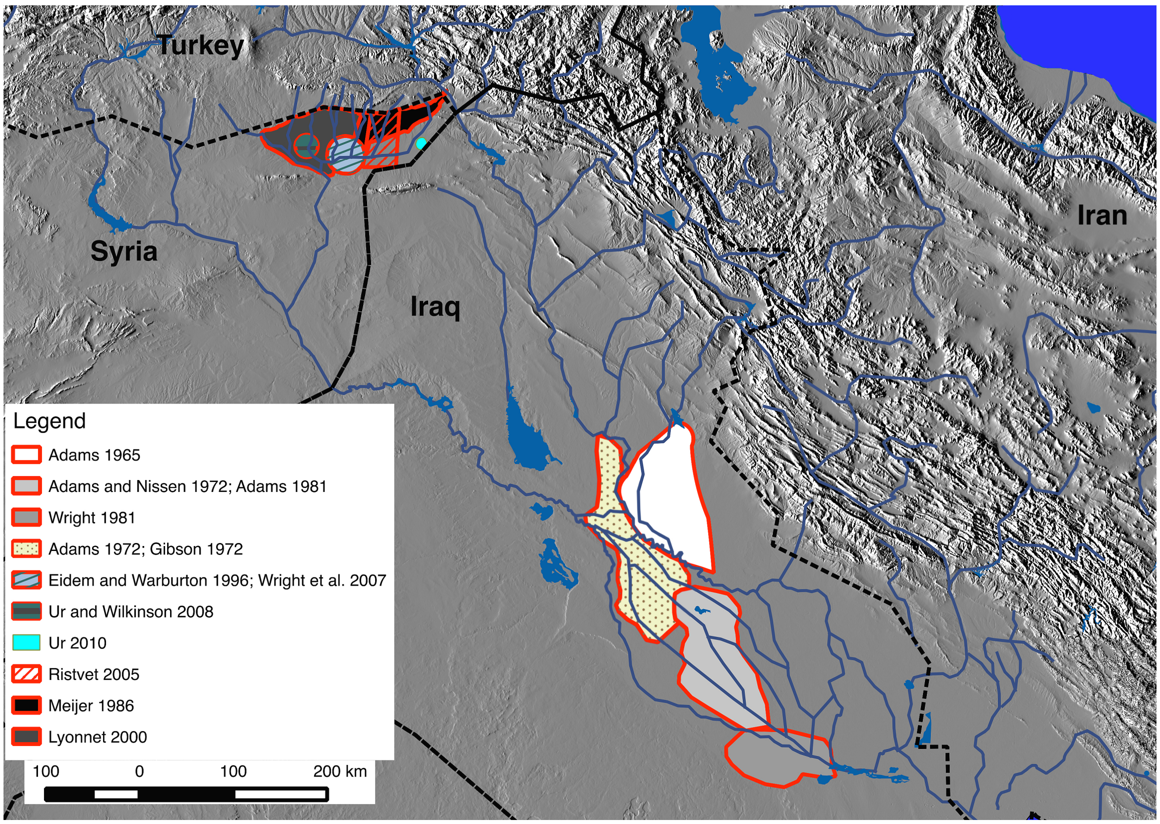

Figure 1. Regions investigated and surveys incorporated.

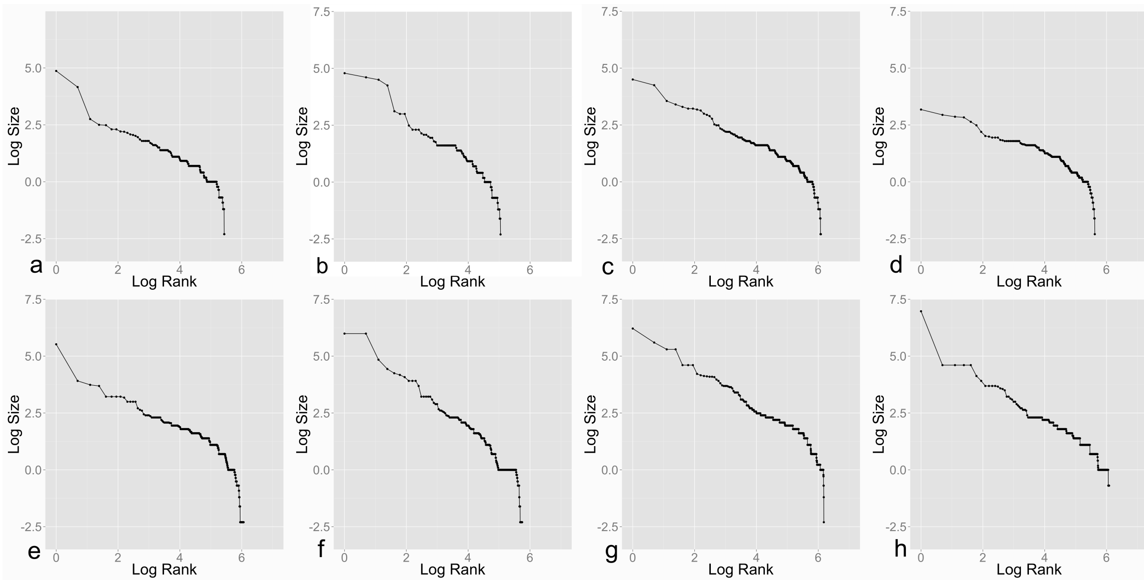

Figure 2. Natural log settlement rank-size distributions for the KT (a-d) and SM (e-h) for the LC (a & e), EBA (b & f), MBA (c & g), and IA (d & h) periods investigated.

Table 1. Mann-Whitney-Wilcoxon test comparing settlement size distributions. Highlighted and italicized values indicate statistically significant differences using a Holm-Bonferroni (Holm 1979) statistical test (α=0.05; *m*=tested hypotheses) for settlement distributions.

Survey Period	**KT_LC**	**KT_EBA**	**KT_MBA**	**KT_IA**	**SM_LC**	**SM_EBA**	**SM_MBA**	**SM_IA**
KT_LC	1							
KT_EBA	0.55	1						
KT_MBA	0.15	0.73	1					
KT_IA	0.12	0.64	0.96	1				
SM_LC	*0.04*	0.41	0.33	0.38	1			
SM_EBA	0.42	0.80	0.73	0.48	0.6955	1		
SM_MBA	*2.20E-16*	*2.20E-16*	*2.20E-16*	*2.20E-16*	*2.20E-16*	*2.20E-16*	1	
SM_IA	*1.82E-13*	*5.71E-07*	*1.41E-11*	*1.04E-09*	*2.32E-07*	*9.14E-09*	*8.02E-11*	1

3 Methodology

3.1 Background

The use of SIEM has recently gained some interest in archaeology (Wilson 2012; Bevan and Wilson 2013; Davies et al. 2014; Palmisano and Altaweel 2015). In its early applications, SIEM was used to investigate the growth and success of urban retailers (Wilson 1970; Harris and Wilson 1978). Entropy models have generally been used to study the spatial structure and distribution of settlement sizes incorporating location benefits or attractiveness, while helping to delineate the role of transport in shaping urban spaces (Wilson 2010). For archaeology, the approach allows one to determine areas of population growth or decline based on spatial location and distance to other sites, social relevance or advantage for settlement, and movement capability (Altaweel 2013; Davies et al. 2014). These variables are generalized and so are intended to capture a wide range of possible factors, including those affected by political, economic, or environmental conditions. This provides the method with advantages in determining how evident settlement structures develop from given starting points, such as all sites having an equal chance of becoming the largest site or what might occur if there are differential advantages that settlements have over other sites, with these results comparable between regions of different spatial dimensions. Although one can utilize parameters of site importance and size as inputs, the only input that is required is location, while all other parameters can be derived or tested within the model. While classical SIEM does not account for individual or household decisions for settlement, one can modify the model to accommodate bottom-up, agent-based decision-making within a SIEM framework (Altaweel 2014).

Key factors that drive model behaviors are return of attractiveness, or α, which affects how much emphasis, or feedback, people put on settling in a given place that has any type of advantagee (e.g., economic hub, location of a major temple, access to water) and β, which affects how easy or difficult it is to move/disperse and migrate to sites in a region. Both these values can be determined within the simulation by finding the best fit results of the model with empirical data, which is in this case the estimated size of sites from surveys. What makes a site attractive or affect how people migrate between any two sites could be a wide range of circumstances, which could be interpreted from known archaeological or historical data. Site size could be one proxy from the archaeological record that indicates which sites were relatively more attractive or had advantages and greater incentive for settling. The ability for sites to provide social-economic benefits or incentives that people may require often affects where people choose to live, leading to positive feedback growth (Adams 2001; Persson 2010); settlements without such advantages may diminish. The α variable allows us to relatively quantify these feedbacks and measure to what degree they affect site size growth. Put simply, this variable is used to determine the effect or impact of social-environmental factors (e.g., political, economic, religious, etc.) that made specific settlements more attractive than others (i.e., for migration or commerce).

Mobility (β), on the other hand, is a critical factor that can limit or facilitate settlement choices and how people disperse to obtain needed goods, as seen from historical examples (Fox 1971; Desrochers 2001), including in Mesopotamia (Wilkinson 1994; Algaze 2008). For example, as β increases, individuals' preferences to travel shorter distances increases for any reason, while as β decreases, individuals are able or willing to travel longer distances. This variable may be used for determining general social or physical factors that may have facilitated (e.g. roads, privileged pathways between settlements) or constrained (e.g. rivers, physical or political boundaries, warfare) movement between settlements. One possibility is that people may want to live some place because it provides them with advantages, but physical, economic, political, or other social circumstances could limit individuals' ability to migrate to more attractive areas. Overall, these variables together model interactions between sites that over time affect site size differentiation. At a macro-scale, the result of simple settlement choices can lead to site size hierarchies that could reflect social and/or political integration over larger regions (Johnson 1980; Steponaitis 1981; Adams 2001). In essence, α and β together allow us to measure any settlement structure and pattern to determine the role of site importance feedback and mobility in a given region.

3.2 Methodology Details

In employing SIEM, the key output measure is site population, used as a proxy rather than any absolute or estimate of what site population was in the past. Site population allows us to measure which sites are relatively larger or smaller in comparison to others in the region, which can then be compared to empirical settlement size estimates determined from archaeological surveys. Values of α and β that create modeled settlement structures very similar to empirical patterns allow us to begin to understand possible dynamics that enabled such structures. In other words, we measure return on site attractiveness (α), a measure of feedbacks to site benefits or incentives, and mobility (β) as factors that drive settlement structures. These two factors are then compared for all assessed cases. The variables applied in our approach include:

α: return of attractiveness that diminishes or expands the effect of Z (see below) and ultimately flow (S)

β: ability to move in the landscape or conduct transportation, with higher β signifying greater restrictions to movement

X_i: population, used as a relative measure, at a given site i

Z_j: any factor that gives a site an advantage or attractiveness (i.e., social or environmental) for settling, including exogenous or endogenous benefits; this is used to influence flow (i.e., interaction and migration) between sites and provides a proxy for measuring incentive to settle in a given area

S_{ij}: flow, which acts as a proxy for how well a site is able to support a given population relative to other surrounding sites

d_{ij}: the natural log distance between any two sites i and j using a cost surface (Fontenari et al. 2005).

In the model, α allows a site's advantages (Z) to grow or decrease relative to other sites. The other key variable that is varied is β; this is used to determine how significant or insignificant distance, or in this case cost surface, is in affecting settlement interactions and migration. For α (i.e., return of attractiveness), higher values lead to a larger site, while lower values lead to less differentiated or smaller sites. Settlements also exert demand for goods, with this demand affected by population (X) size at a given time. Additionally, Z allows us to address edge effects, as it could represent any exogenous benefits given to a settlement from regions or areas outside our study. The variable Z has the potential to place greater interpretation on internal site features versus interaction with exogenous sites. Generally, such non-geographic factors do make specific known sites larger, as sites become relatively large through modifications of Z, which can, for instance, reflect external political conditions or a favorable settlement environment.

Overall, what the model does is allow feedbacks for site advantages, ability to move in a landscape, and spatial location to influence settlement interactions that affect how effective settlements can accommodate their population's needs relative to other sites. Below, the specific flow and methods of the model are given; the code and settlement data used in these methods can be downloaded in the link found in the Supplementary Data section.

The model assesses all sites in a region and looks at their interactions. The first step of the model, used as a simulation as it incorporates time, determines the flow (S_{ij}) between sites i and j by using the following formula:

$$S_{ij} = X_i \frac{Z_j^{\alpha} e^{-\beta d_{ij}}}{\sum_k Z_k^{\alpha} e^{-\beta d_{ik}}} \tag{1}$$

In essence, flow (S) between interacting sites i and j is affected by site benefits (Z) from site j, based on return of attractiveness (α) and ability to move/disperse (β) over a cost surface distance (d) between the two sites, with population (X) regulating demand for goods between i and j. Total summed interactions among other sites (k) are used to provide a relative measure for a settlement's interactions. Flows are then summed to give the total flow (D_j) for each site j:

$$D_j = \sum_i S_{ij} \tag{2}$$

This total flow is then used to determine Z_j, or site advantages, at the next time step (i.e., $Z^{t+\delta t}$), with ε used to control the speed of change for Z. This, in essence, adjusts advantages based on total interactions of a site, as total flow (D_j) measures goods to a site or strength of interactions a site has relative to other surrounding sites. Here, k acts as a constant that is used to scale Z_j:

$$Z_j^{t+\delta t} = Z_j^t + \varepsilon(D_j - kZ_j^t) \tag{3}$$

The new site population for the next time step ($X^{t+\delta t}$) is determined by taking the new site advantages value ($Z^{t+\delta t}$), relative to all sites (k), and then rescaling based on the total population in a simulation (n) so that a site's new population is made proportional to site benefits. This is determined in this following step:

$$X_i^{t+\delta t} = n \frac{Z_i^{t+\delta t}}{\sum_k Z_k^{t+\delta t}} \tag{4}$$

Then the simulation goes back to (1) for the next time step and continues until the end. Overall, our approach follows Palmisano and Altaweel (2015). For the given model, simulations are run for 100 time ticks, which is enough time to determine what the interaction results lead to in settlement structures, as model outputs reach equilibrium. As scenarios are not stochastic, each parameter setting is executed once.

For scenarios involving relatively equal chances for sites to become the largest, there can be multiple pathways in which the simulated results could be comparable to the empirical record. At times, β, representing more and less restrictions to transport, can create comparable settlement structures at different values. When movement is more constrained, then movements are less direct, where the population can still migrate to settlements; however, they may do this through intermediate sites or move only short distances before reaching a destination where the population begins to stabilize. Greater restrictions result in more equal populations in settlements, as the population cannot easily migrate. On the other hand, α has a key role; as values become greater, larger returns for site population and advantages are enabled, allowing one or few sites to become much larger than other sites through positive feedback. This not only differentiates site population, but as α increases there are less possibilities or narrower ranges where very low or high β values can lead to comparable results. The end result is that high α ranges generally have much greater variance in population. Figure 3 serves as a guide to understanding how variance in site population and site sizes develop as α and β values increase when sites have equal advantages in becoming the largest.

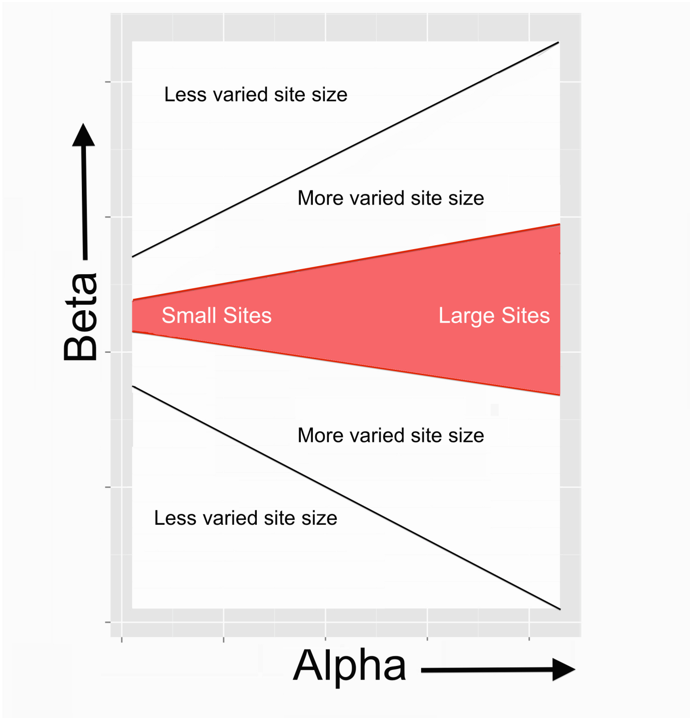

Figure 3. Conceptual graph showing where α and β values lead to given settlement structures of more even or differentiated site populations and relatively large to small sites.

4 Results

The first test looks at the role of geography and transport in shaping urban growth and settlement size structures. The aim is to identify which sites could have taken advantages of their geographic location and to what extent site attractiveness (α) and willingness to travel or capability of movement (*β*) could have affected urban growth and settlement structure if all sites had equal initial advantages (*Z*). Table 2 lists the first test's parameters.

Table 2. Parameters and value ranges in Test 1.

Alpha (α)	**Beta (β)**	**Advantage (*Z*)**	**Initial Population (*X*)**	***k***	**ε**	**Simulation Time**
0.1-10.1	0.001-1.011	1.0	200	1.0	0.5	100

4.1 Test 1: Equal Advantage

Test 1 looks at all surveyed sites from the four analyzed periods and two regions; although no site has specific advantages given to it, geographic location could enable easier access for interactions with other sites, particularly for sites near each other. This leads to some sites gaining benefit more than others after the simulation begins, which makes them larger. While geography acts as a catalyst for site growth in some settlements, the results, more importantly for this test, allow us to determine what levels of α and β lead to given settlement structures. Testing α and β at different levels in the simulation allows us to see which settings best fit the empirical data of site size. The resulting simulated settlement structures are statistically compared to the empirical settlement structures for the periods and regions, allowing us to explain and compare the roles of α and β in shaping observed results. This is accomplished by comparing the empirical site size estimates with the simulated populations, where the portions of these two measures from the total are taken from each site and applied to a linear least squares regression that measures how well results fit. The specific sites that become larger than others are not relevant in this test. The implications of the results are discussed further in the discussion.

The results for α and β values, using the ranges given in Table 2, that have moderate to high correlations (0.7-1.0) or fit between the empirical and simulated results are indicated in Figure 4. Figure 5 shows the best or nearly best fit results. Graphs in Figure 4a-c indicate that the KT LC, EBA, and MBA scenarios have some results that are comparable. In all these cases, values for α at 2.1 have well correlated results with the empirical data, ranging between 0.93-1.00. This shows that these scenarios are at about the same amount of feedback to site advantages/incentive. The scenarios also show that it is possible to get reasonable fit for results when α is > 2.1, but these results are generally weaker than 2.1. The main differences between these three KT scenarios are in β. When α is 2.1 in the KT LC, the upper range of good fit is between 0.6-0.65; for the same α value and upper range of good fit it is 0.44-0.48 in the EBA. For the KT MBA the upper range of good fit is between 0.61-0.65 when α=2.1. Additionally, lower ranges of good fit when α is 2.1 are 0.13-0.18 in the KT LC, 0.1-0.15 in the KT EBA, and 0.1-0.15 in the MBA. Figure 5a-c graphs indicate outputs where there is the best fit. These results show that the KT LC has its best and most of the better results when β is between 0.13-0.18. For the KT EBA, the best fit results are between 0.1-0.15. On the other hand, for the KT MBA the best fit results are when β > 0.6. This suggests that the KT MBA could have greater impedance to migration than earlier periods.

For the KT IA (Figure 4d & 5d), we see greater differences. On the one hand, α could be comparable to the earlier cases (i.e., at 2.1); however, there is also good fit when α is even lower. This seems expected considering the IA sites are generally small and not greatly differentiated from each other as they are in the other cases. In addition, the best fit results are when β is lower than all other cases, specifically between 0.03-0.06 when α=2.1. However, β values comparable or higher than the previous cases' upper ranges of good fit are also among the best fit for the IA. The two best fit results are when β is 0.641 and 0.051, with α=2.1. This apparent contradiction is explained by the fact that settlement size distributions are relatively even in this case. Allowing easy movement, which spreads the population across all sites, could create settlement sizes comparable to the empirical record and no site easily gains a large population as α is lower. Alternatively, more restricted movement prevents some of the population from flowing into local hub sites. Thus very easy movement or more difficult movement cases create very comparable settlement structures when α is lower.

Looking at SM (Figures 4&5e-h), we see similarities and differences to the KT. In the SM LC (Figure 4e & 5e), once again α at 2.1 has good fit with the empirical data.

Ranges for β are slightly lower than the KT LC at the lower end of the well-fit ranges, that is when β is between 0.1-0.15, while the upper range is also lower than the KT LC, being at around 0.54-0.59. Where α values of good fit are > 3.1, β is lower than the KT LC. The best and most of the better fit results, however, are α=2.1 and β=0.1-0.15.

The SM EBA (Figure 4f) also yields α (at 2.1) and β ranges comparable to earlier scenarios. In this case, good fit is observed between 0.12-0.17, although the upper range of good fit β is 0.51-0.54 when α=2.1, suggesting slightly more difficult movement at the upper ranges of β than the KT EBA. However, there is a lack of good fit for α values > 4.1, implying site advantages may not have been much greater in specific settlements as multiple large sites emerge, although two large sites, both at about ~400 ha, are the dominant sites. The best and good fit α and β results are similar to SM LC (Figure 5f).

In the SM MBA case (Figures 4g and 5g), the best fit α is again at 2.1, with β ranging in the lower range of good fit at around 0.13-0.17; the upper range is 0.53-0.59. Values up to α=7.1 show reasonable fit; when α > 3.1, we now only see good fit at high values of β (i.e. > 0.7), where one larger site emerges (Babylon). Nevertheless, there are other larger sites such as Umma (~ 100 ha), where constraints to movement allow a large site to emerge but also allow moderately large sites to be possible. The best fit results are α=2.1 and β=0.551, suggesting restrictive movement in this case.

For the SM IA scenario (Figures 4h & 5h), what is evident is only when α > 2.1 is there good fit with empirical data. As one site (Babylon) is far larger (i.e., it is primate) than all other sites, it can achieve this with greater feedback on site attractiveness that distinguishes its growth from other sites. On the other hand, β ranges of good fit for α > 2.1 are lower than other scenarios, indicating relatively easier movement as site size increases. In fact, one of the best fit results is when β =0.011 when α =3.1. In other words, it is not just high attractiveness that makes one site large, but relatively easy movement when α is large further increases a site's growth.

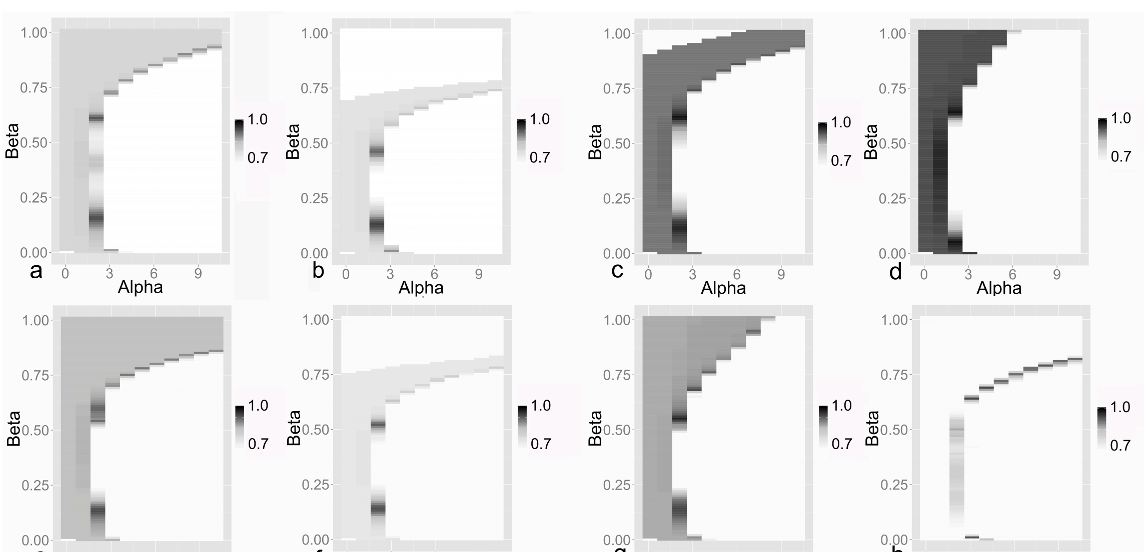

Figure 4. Fit (0.7-1.0) results (a-h) for the KT (a-d) and SM (e-h) in the LC (a & e), EBA (b & f), MBA (c & g), and IA (d & h) periods investigated using a least squares regression for α (x-axis) and β (y-axis) population results vs. empirical site sizes.

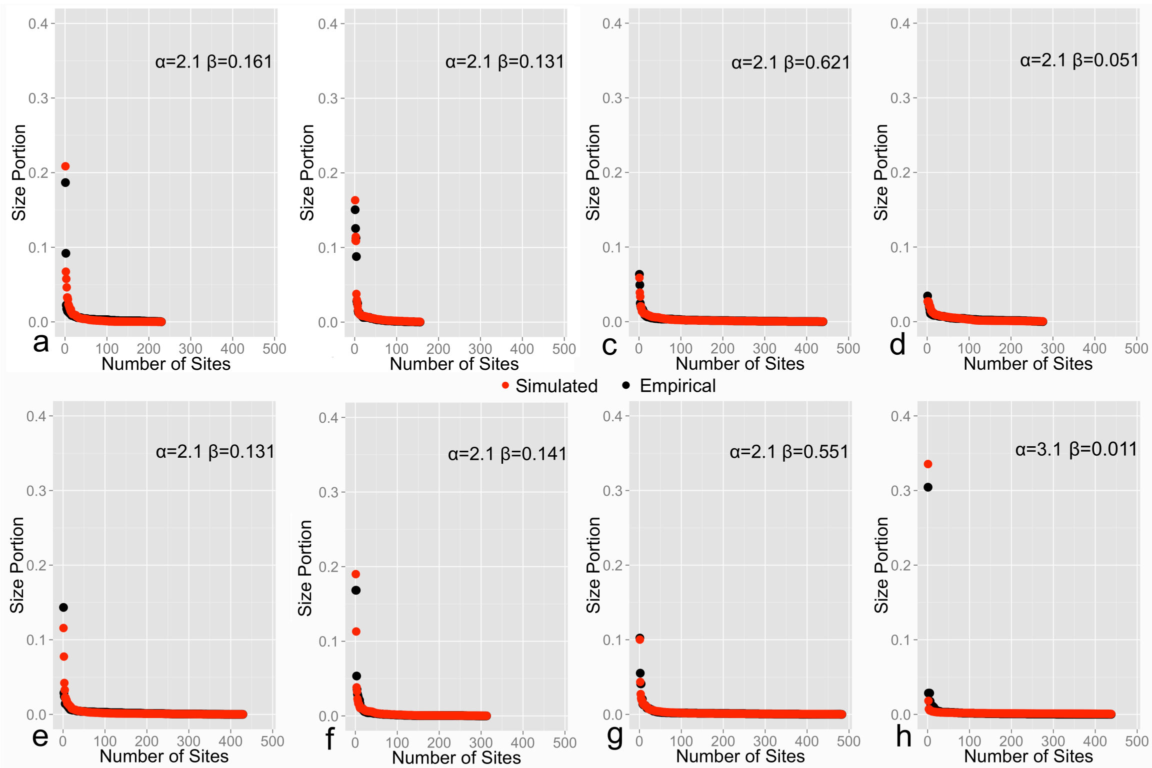

Figure 5. Results (a-h) for the KT (a-d) and SM (e-h) in the LC (a & e), EBA (b & f), MBA (c & g), and IA (d & h) periods showing α and β values and comparing simulated settlement population portion with empirical site size portion from all sites; correlations in all cases are ≥ 0.93.

4.2 Test 2: Differential Advantage

While Test 1 allows us to see how settlement structure emerges if sites do not have endogenous or exogenous advantages relative to other sites, with the exception of their geographic position, this case tests to see what factors of α and β affect site size structure in cases where sites had different initial advantages. This test, therefore, assess how settlements in the different cases can emerge or maintain rank-size hierarchy during a period based on initial advantages. Such advantages could be inherited from previous periods or socio-environmental factors that give a settlement more living benefits. For this case, *Z* now equals the survey size estimate for a given site. This acts as a way to give a site possible advantages or disadvantages relative to other sites, which is also based on the empirical record, for the entire archaeological period being assessed. Such settlement importance would, therefore, affect how other sites are structured and levels of site attractiveness feedbacks (α) and mobility (β) required.

Because Z is now different for sites, the range of α and β values that allow a close replication between model and empirical data differs. In all cases, it is possible that α near 1.0, that is return of attractiveness that keeps initial advantages, and β near 0.1, where movement is relatively easy and thus populations can go to the advantaged sites, enable initial advantages to result in site populations comparable to empirical survey size data (Figure 6). In general, high α and low β enable more site size differentiation and larger sites. In many cases, results differ from Test 1 significantly, as acquiring advantage or maintaining an initial settlement advantage may require different types of site advantage feedbacks and movement. In the discussion, we will interpret results obtained here to suggest the insights gained.

Similar to the previous test, a least squares regression is used to measure fit of results as the test applies different values for α and β. For this case, it was found that α and β ranging from 0.0-2.1 lead to results that best fit the empirical data. Additionally, a Spearman's rho value is used to measure how well sites maintain their initial rank, and thus initial advantages, over the entire scenario run. Spearman's rho and the least squares regression, which better measures how well simulated sites' populations match empirical site size results, are, in fact, used together for displaying results (Figure 6). For this case, when both Spearman's rho and least squares' fit are > 0.9 and 0.7 respectively the results are displayed.

For the KT LC (Figure 6a), mostly low β (<1.0) could enable or maintain the given settlement structures, while α is found to generally be below 1.5. For the KT EBA (Figure 6b), there are more good fit results as α and β increase, with ranges of good fit also lower and comparable to the KT LC found. For the MBA (Figure 6c), β has a wide range of good fit and α can be up to 2.1, suggesting that movement restrictions, similar to what was seen in Test 1, are evident in well-fit results, while there can be greater site size feedbacks in this case. In the KT IA (Figure 6d), the well-fit results are broad, particularly where very high fit (>0.94) is evident in α and β; values for β have a lower top range than the KT MBA, suggesting that, similar to Test 1, easier movement than the KT MBA could facilitate site structures comparable to the empirical record. Interestingly, α has a high range, which is because advantage (Z) values are relatively equal for sites, resulting in lower differential returns for population size as α increases.

For SM LC (Figure 6e), as α increases toward 2.1, then β increases to near 1.5. In this case, for the largest site (i.e., Uruk) to be maintained, β at greater ranges when α increases prevents population from over concentrating in Uruk, which has the greatest advantages. Overall, the ranges for well-fit α and β are greater and reach higher values for this case than they do for the KT LC. For SM EBA and MBA sites (Figure 6f-g), very narrow α and β ranges for good fit are found, suggesting that there are fewer pathways to enable or maintain site structures comparable to the empirical record when there are differential advantages. In both these cases, there are a number of larger sites (e.g., Uruk, Lagash, Umma, and Babylon), creating a situation where flow of population needs to have easier movement (i.e., low β), but returns to attractiveness, which differentiates advantages for sites more greatly as it increases, stays relatively low (i.e., α < 1.5) so that no site gains too much advantage. For the SM IA, there is an increased range for α and β parameters that can fit empirical results closely, similar to what is seen in Test 1, with now only one site dominant in size. However, β is slightly lower than the SM LC for upper ranges of α, suggesting easier movement in the SM IA is possible given the greater differences between site sizes in the SM IA. Nevertheless, restrictions to movement are needed in order to prevent the largest site from attracting even more of the population. Overall, the α and β ranges for good fit results are narrower than the KT IA.

Another important measure in this scenario is the degree of site interactions that are necessary to enable given settlement structures to be developed or maintained. In other words, because the applied model looks at site interactions, where flow measures how much benefits in the form of goods and people a site is able to attract, we can use these interactions to see how they enable settlement structures to develop and how many dominant centers are possible. Site interactions act as a proxy for how sites relate to each other and which are more dominant. Figures 7 and 8 apply Nystuen and Dacey (1961; N-D) and Markov Clustering (MCL; van Dongen 2000; Enright et al. 2002) algorithms, with both these methods helping to emphasize nodes that have greater flow. In the case of N-D, the approach simply displays the links that have the greatest flow to a given node, while MCL uses a stochastic Markov simulation to emphasize links with greater flow.

In Figure 7, applied α and β values are 0.8 and 0.6, 0.9 and 0.5, 0.9 and 0.7, and 0.9 and 0.6 for the KT LC-IA periods respectively, which are relatively good fit results. High flow or hub sites (i.e., those that attract the greatest flow (*S*)) indicated are among the larger or largest sites in Test 2. In the KT LC (Figure 7a), site 62 (Tell Brak) is relatively dominant in interactions. In the KT EBA (Figure 7b), high flow interactions spread to more sites, including sites 156 (Tell Mozan), 152 (Hamoukar), 60 (Tell Leilan), and 62 (Tell Brak). In the MBA (Figure 7c), two sites, specifically 60 (Tell Leilan) and 61 (Tell Farfara), are more dominant in flow, while 62 (Tell Brak) is less so. In the IA (Figure 7d), high flow interactions occur over the full length of the region. Diffuse or even interactions between sites is more evident, where small hubs (e.g., 68 (Tell Efendi), 231 (Tell Hamadiya), 233 (Tell al-‘Id), etc.) emerge.

For SM, high flow interactions can be investigated, with applied α and β values being 1.1 and 0.7, 0.9 and 0.5, 1.0 and 0.1, and 1.0 and 0.6 for the LC- IA periods respectively (Figure 8). In the LC, site 309 (Uruk; Figure 8a) dominates interactions, particularly with high volume interactions, with greater flow from sites that are more near to it but more distant sites also appear to have high flow to Uruk. For the EBA (Figure 8b), the pattern indicates more dispersed flow among several sites, although the southern part of SM has sites with relatively higher flow. Sites 309 and 305 (Lagash) dominate all interactions, but sites such as 93 (Umm al-Aqarib) and 303 (Kish) also form smaller hubs. For the MBA (Figure 8c), we see Babylon (site 137) being important in interactions across long-distances, although site 310 (Umma) attracts a somewhat substantial flow. Isin (236) is another hub site. Overall, we see a single site becoming more dominant than others, but it is not vastly more dominant in interactions. In the IA (Figure 8d), site 137 greatly dominates, far more than it did in the MBA, with flow throughout the region coming to it and distance is not relevant in affecting high volume interactions.

Another way to show interactions and to display how much flow (*S*) sites are able to capture is to graph the portion of total flow for all sites in rank order (Figure 9). This displays how much portion of the total flow the top sites are able to capture relative to all other sites. Interestingly, for the KT, there is a general trend of more even flow or interactions as one goes from early to late in time. In other words, the LC and EBA

(Figure 9a-b) show greater portion of flow for the top sites than the KT MBA-IA (Figure 9c-d). This indicates interactions more greatly spread in the later periods and over time there is less development of large hub sites that pull more goods and people. For SM (Figure 9e-h), the trend, with a minor decrease in the EBA, is more portion of flow to one site as one goes later in time from the LC to the IA. This reflects that larger sites continue to develop in SM in late periods, while the opposite is true for the KT. For the EBA and MBA, while the top sites have a large portion of total flow, other sites also capture large portions. By the IA in SM, one site dominates a large portion of total flow.

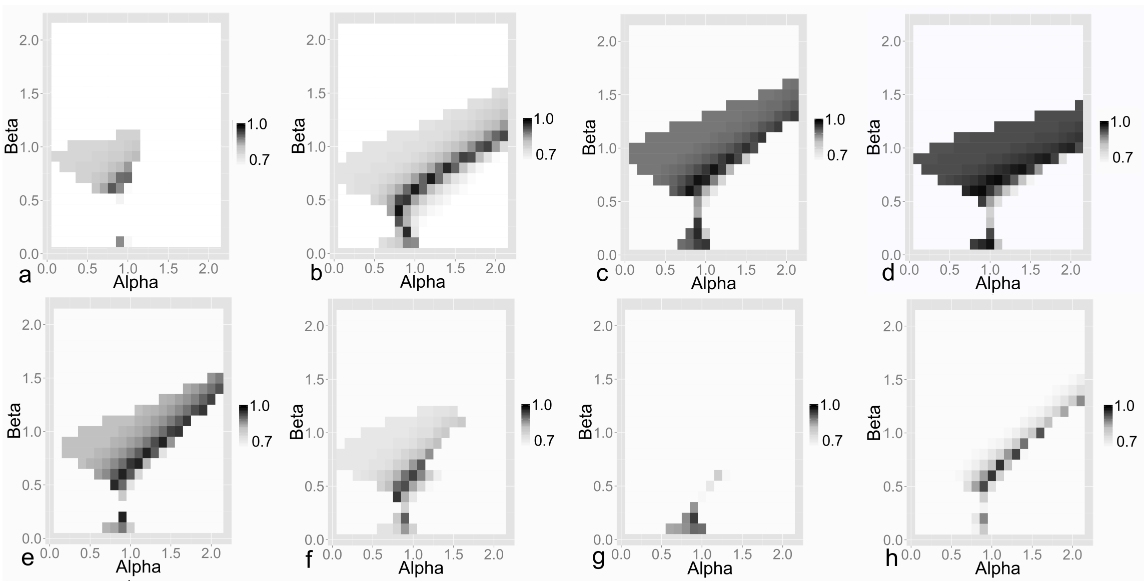

Figure 6. Spearman's rho combined with least squares fit results for the KT (a-d) and SM (e-h) in the LC (a & e), EBA (b & f), MBA (c & g), and IA (d & h) periods with least squares correlation values ranging 0.7-1.0 for α (x-axis) and β (y-axis) values between 0-2.1.

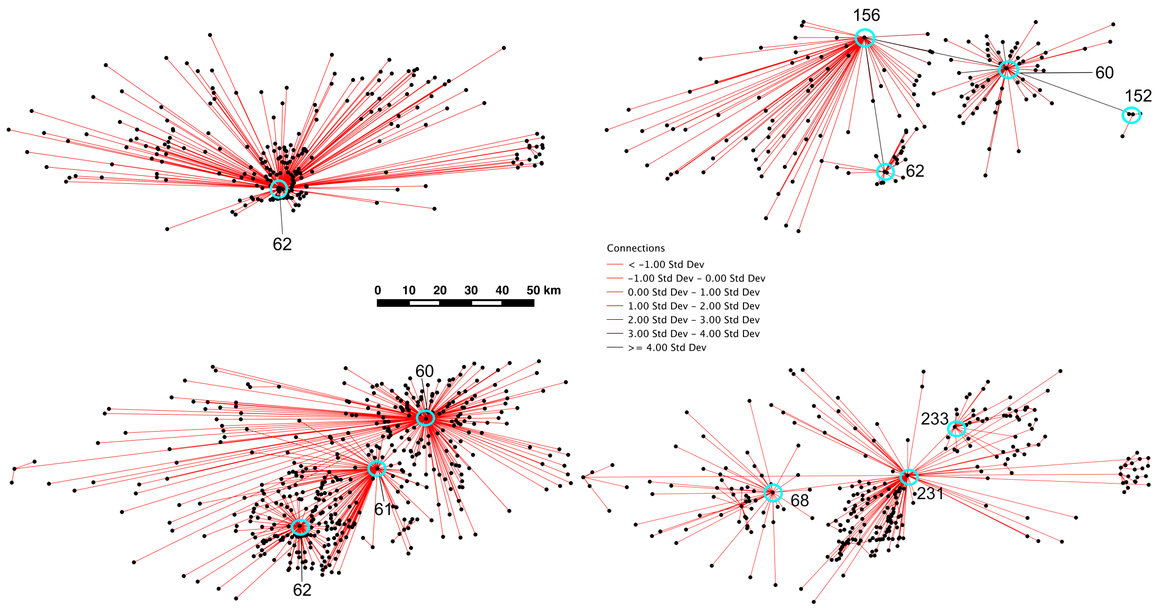

Figure 7. Settlement flow interactions for the KT in the LC (a), EBA (b), MBA (c), and IA (d) periods using N-D. Circled sites indicate hubs or more central locations.

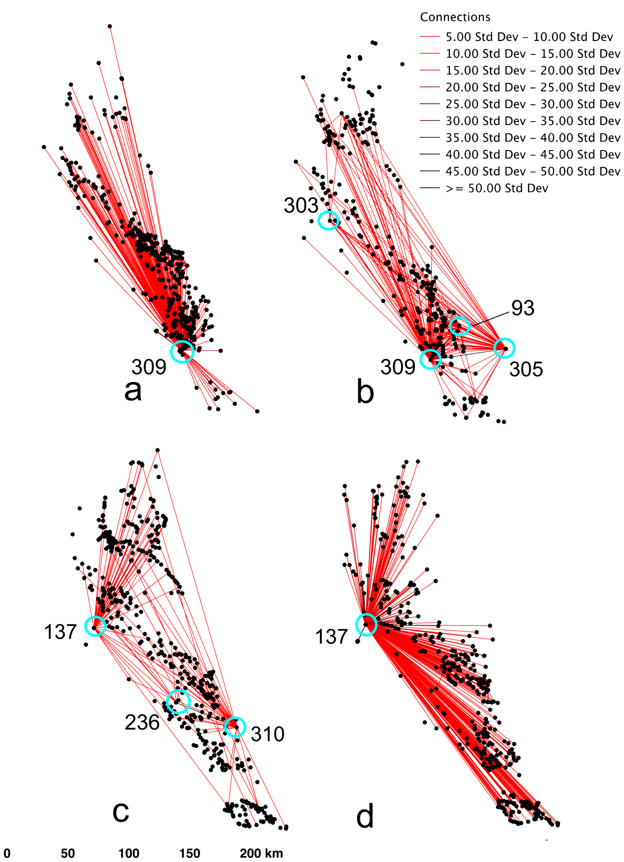

Figure 8. Flow settlement interactions for SM including the LC (a), EBA (b), MBA (c), and IA (d) periods using the MCL. Circled sites indicate hub locations.

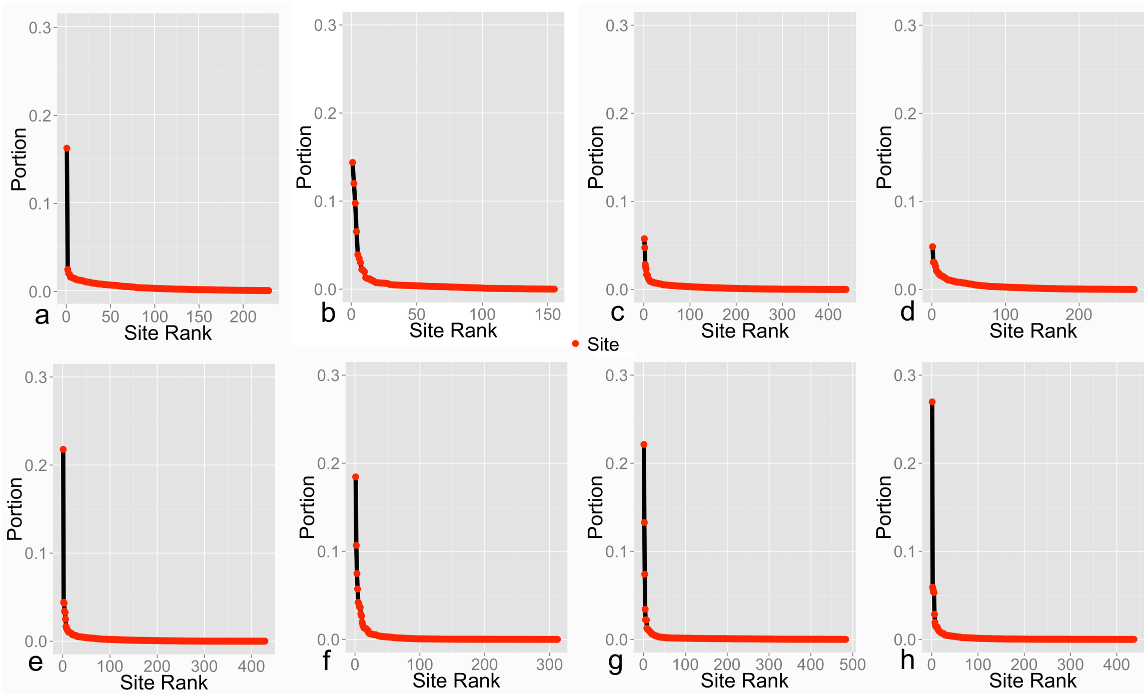

Figure 9. Settlement link interactions measuring flow portions for sites in the KT (a-d) and SM (e-h) regions in the LC (a & e), EBA (b & f), MBA (c & g), and IA (d & h) periods.

4.3 Test 3: Robustness of Results

While the previous scenarios demonstrate what values of α and β enable given settlement structures and size hierarchies to emerge based on relatively equal (Test 1) or established advantages (Test 2), this scenario tests the robustness and sensitivity of these previous tests and what happens when a percentage of sites are not contemporary. This test applies a bootstrap sampling procedure. The intent is to look at the entire period and see how multiple combinations of settlements using only part of the dataset at any given time would affect the overall settlement structure and hierarchy; this provides an idea of how well surveys have likely captured the general settlement structure, while helping to support modeling results. For periods, particularly the long LC, such a test is relevant as it allows us to determine what levels of sampling the results from Tests 1-2 are more meaningful. For every case, this sampling is repeated 500 times and averaged to ensure many different site combinations throughout the entire period. Additionally, different sampling ratios are used, where these probability ratios represent a portion of sites that are removed from runs, with sites selected randomly chosen in each run. These probabilities are 0.05, 0.15, 0.25, and 0.5 for all the eight settlement cases. As Test 1 investigates size hierarchy only, least squares correlation results are used to measure how well simulated population matches empirical site size data (Table 3). For Test 2, Spearman's rho and least squares are used (Table 4).

Table 3 applies parameters for α and β that are indicated on Figure 5, as these are well fit results that can test if the fit can be maintained in this test. For the KT LC-IA, we see robust results throughout the ratios applied (0.05-0.5). In SM, some robustness is seen in the SM LC until the site removal ratio reaches 0.25-0.5. For SM EBA and MBA, robustness drops more greatly at ratios of 0.05, particularly for the MBA, suggesting the surveys and simulation results are sensitive to settlement pattern variations within the EBA and MBA. In both cases, interestingly, the results are more robust with greater sampling ratios. This could be a product of the stochasticity or reflect that fewer sites could have been occupied at a given point during the period. The SM IA is generally robust until the sampling ratio is > 5% of the sites are removed. Overall, Test 1's SM results are less robust or more sensitive to change than the KT, which may reflect the fact that the surveys conducted cover a wider area, with less intensive survey employed that may have missed sites. This could make settlement structure results sensitive to change if the recovered sites were not contemporary for different periods, as long archaeological periods suggest that some sites may have not lasted an entire period. On the other hand, we are more confident that the results for Test 1 in the KT reflect the empirical settlement structure, even if many sites were not contemporary.

Table 4 applies parameters from Figures 7 and 8 in Test 2. Many of the results in this test show that there were relatively minor variations from the 0.0 cases, indicating generally robust and less sensitive results. This is expected given that sites and site advantages, using empirical site sizes, are generally maintained in each sample run, although individual runs could be very different from the overall settlement structure. Only in cases where the ratio was 0.5 for the KT LC, SM MBA, and SM IA do we see weaker least squares result, although the Spearman's rho results (i.e., rank order) do stay consistent in tests.

Table 3. Bootstrapping sampling method using well-fit least square Test 1 parameters where the sampling probability is 0.05, 0.15, 0.25, and 0.5 for sites having a probability of not being simulated in a given run. Test 1's results (i.e., ratio is 0.0) are also included. Results reflect averages of 500 runs.

Measure	KT_LC	KT_EBA	KT_MBA	KT_IA	SM_LC	SM_EBA	SM_MBA	SM_IA
L-S (0.0)	0.93	0.95	0.98	0.98	0.94	0.98	0.97	0.94
L-S (0.05)	0.92	0.95	0.98	0.97	0.92	0.83	0.55	0.92
L-S (0.15)	0.91	0.94	0.96	0.97	0.91	0.91	0.89	0.78
L-S (0.25)	0.90	0.93	0.94	0.97	0.90	0.89	0.94	0.70
L-S (0.5)	0.87	0.90	0.91	0.98	0.89	0.86	0.90	0.69

Table 4. Bootstrapping sampling method using well-fit Spearman's rho and least squares Test 2 parameters and where the sampling ratio is 0.05, 0.15, 0.25, and 0.5. Test 2's results (i.e., ratio is 0.0) are also included. Results reflect averages of 500 runs.

Measure	KT_LC	KT_EBA	KT_MBA	KT_IA	SM_LC	SM_EBA	SM_MBA	SM_IA
Spearman (0.0)	0.97	0.96	0.99	0.97	0.98	0.96	0.99	0.98
L-S (0.0)	0.93	0.98	0.98	0.99	0.97	0.94	0.91	0.96
Spearman (0.05)	0.98	0.96	0.99	0.98	0.98	0.96	0.99	0.98

L-S (0.05)	0.92	0.98	0.98	0.99	0.97	0.94	0.91	0.95
Spearman (0.15)	0.98	0.96	0.99	0.98	0.98	0.95	0.99	0.98
L-S (0.15)	0.92	0.98	0.97	0.99	0.99	0.95	0.91	0.94
Spearman (0.25)	0.98	0.97	0.99	0.98	0.98	0.95	0.99	0.98
L-S (0.25)	0.90	0.98	0.96	0.99	0.91	0.95	0.90	0.94
Spearman (0.5)	0.98	0.99	0.99	0.98	0.98	0.96	0.99	0.98
L-S (0.5)	0.87	0.95	0.95	0.98	0.94	0.91	0.88	0.87

5 Discussion

5.1 Results and Interpretation

The scenarios present a number of results that provide insights into understanding settlement structures. First, we have to acknowledge the limitations of this work, primarily being that data from surveys can be inaccurate at estimating sites' true sizes. Furthermore, there is possible unevenness in settlement size distributions, potentially skewing results or misrepresenting the actual settlement structure for a given region. Smaller sites are often missed on surveys, while sites may have been destroyed or damaged, potentially meaning we don't have the full extent of total settled areas in regions (Falconer and Savage 1995). Surveys generally cover long periods, whereas settlement structures were likely to have been constantly changing; the best we can hope for is what the overall structure looks like over an entire period. Test 3 addresses this somewhat by sub-sampling to see how sensitive to change and robust the overall results are under different settlement distributions. Given this, we try to interpret the outputs from the different tests, demonstrating the feasibility of the approach for settlement structure understanding. The tests presented sometimes demonstrate multiple pathways in which given settlement structures emerge or persist. This could mean multiple pathways did indeed occur, as the periods examined were hundreds of years long and multiple settlement structures could have existed that overlap archaeological periods. For interpreting results, site size hierarchies and settlement structures have long been used to discuss the degree to which regions are politically, socially, or economically integrated (Wright and Johnson 1975; Johnson 1980). We use our results to discuss how well settlements demonstrate such integration and archaeological meaning from the variables tested.

5.1.1 KT

In the long LC period, very likely there are multiple settlement structures occurring during this time. Based on Test 1, we see evidence of feedbacks to site benefits and incentive for settlement being mostly at α=2.1. Relatively low β (0.13-0.18), and thus easier movement, appear to be the best fit results, although other possibilities are evident (β=0.6-0.65). Test 2 suggests relatively low α and β best lead to the empirical structure, suggesting that if there were advantages by large sites such as Tell Brak then relatively unrestricted movement enables the settlement structure to emerge or be maintained once advantages for sites are established. Interactions (Figures 7a and 9a) indicate relative dominance by Tell Brak over much of the region, but not to the dominant extent as in SM during the IA. Archaeologically, this is a period of early urbanism (Algaze 2008), where Tell Brak is larger than other sites (Oates et al. 2007; Ur et al. 2011). Results suggest that early urbanism was very focused toward single or very few sites, such as Tell Brak, with somewhat easy movement and regional interaction facilitating urban growth for Tell Brak. For the KT EBA, Test 1 suggests good fit α and β are similar to the KT LC, although β may have been somewhat easier at the lower and upper ranges of good fit when $\alpha=2.1$. Wider ranges of α and β in Test 2 suggest once sites achieve dominance, multiple pathways are possible, including restrictive movement and incentive for settlement in large settlements. Short-distance hollow ways, which are remnants of ancient roads, were a well-established pattern (Wilkinson 1994; Ur 2003), suggesting high flow traffic interactions were occurring over mostly short distances in this period of larger urban locations (McMahon 2013). The results in Figures 7b and 9b also show mostly short-distance interactions, with flow more equal among multiple settlements than the KT LC, indicating restricted movement over the region. Politically, much of the period was likely fragmented, with multiple kingdoms in the wider region, including Ebla and Mari to the west and south respectively. The KT may have been more unified and politically integrated near the end of the EBA (Archi 1998; Sallaberger 1999), but evidence for larger regional economic and political integration is scant for much of the early third millennium (Akkermans and Schwartz 2003; Ur 2010). Our results support a scenario of greater socio-political fragmentation.

In the MBA, the best results in Test 1 show greater restrictions ($\beta > 0.6$ at $\alpha=2.1$) to movement than the previous cases (Figure 5c), while good fit α at higher values show even greater β restrictions. This leads to some sites that become relatively larger than surrounding sites. Test 2 has greater ranges for α and β than seen in earlier periods, with some of the results suggesting it is possible that restrictions on movement and greater feedbacks to site advantages may have been persistent even after sites became relatively dominant or had established advantages. We suggest this settlement structure reflects the political landscape in the early second millennium BC, which was divided into several competing small states (Dalley 2002; Charpin and Ziegler 2003; Guichard 2009; Eidem 2012; Ristvet 2008, 2012 and 2013; Palmisano 2015). Restrictions on movement and political fragmentation, therefore, can lead to multiple large centers (e.g., Tell Leilan and Tell Farfara) acting as local hubs for regional flows. Interactions (Figures 7c and 9c), in fact, indicate multiple sites have a greater portion of total flow; these results are similar to Davies et al. (2014), which also suggests settlement structure in the MBA for the KT reflects the fragmented political climate of the period.

During the IA, the picture is that settlement size is more even and α ranges are the same or lower than other KT cases, as shown by Test 1, with the largest sites now smaller than other cases. There are two possible ranges of good fit for β: lower β (< 0.061) than the other KT cases or an upper range comparable or higher than the other KT scenarios. Test 2 supports a wide range for α and β that could create or maintain structures observed. Figures 7d and 9d show dispersed, even, and long-range interactions among a number of sites, with no site greatly dominating interactions. We suggest that the low β range in Test 1 (i.e., Figure 5:d) is supported by the empirical data. When the region was integrated into the large Neo-Assyrian state, long-distance roads became important features in the landscape (Altaweel 2008), suggesting movements were commonly occurring over far distances. The Neo-Assyrian state, with its centers to the east, politically integrates the KT early in the IA (Radner 2006; Radner 2011). Such political integration suggests much easier movement is likely to occur in the region, resulting in populations being more dispersed and even, as previously demonstrated by Davies et al. (2014).

5.1.2 SM

For SM LC, the best fit Test 1 results are very similar to the KT LC. The main difference is movement restrictions (i.e., β) have a slightly lower range. While there is a wider range of fit for α and β in Test 2 for SM LC (Figure 6e), the interactions suggest regional influence by a single site (Figure 8a) is similar to the KT LC. Generally, this is a period seen as the rise of urbanism in SM (Adams 1981; Algaze 2005 and 2008), with Uruk becoming the key site of growth. Overall, the similarity between the KT and SM, specifically site advantage feedbacks and movement or migration that are comparable in both regions, show this period of early urbanism was focused on single or very few sites.

In the EBA, no site was able to dominate the entire region (Figure 8b). Although movement restrictions may have been comparable to the KT EBA, as suggested by Test 1, well-fit results are also found when β is 0.5-0.55 for α=2.1, suggesting greater restrictions to movement in SM can lead to the observed settlement pattern. Although sites such as Uruk are very large, other large sites, particularly Lagash, are found. This was a period of political fragmentation, as supported by the historical records, where wars and contests between small city-states are known (Van de Mieroop 2006). Adams (1981) has already suggested that this period and the settlement pattern largely displays a period of political vicissitudes and changing fortunes for cities. Bronze Age city-states dominated their local areas, but larger kingdoms and empires were more ephemeral. Multi-hub interactions and flow in Figures 8b and 9f could be evidence for multiple centers arising without one site gaining large-scale dominance, which supports the idea that the settlement pattern suggests political fragmentation. Test 2 may simply show how the given rank-size structures are maintained. In fact, Uruk, the site dominant in the SM LC, continues to be among the largest sites in SM EBA, suggesting some of its advantages may have been inherent during the EBA period. Test 3 (Table 3) shows this was among the weaker cases, specifically the results in Test 1, suggesting variation in survey results could alter interpretation.

During the MBA, we similarly see evidence for political fracturing, although Babylon begins to dominate interactions (Figures 8c and 9g). This may reflect the slow rise and conquest by Babylon of the region (Yoffee 1979). Several large settlements existed at least at the beginning of this period, although many of these settlements may have been abandoned near the end of the period (Stone 2013). Results from Test 1 show movement seems to have been relatively constrained, although possibly not as constrained as the KT MBA (Figure 5g). This leads to other larger centers in addition to Babylon (e.g., Umma). Test 2 (Figure 6g) indicates that if there were initial advantages then movement would need to be unconstrained to enable the observed settlement structure. This could map well to the historical pattern in this period, where the period begins with a politically fractured landscape, where we would expect higher β as conflict would prevent easier movement.

Then, one large state began to dominate the region politically, led by the city of Babylon, which would facilitate lower β situations. Alternatively, rebellions did occur during this unified Babylonian period (Frayne 1990), suggesting conflict, and thus higher β, as possible throughout this time. Removing just 5% of sites from simulation runs did make the results weaker in Test 3 (Table 3), which was the weakest result among all cases, suggesting that multiple settlement patterns and structures could be evident in the data.

In the IA, a different pattern compared to the KT IA is evident, although we suggest it reflects a similar political dynamic. In this case, the region has a very large capital, leading to high α values in Test 1 (Figures 4&5:h). As α increases to > 2.1, we see β remaining relatively low for such a high value. This low β for high α values, which increases benefits or advantages for one site, facilitates easy movement and helps to increase flow to what is now a primate city (Babylon). Test 2 also shows that relatively lower β could enable or maintain given structures based on established advantages. Given that Babylon had already emerged as a more dominant site in the SM MBA, the SM IA could be a case where Test 2 shows how that dominance could have been maintained. Interactions (Figures 8d and 9h) reflect this dominance by one single site, where it became a hub of foreign wealth (Jursa 2009) and capital of Neo-Babylonian empire at the end of the IA (Oates 1986; Pedersén 2011). Easy movement to a primate city or one that greatly benefited from its well-established advantages, as suggested by the results, is very likely, representing the socio-political integration of the region around Babylon.

5.2 Method Benefits

More broadly, we present a simple methodology (SIEM) to test how feedbacks to site advantages or settlement incentives as well as abilities to migrate and disperse in a given region could enable observed settlement structures. While multiple types of pathways are suggested, integrating results with known archaeological and historical data could facilitate interpretation. We apply the model utilizing estimated survey size structure, but other applications include applying such modeling to even more limited data circumstances where site sizes and number of sites are less known (e.g., Bevan and Wilson 2013). The results provide a further step beyond simple descriptive statistics, as underlying dynamics are addressed, specifically settlement advantage feedbacks and movement, and the method is transferable to multiple types of cases with different spatial scales. The results produced allow us to addresses both the emergence and maintenance of settlement structures, indicated by Tests 1 and 2.

6 Conclusion

Although the various cases demonstrate the utility of SIEM for assessing reasons as to why some settlements become dominant while others become small, we do see limitations to what has been produced. The method is general and does not address specific social-ecological factors of how settlement structures may develop beyond anything that may promote site advantages or movement within regions. While this is an advantage that allows various examples to be compared more easily, case studies and research questions could have nuances that would require the model to be more developed. We did not attempt to look at how settlement structures emerge from a bottom-up theoretical perspective, although derivations from this methodology are possible (Altaweel 2014). Limitations in the data are seen, where multiple and different settlement structures could change results substantially in some cases, as indicated in Test 3. This includes patchiness in surveys and long archaeological periods. To increase utility of the approach, the model could be incorporated with survey cases where a more detailed chronology is present. As an example, allowing within-period changes in site advantages where sites could be relatively equal in initial advantages but exogenous or endogenous circumstances, such as Babylon becoming more dominant politically, enable shifts in site advantage feedbacks and movement to be studied. Improving data quality through intensive surveys and having more specific chronologies would potentially improve results. Overall, we see that SIEM has proven to be useful for studying general site advantage feedbacks and movement dynamics that create settlement structures and comparing regions temporally and spatially, making it transferable to different settings. Such topics that can be addressed include the rise of urbanism, the role of transport in shaping settlements, and how polities affect settlement structures.

Supplementary Data

The archaeological survey data used and model applied can be downloaded here: http://discovery.ucl.ac.uk/1464057/.

Acknowledgments

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