Spatializing Social Network Analysis in the Late Precontact U.S. Southwest

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It is a truism that social interaction is structured by spatial proximity, but the nature of spatial relationships among people influences the variety of social opportunities and expressions of identity they experience in complex and mutable ways. Our goal in this paper is to evaluate the association between certain kinds of spatial relationships and evidence for variation in social networks in the western half of the United States Southwest (Southwest) during the thirteenth through fifteenth centuries A.D. To formally explore the relationships between space and social interaction, we rely on methods and models for geographic information systems (GIS) and social network analyses (SNA).

GIS is a widely used technology for analyzing spatial relationships among diverse entities and is commonly applied to archaeological data to model social and ecological relationships among people (Allen et al. 1990; Kantner 2008). In our analyses, we employ it to model variability in distances and topographical contexts of actors engaged in social interactions. SNA refers to a suite of methods for characterizing the nature and structure of relationships among a set of actors (Scott 1991; Wasserman and Faust 1994). These formal methods are further linked by a relational perspective on social interaction according to which an understanding of the structure of interactions among actors is important for understanding the behavior of, and predicting outcomes for, those actors (Borgatti and Halgin 2011). Combining these technologies offers useful insights into the relationship between spatial context and social interaction.

Studies integrating GIS and SNA, especially with the temporal depth and resolution characteristic of the Southwest, are relatively rare but offer great potential to observe social networks as they changed through time (for recent examples, see Golitko et

ABSTRACT

In this article we explore the relationship between spatial proximity and indices of social connectivity during the A.D. 1200–1450 interval in the United States (U.S.) Southwest. Using geographic information systems (GIS), we develop indices of spatial proximity based on the terrain-adjusted cost distance between sites in a regional settlement and material cultural database focused on the western U.S. Southwest. We evaluate the hypothesis that social interaction is a function of proximity and that interactions will be most intense among near neighbors. We find that this hypothesis is supported in some instances but that the correlation between proximity and interaction is highly variable in the context of late precontact social upheaval. Furthermore, we show important discrepancies between the Puebloan north and the Hohokam south that help to explain differences in community sustainability in the two regions.

En este articulo exploramos la relación entre la proximidad espacial y los índices de conectividad social durante el intervalo de 1250–1450 d.C. en el suroeste de los Estados Unidos. Usando Sistemas de Información Geográfica, desarrollamos índices de proximidad espacial basados en el costo ajustado de la distancia del terreno entre sitios, a partir de la base de datos Southwest Social Networks. Evaluamos la hipótesis que sugiere que, la interacción social es una función de proximidad y que las interacciones serán más intensas entre vecinos cercanos. Encontramos que esta hipótesis se sostiene en algunos casos pero que la correlación entre proximidad e interacción es altamente variable en el contexto de la revuelta social del pre-contacto tardío. Además, indicamos las discrepancias importantes existentes entre los Pueblo del norte y los Hohokam del sur, las cuales ayudan a explicar las diferencias en la sostenibilidad comunitaria entre las dos regiones.

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al. 2012; Knappett 2011, 2013; Mills et al. 2013a, 2013b; Peeples and Haas 2013). We explore how spatially defined groups of archaeological sites relate to each other in terms of network properties such as the strength of social ties among settlements (degree) and network density. A useful null hypothesis is that social connectivity is isomorphic with spatial connectivity, but to what degree does social distance correspond to spatial distance? How does this relationship vary through time and across space? This paper highlights some convergences and contrasts between measures of spatial and social connectivity against the background of the well-documented social upheavals of this pivotal period in the Southwest. Here we build on previously published work by Mills and colleagues (2013a) with more detailed discussion of methods and potential applications, as well as closer consideration of the unexpectedly low correlation between spatial proximity and social connectivity described there. Our work follows similar recent efforts to explore the relationship between proximity and social connectivity, such as proximal point analysis and gravity models (e.g. Clark 2013; Hart 2012; Rivers et al. 2013a, 2013b). We offer refinements on this body of research with a combination of terrain-adjusted distance (as opposed to Euclidian) and a measure of linear chained spatial connectivity that we think more closely reflects the kinds of connections seen in social networks.

We use data provided by the Coalescent Communities Database (CCD) (Hill et al. 2012; Wilcox et al. 2003) comprising a large proportion of known habitation sites in the Southwest with at least 13 rooms and dating between A.D. 1200 and 1500. This is an interval of large-scale social upheaval, migration, reorganization, and demographic decline in the Southwest. The CCD data are augmented by the Southwest Social Networks Project, or SWSN (Mills et al. 2013a, 2013b), which adds material culture information. Based on material similarities among habitation sites, this interdisciplinary, collaborative research program examines social networks at broad spatial and temporal scales to identify linkages among communities spanning the region west of the Continental Divide in New Mexico and Arizona (Figure 1). The SWSN project database contains ceramic type and ware counts (over 4.3 million sherds) for more than 700 sites across the study area (see Figure 1) gathered from publications, reanalyses of museum collections, and new in-field recording. This database offers an unusual opportunity to examine dynamic changes in social networks at a large scale.

THE STUDY AREA

The study area comprises 334,000 km^2 of largely desert and mountainous terrain, where substantial Native American populations lived in agricultural hamlets, villages, and towns (large nucleated settlements housing several hundred to over 1,000 people). The study area is divided along a northwest to southeast axis between the southern Basin and Range Province and the Colorado Plateau to the north (see Figure 1). In the lower elevation Basin and Range zone (hereafter south), ancient settlement was primarily focused along the Gila River Valley and its tributaries. On the higher elevation Colorado Plateau (hereafter north), settlement was located along watercourses such as the Little Colorado and San Juan rivers, but many habitation sites were also located along the lower slopes of mountain ranges, where residents made use of smaller upland water sources.

Settlements within these two zones were often closely linked through trade and migration but are characterized by quite different trajectories of population growth and decline, settlement density, and interaction through time. We argue that these trajectories reflect changing types of community as socioeconomic interactions fluctuated among variably dispersed groups of people and different ecological settings. However distinctive the north and south were in some ways, their trajectories were also mutually constitutive, as changes in neighboring communities cascaded throughout the region.

The data used in our analyses comprise over 1,600 habitation sites with adequate documentation to distinguish occupation intervals. Using methods previously published by Hill and colleagues (Hill et al. 2004), we estimate the population of each settlement in this database in 50-year intervals between A.D. 1200 and 1500, based on room counts and modeled rates of site growth and decline. In addition, we have systematic ceramic information for 709 of these habitation sites, representing approximately a quarter of the sites occupied for any given 50-year interval (Table 1). Our GIS measures of spatial proximity and isolation are based on all sites occupied for each interval (whether or not they have ceramic information), and our SNA are based only on the subsample of sites with systematic ceramic collections. As described further below, ceramic assemblages at each of these sites are also apportioned into 50-year intervals. In this way we are able to consider proximity and interaction among contemporary sites and to assess how proximity and interaction among sites changed from one interval to the next.

MIGRATION AND COMMUNITY REORGANIZATION

Although there is regional variation, the period from around A.D. 1200 until the middle of the 1400s is known to archaeologists working in the southern Southwest as the Classic period and to those working in the northern Southwest as the Pueblo III and IV periods. In both regions, these are recognized as times of tremendous change. Many areas on the northern Colorado Plateau (the Four Corners) were abandoned during this time, as populations migrated to other areas further south, including the valleys of southern Arizona and the Rio Grande Valley east of the current study area. For present purposes, we employ a definition of migration as long-term residential relocation by social groups across traditional community boundaries in response to changing social and economic conditions (Clark et al. 2013:400).

Evidence of the arrival of northern migrants in the portions of southern Arizona and New Mexico considered here includes the appearance of locally produced Puebloan-style pottery and northern-style architecture in areas previously occupied by local groups that archaeologists call Hohokam. The interactions between these newcomers and local populations varied from place to place. In some settings, distinct migrant villages or enclaves were established; in others, diverse communities formed (Clark 2001; Clark and Lyons 2012; Lyons 2003; Woodson 1999). This period was also marked by a trend toward increasing settlement size and a reduction in the total number of settlements (Adams and Duff 2004; Wilcox et al. 2007).

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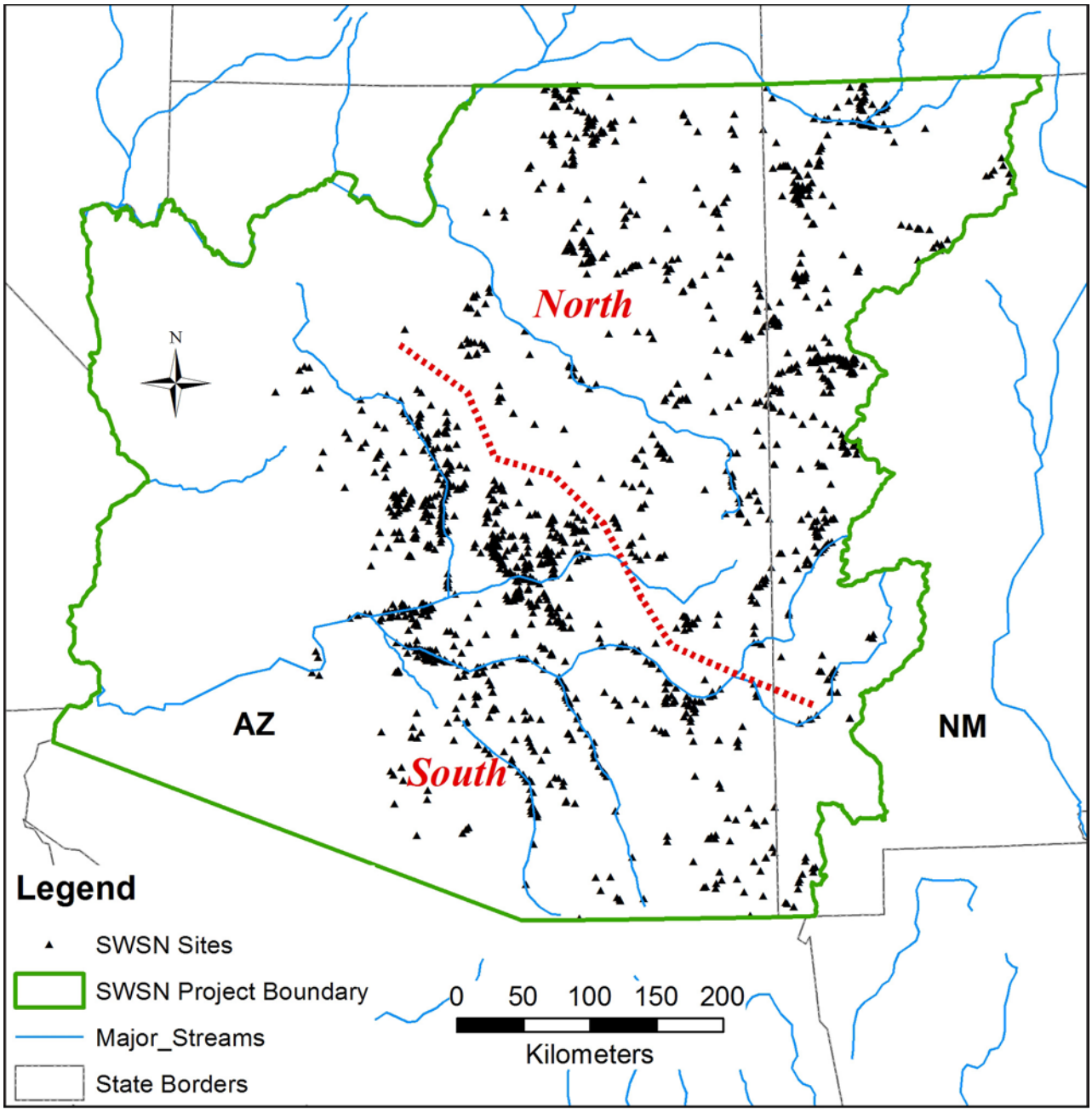


FIGURE 1. Study area.

TABLE 1. The Total Number of Known Settlements through Time

	A.D. 1200–1250	A.D. 1250–1300	A.D. 1300–1350	A.D. 1350–1400
Number of settlements	1143	1198	688	583
Number of settlements with ceramic data	279 (24%)	313 (26%)	174 (25%)	144 (25%)

Note: Includes known settlements in the study area with greater than 12 rooms where decorated ceramic counts are available.

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The mixing of local and migrant populations and their material culture traits in the southern Southwest presaged developments that archaeologists refer to as the Salado phenomenon. Most visible as a widespread ceramic tradition (known as Roosevelt Red Ware or Salado Polychrome), Patricia Crown (1994) and others (Lyons and Clark 2012) argue that it represented a regional religion integrating increasingly diverse communities of the southern Southwest. Hill and colleagues (Hill et al. 2004; Wilcox et al. 2007) have previously argued that the subsequently diminished population of the region is in some way related to tension resulting from the presence of immigrants. The process of coalescence brought on by the arrival of Puebloan immigrants in southern Arizona, as well as other demographic changes, promoted population aggregation, reduced subsistence diversity, and led to the deterioration of cooperative community relationships, resulting in gradual but sustained population decline throughout the region.

The concept of community is a central problem in Southwest archaeology and has inspired abundant literature. One early influence was George Murdoch's (1949) definition emphasizing residence and the importance of regular interaction (Wills and Leonard 1994). Others acknowledge the importance of frequent interaction in the structuring of behavior and identity (Abbott 2000; Canuto and Yaeger 2000; Varien and Potter 2008), but also recognize the potential for identity to transcend local interaction through perceived common interest or obligation. This may produce an imagined community incorporating individuals who maintain social ties not necessarily reinforced through frequent face-to-face contact (Anderson 2006). Many factors, including shared religion or cultural tradition, may influence the establishment and maintenance of such imagined communities.

Following recent trends in the Southwest and elsewhere (Isbell 2000; Schachner 2008), we address our analyses to this tension between natural and imagined community in the ancient Southwest as people alternately aggregated into large settlements and migrated to distant lands. Jeffery Clark and colleagues (2013) contrast the ideas of coalescent and diasporic communities to describe complementary organizational forms of, respectively, shared space separated by culture and shared culture separated by space. Coalescent communities have been described in different parts of the world and are generally marked by a common set of features and processes including aggregation, multi-ethnic co-residence, and evidence for increased conflict (Birch 2012; Hill et al. 2004; Kowalewski 2006). In contrast, diasporic communities are defined in relation to connections of shared history and identity among scattered populations who have a common homeland but reside in different regions. Diaspora has often been associated with forced population movement, but it can also be used to describe any community of immigrants displaced from a common homeland (Ember et al. 2004). We argue that, by comparing measures of spatial proximity to synchronous measures of social connectivity, we can track the ebb and flow of these two forms of community in the archaeological record.

Forms of community during this period of demographic change in the thirteenth through fifteenth centuries should reflect the different degrees and distances of communication as immigrant groups maintained contacts with distant relations and encountered established but less familiar populations in their destinations. Through time, we expect to see decline in the isomorphism between location and social relations. In other words, during this period of migration and diaspora, the degree of social interaction becomes less limited by close proximity. After the arrival of immigrant populations in the late thirteenth and early fourteenth centuries in the southern Southwest, expressions of social relations increasingly connected groups marked by shared expressions of identity in dispersed locations.

We use information on the relative frequency of different kinds of decorated ceramic wares[1] to identify the most robust patterns of similarity among settlements, which we then use as a proxy for the strength of social connections across our study area. Specifically, we argue that similarities in the relative ware frequencies are not random, but result from two general processes: the flow of goods or raw materials and the flow of ideas about how to make those goods. The former most often occurs through exchange, although migrants may carry some goods during resettlement (Zedeño 1994).

Similarities in ceramic production are affected by the flow of ideas about how to make and use vessels, including the transmission of technological knowledge through communities of practice, the movement of people through marriage networks, diffusion of innovations, participation in shared ideologies, emulation, and active signaling of social boundaries. The residents of settlements with similar ware assemblages were more likely to have interacted with each other in the exchange of ideas than the residents of settlements with quite different assemblages (see also Duff 2002; Mills et al. 2013a, 2013b; Nelson et al. 2011; Rautman 1993), but a high degree of similarity between two sites does not always imply direct interaction.

The flow of ideas is less constrained by material exigencies of economy and ecology, and it frees the imagined community to more easily span distances that preclude frequent interaction. These types of communities are especially likely to form in times of diaspora when people may interact frequently, sharing traditions and learning frameworks during some periods, and then maintaining those commonalities even after migration to distant places has diminished the frequency of actual interaction.

This decoupling of interaction from proximity allows us to examine tendencies toward natural or imagined communities. The degree to which a sense of community departs from the constraints of residence must reflect some measure of its emergence in the imagination. Comparison of the geographic structure of interaction with evidence of expressive identity markers, such as decorated pottery, provides compelling insight into the changing dynamics of community in the Southwest, as populations migrated through multiple regions over a span of approximately 200 years. These analyses support our hypotheses that the upheavals of the late thirteenth-century Colorado Plateau cascaded throughout the rest of the region in a cycle of reorganization and decline lasting until most settled agricultural communities were completely depopulated by the late fifteenth century.

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GEOGRAPHIC ANALYSES

In this paper, we introduce a novel approach to measuring the spatial connectedness of archaeological sites that provides indices usefully compared with measures of social network analysis. These indices use common GIS procedures to identify site groupings based on terrain-adjusted cost distance, and to indicate degree of spatial association through potential network linkages that produce such groupings across large areas of variable geography. These groupings may be thought of as landscape images of a proximity constraint, and changes both within and between groups reflect changes in likelihood of face-to-face interaction.

Population Histories

To begin with a simple illustration of the different trajectories of community organization in the ancient Southwest, we focus first on population trends at sites in two regions. Using techniques described in greater detail elsewhere (Hill et al. 2004), we modeled population at individual sites based on room counts, site life history curves, and estimates of site occupation percentage.

Figures 2–4 clearly show divergent patterns of occupation in these two regions. Total site count, total population, and mean site size are fairly similar in the two regions during the early 1200s. Coincident with drought in the north during the late 1200s, the trajectories of the two regions depart significantly. The total number of occupied sites in the north begins to decline in the late 1200s, while the south remains relatively stable until the late 1300s. Similarly, total population in the north begins to decline in the late 1200s, but continues to grow in the south until the mid 1300s. Apparent population growth in the early 1200s in the south may reflect an increase in the number of people living in larger and more archaeologically visible sites recorded in our database, rather than actual population increase. Population growth in the south during the late 1200s, however, appears to reflect actual growth and is likely in part due to immigration from the north.

In contrast, mean site population in the north more than quadruples throughout the 1300s, representing the large-scale aggregation of populations into villages and towns of unprecedented size, while growing much more modestly in the south during the same interval. Finally, site count, total population, and mean population all decline in somewhat comparable fashion in the two regions during the early 1400s.

In short, demographic characteristics in the two areas diverge significantly in the late 1200s and 1300s in ways that suggest different experiences of community. In the north, large percentages of the population died off, failed to reproduce, or emigrated, while remaining groups aggregated into much larger sites. These aggregated settlements did, however, appear to reach some degree of sustainability and were encountered in similar condition at the time of European contact in the mid 1500s. On the other hand, settlements in the south underwent a similar but more modest transformation a century later, but ultimately were not sustainable in their traditional form. Instead, southern groups appear to have reorganized themselves and employed a more fluid and ephemeral land-use strategy that is difficult to identify in the archaeological record after the mid

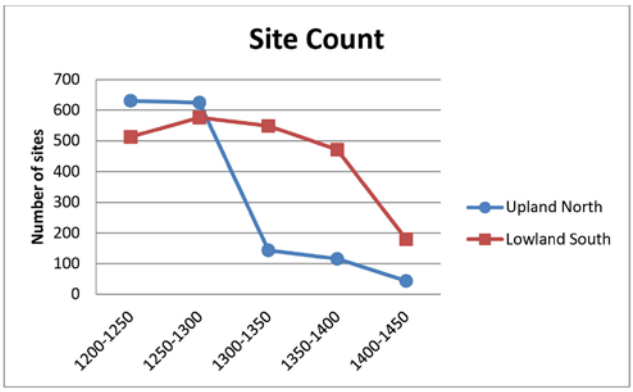


FIGURE 2. Site count.



FIGURE 3. Total population.

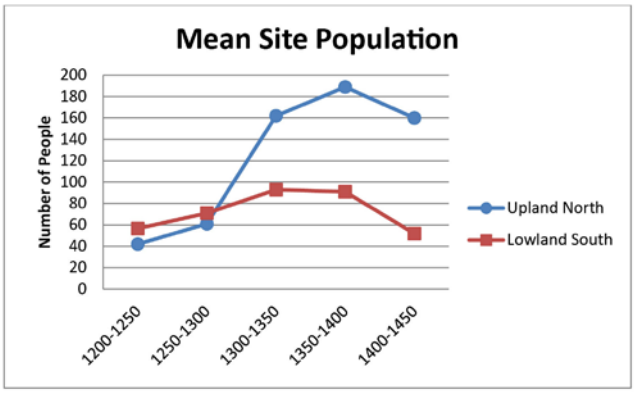


FIGURE 3. Mean site population.

1400s. These differences in demography and community experience should be visible in other indices of social connectivity.

Potential Spatial Connectivity

In our effort to measure spatial proximity among sites and to develop indices of their potential connectedness, several problems influence our methodology. Our primary goal is to create a measure that is representative of actual cost consid-

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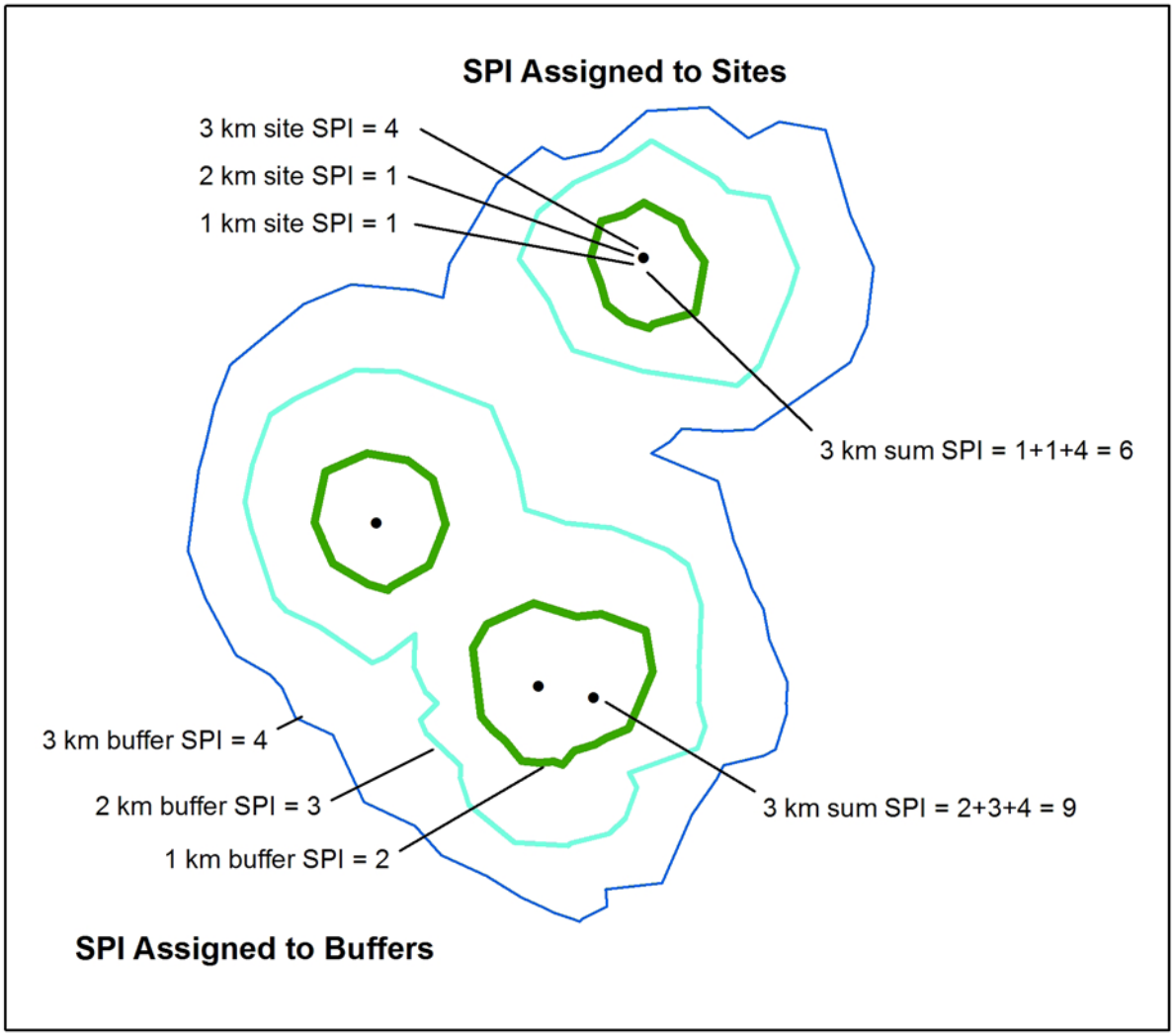


FIGURE 5. Calculating Site Proximity Index (SPI).

erations influencing pedestrian travel by humans. The most straightforward factor to model is the energy cost of movement across the landscape. Our study area is a mosaic of mountain ranges, valleys, and canyons that would have presented logistical challenges to travelers, especially those in family groups. Least-cost analysis (LCA) is a common GIS analysis tool that considers factors other than simple distance in calculations of travel cost (White and Surface-Evans 2012). Though LCA is one of the more popular GIS tools employed by archaeologists, and recent conceptual advances have improved our understanding of its use, it remains problematic primarily because there are so many factors that influence travel cost. Among these are slope, vegetation and surface composition, directionality and related questions about trip frequency and return, load size, and individual physiology, to name a few. Improved understandings of these variables, as well as ongoing refinement of algorithms, are fruitful areas for further research. For present purposes, we use a formula described in greater detail elsewhere (Herhahn and Hill 1998; Hill 2000) that includes slope, weight, and leg length to model the contribution of variable slope to pedestrian travel. We make no assertions about specific paths but, rather, strive for a better approximation of the general cost of movement between settlement locations in a mountainous landscape. Continued development of LCA and related techniques for distance modeling may enhance the results obtained here.

To develop measures of cost-adjusted proximity, we first calculated cost distance from all habitation sites occupied during each 50-year interval. The result is a continuous grid for each chronological interval of distances from the nearest site occupied during that interval. Next, we divided these grids into polygons at incremental radii of cost distance, producing a set of nested buffers around all sites (see Figure 5).

Then, we calculated the total number of sites within each buffer's boundaries and overlaid the nested buffers by summarizing their values across a range of distances. In this summary, sites are counted as neighbors repeatedly at expanding radii. For example, a site counted as a neighbor at 1-km radius will be counted again at 2-km radius, 3-km radius, and so on. This repeated counting weights nearby sites more than distant sites. In this case, a neighbor sharing a 1-km buffer is twice the weight of a neighbor at 2 km and 10 times the weight of a neighbor at 10 km.[2]

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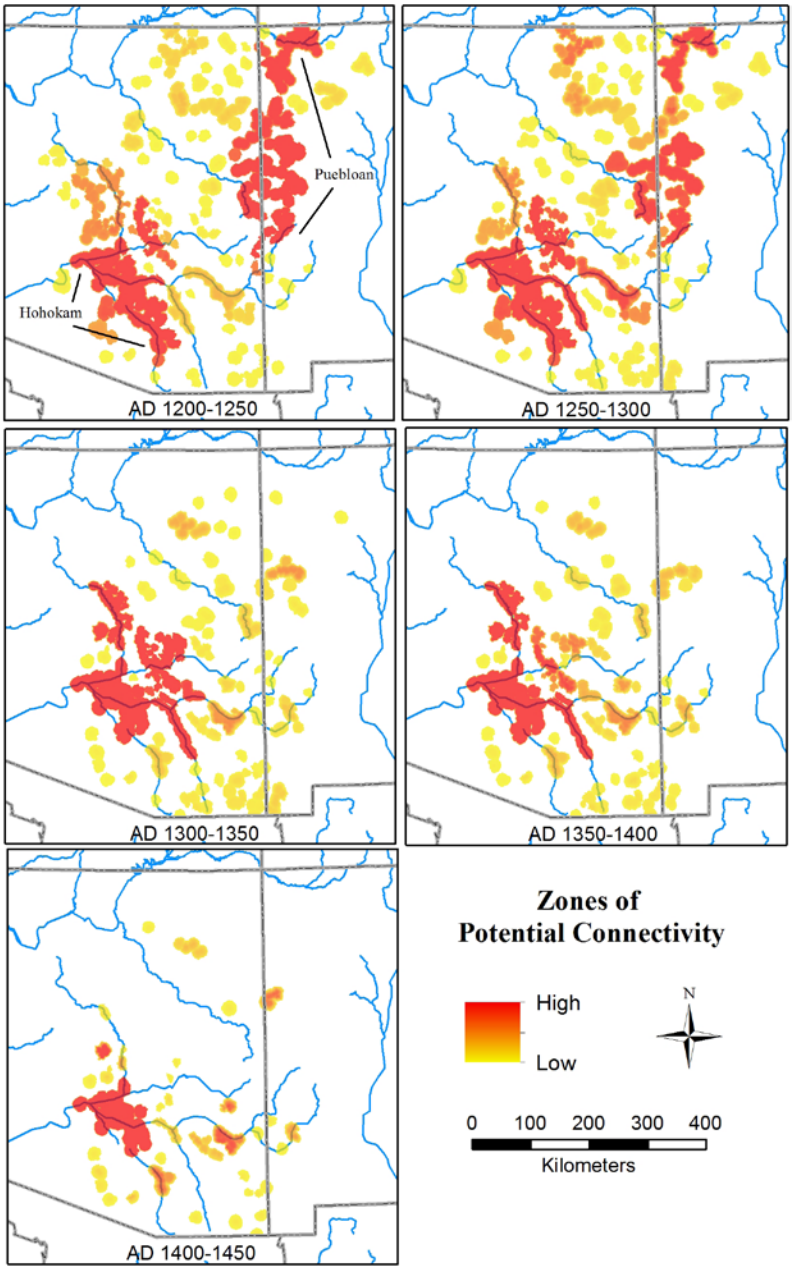


FIGURE 6. Potential connectivity as a function of site proximity.

Initially, we developed buffers for distances at regular intervals from 1–36 km, but we focus here on values from 1–10 km at 1-km intervals because larger radii tended to become so inclusive as to lose discrimination among groups of sites.

By summarizing the number of sites in each buffer at multiple radii, we produce an index of a given buffer's potential connectivity that models the potential effect of proximity on interaction. Thus, the cumulative neighbor count provides a measure of overall site proximity at variable distances but emphasizes near neighbors more than more distant neighbors. We refer to this measure as the Site Proximity Index or SPI. The resulting summary cost buffers (Figure 6) illustrate the areas of most potential connectivity among sites as a function of SPI.

Several interesting patterns are apparent. For example, in the earliest intervals, we have two clearly prominent regions, one each in the two geographic zones described above. One in the northeast spans the Puebloan middle San Juan through Cibola regions, and one in the southwest spans the Hohokam Lower Salt through Santa Cruz regions.

In subsequent chronological intervals, we see the transition from relatively equal patterns of potential connectivity in these two regions to a pattern of stronger potential connectivity in the

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Lower Salt/Middle Gila Hohokam region. This pattern continued into the early fifteenth century when other evidence indicates that population in the south was in severe decline.

While the northern areas then stabilized near the population levels they held until Spanish contact in the mid-1500s, the southern areas continued to decline. By the mid-1400s, settlements in the southern areas became archaeologically invisible. This is not to say that the southern Southwest was abandoned, but the types of habitation sites identified with previous centuries of occupation were no longer in use, and the population that remained practiced more mobile and ephemeral land use, which probably influenced their sense of community.

Also notable is the strong division through all time periods between buffers with fewer than about 50 sites and buffers with more than about 50. Very few buffers contain between 50 and 100 sites for any time period. This division may suggest a scalar threshold in site density that merits closer examination. Further analyses of the relationships among social interaction and distance classes are ongoing and await future analyses.

Another important quality of SPI is that it can be assigned to individual sites within the buffers, producing new variables comparable to other useful site-level attributes. We assigned the SPI to each site at each radius (Figure 5). This lets us determine how many neighbors a site has at a given radius. The number of neighbors a settlement has at a given distance offers a useful starting point for formulating hypotheses about social connectivity. We propose that grouping sites at increasing levels of inclusiveness offers advantages over simple site density figures by emphasizing linear chained connections common to many valley bottom settings in our region and similar to social network ties.

Combining SPI values at the site level with other site attributes offers insights into the variety of factors structuring community organization. For example, we can divide site population by site neighbor count to provide a measure of spatial isolation: in other words, isolated sites are those with relatively large populations without many neighbors. During our earliest interval, we see an expected pattern of relatively isolated populations ringing the southern margins of our study area (Figure 7). By the late thirteenth and early fourteenth centuries, however, a pattern emerges in which the most spatially isolated populations are no longer on the margins but become strongly situated along the Mogollon Rim and transition zones between the north and south. Previous work by the SWSN project team (Peeples and Haas 2013; Peeples and Mills 2014) suggests that these same sites found along the transition between the northern and southern Southwest were marked by diverse network connections and intermediate positions spanning the gap between northern and southern components. At the same time, these sites were also among the most short-lived settlements in the study area, suggesting that isolation may be negatively correlated with longevity.

SOCIAL NETWORK CONNECTIVITY

Next, we consider similarities in decorated ceramic assemblages as indicators of the relative strength of social connections among sites. Because many artifact assemblages are composites of sites occupied for a century or more, the SWSN team has developed a quantitative model that allocates ceramic wares to 50-year periods within the occupation span assigned to each site (Roberts et al. 2012). Briefly, this apportioning model incorporates the occupation spans of sites, the dated production ranges of specific ceramic types, estimates of population and deposition rates through time, and assumptions regarding popularity curves of types and wares through time (assuming type frequencies through time follow a normal curve) to estimate the relative proportions of each ware likely to have been deposited in each 50-year interval in which a site was occupied. This apportioning procedure allows us to produce one table for each 50-year interval between A.D. 1200 and 1500, with sites as rows and ceramic wares as columns.

Using these apportioned tables of ceramic ware frequencies for each 50-year interval, we then define a single measure of similarity among all sites occupied during each period. To do this, we use a modified version of the Brainerd-Robinson coefficient of similarity (Brainerd 1951; Robinson 1951), where similarity (S) between site a and site b is defined as:

$$S_{ab} = \frac{200 - \sum_k \left| P_{ak} - P_{bk} \right|}{200}$$

k = ceramic ware ($k = 1, \ldots, K$)
P_{ak} = Percent of ware k at site a
P_{bk} = Percent of ware k at site b

The Brainerd-Robinson similarity coefficient works well for calculating similarities based on the frequency of nominal categories and has formed the basis for many recent archaeological SNA studies (Golitko et al. 2012; Hart and Engelbrecht 2012; Mills et al. 2013a, 2013b; Peeples 2011; Peeples and Haas 2013). This measure normally ranges between 0 and 200, but we rescale it here to range between 0 (indicating no similarity) to 1 (indicating perfect similarity).

Using this procedure, we produce a symmetric matrix with sites as both rows and columns for each 50-year interval, with values between 0 and 1 indicating the relative similarities of each site to every other site. We interpret the similarity scores among pairs of sites as the weights of ties in the regional network. In the analyses presented below, we first use this full weighted matrix to assess relative similarities in relation to spatial proximity and then present a second set of analyses based on a binary network where ties are defined as either present or absent. First, our weighted measure of social connectivity is simply the sum of all similarities of a site to every other site occupied during a given interval and is known as weighted degree centrality in SNA. In this approach, one strong connection between two sites (i.e., Site A is connected to Site B with a similarity score of .75) counts the same in the correlation as several weaker connections among more sites (i.e., Site A is connected to Site B with a score of .25, Site C with a score of .25, and Site D with a score of .25).

In some circumstances, we may also be interested in limiting our analyses to only the strongest ties among sites (which we hypothesize may be more likely to be influenced by spatial

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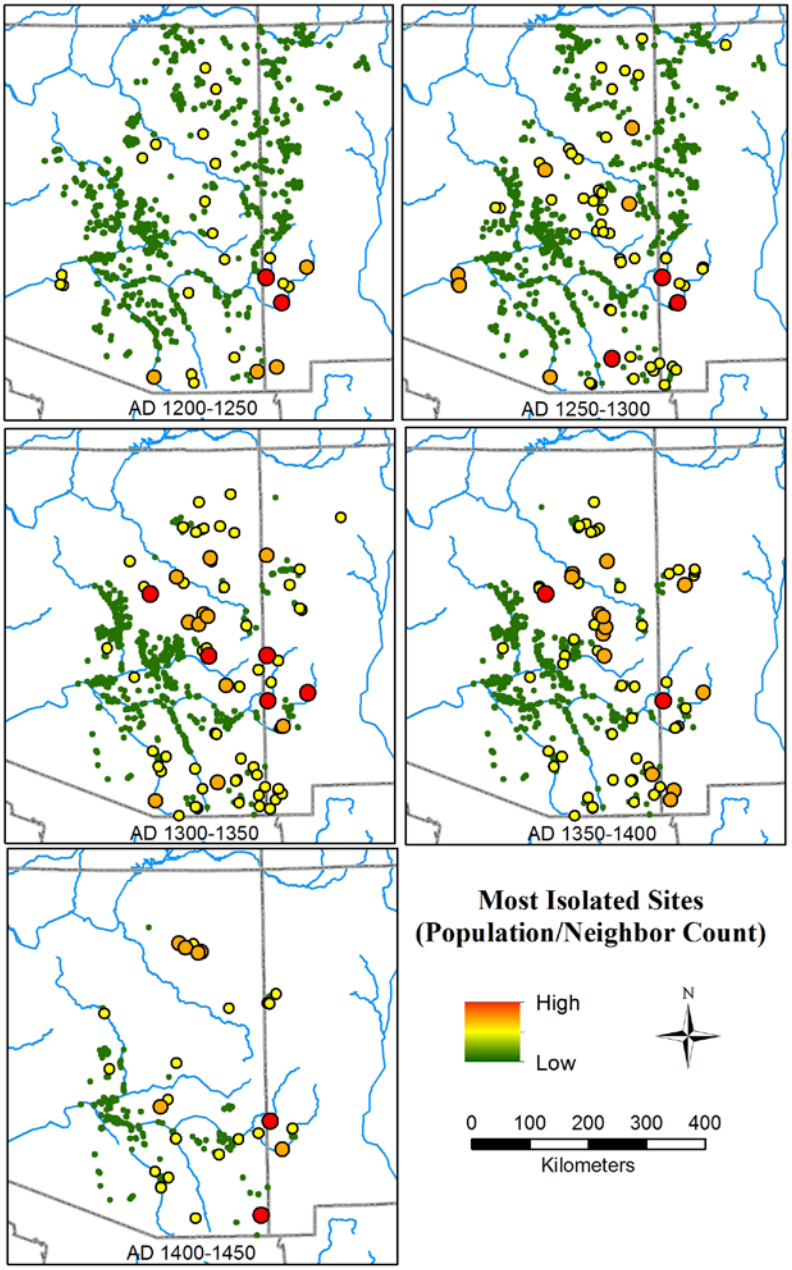


FIGURE 7. Isolation as a function of site size and number of neighbors.

distance). Thus, in our second set of analyses described below, we use a threshold value to define and quantify binary (present/absent) ties among sites. Specifically, we define "strong ties" in terms of similarity scores greater than or equal to .75 (i.e., sites with 75 percent of their ceramic types in common) in order to assess how the strongest connections may be influenced by proximity. Although it is usually preferable to rely on the full weighted values of network connections (see Peeples and Roberts 2013), these analyses provide an example of a case where a profitable distinction between weak and strong ties can be made (see also Golitko and Feinman 2014).

COMPARING NETWORK RESULTS TO SPATIAL CONNECTIVITY

Using techniques described here, we are able to directly compare social connectivity based on ceramic similarities to spatial proximity based on our GIS analyses. Our general expectation is that regions and periods marked by greater spatial proximity among sites might also be marked by greater social connectivity. Further, we suggest that patterns in the relationship between social and spatial connectivity will respond to changing forms of community amid the long-distance population movements that characterize the period considered here.

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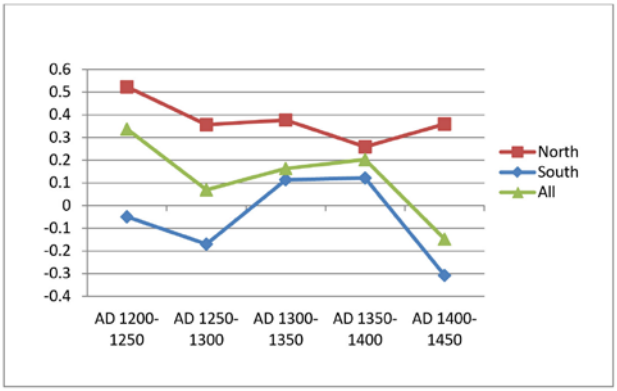


FIGURE 8. Correlation between SPI and degree centrality.

Previous SWSN analyses described correlation at the site level between SPI and weighted degree centrality using Pearson's *r* correlation coefficient (Mills et al. 2013b). This approach assesses whether sites with more neighbors are marked by a greater degree of ceramic similarity, which is our proxy for social connectivity (Figure 8).

Briefly, those analyses produced a surprisingly weak correlation between SPI and weighted degree centrality for the study area as a whole, but with distinct trends in the northern and southern study areas. The correlation between SPI and weighted degree centrality is lower in the south than in the north for every interval. These findings suggested that proximity of neighbors did not structure social relations as strongly as expected and that it did so even less in the southern Southwest than in the north.

Here we consider two approaches to refining these analyses. First, we compare the measure of spatial isolation discussed above to weighted degree centrality. If spatial isolation were a primary factor constraining the establishment and maintenance of social relationships that result in the movement of materials or ideas, we would expect that the most isolated sites would tend to be those marked by the fewest social connections. Figure 9 shows scatter plots of the degree centrality against the isolation measure described above (calculated based on all known sites, not just those with ceramic data), with the northern and southern Southwest separated.

In these plots, the different symbols denote each 50-year interval, with periods prior to the massive migration out of the northern Southwest shown in the upper pair of graphs and intervals after the migration shown in the lower pair. Both the degree centrality and isolation scores are standardized within periods to range between 0 and 1, so that comparisons can be made across different periods.

Comparing plots for the northern and southern Southwest through time reveals some interesting differences. First, there is no easily discernible patterned relationship between weighted degree centrality and isolation in the northern Southwest. Sites marked by the full range of isolation scores also show considerable variation in weighted degree. This lack of a strong relationship (either positive or negative) is consistent for all periods. In the southern Southwest, on the other hand, there are important changes through time. For the two intervals prior to (and encompassing the very beginning of) the major depopulation of the Four Corners and the subsequent resettlement of northern populations in the south (A.D. 1200–1250 and A.D. 1250–1300), sites marked by the highest isolation scores are bimodally distributed in terms of weighted degree centrality. Several isolated sites are marked by low degree, and a somewhat smaller number of sites are marked by high degree, with few in between. This suggests that many settlements did fit the expected association between isolation and decreased social connections, but several other settlements did not. An evaluation of the specific settlements reveals that the few sites marked by a high degree centrality and a high isolation score are exclusively located in the Tonto Basin along the transition zone between the northern and southern Southwest. Importantly, the higher volume of ties for those sites includes connections to sites in both the northern and southern Southwest.

The three intervals after the period of migration into the southern Southwest (A.D. 1300–1350, A.D. 1350–1400, and A.D. 1400–1450) show a considerably different pattern. During these periods, sites marked by high isolation scores are only those that also have high weighted degree centrality (though there are also sites with high degree centrality and low isolation). As this pattern illustrates, after A.D. 1300, the sites that were the most isolated were the most connected across the network as a whole. Interestingly, this pattern is driven largely by the introduction and spread of Roosevelt Red Ware ceramics, which we earlier suggested was associated with the arrival of northern immigrants in the southern Southwest. The increased weight of ties for many isolated sites in the south after A.D. 1300 perhaps provides evidence of the increasing importance of diasporic communities among those immigrants and their descendants.

Evaluating Strong Ties and Close Distances

In addition to analyzing the full matrix of weighted ties (which is typically a good practice; see Peeples and Roberts 2013), as mentioned briefly above, it is often also useful to consider binary network ties for the purposes of visualization and to distinguish strong ties for closer examination (see also Golitko and Feinman 2014). For present purposes, we define a tie as strong (1) when two sites have a similarity of .75 or greater (they share at least 75 percent of their relative ware frequencies) and all other relations are defined as absent (0). To test the relationship between strong ties and SPI, we compare the total number of strong ties within overlapping site buffers and between them. Though here we present the results of a single threshold similarity value for defining ties, we have conducted these analyses across a range of values with similar results.

A related problem is modeling distance in a manner that is empirically significant on a human scale. The LCA described above does not, by itself, address the meaning of variable distances to social actors. The importance of distance to human interaction was a function of particular metabolic, daily, and seasonal cycles. For example, the distance a person can walk in a day probably influenced the likelihood of a trip. Moreover, the difference between a 5- and a 10-km walk may be more significant in human terms than the difference between a 105- and a 110-km walk, or even between a 100- and a 150-km walk.

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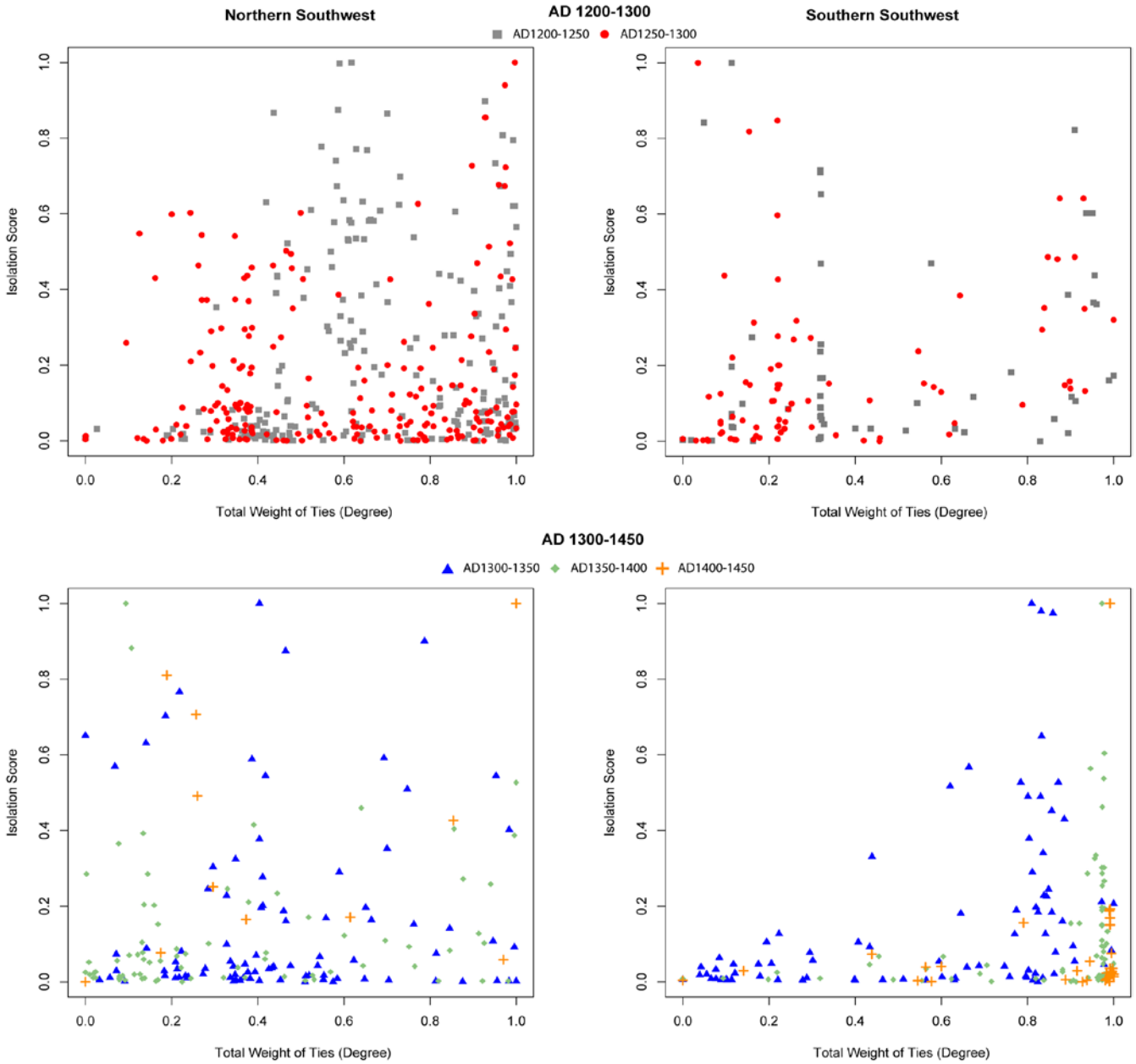


FIGURE 9. Correlation between isolation and degree centrality.

The catchment concept is one way of considering the human scale of distance that has a long history in archaeology. Early approaches focused largely on the cost and benefits of subsistence and resource acquisition (Chisholm 1968; Vita-Finzi and Higgs 1970). More recently, archaeologists working in the Southwest have also considered social interaction and multiple distance classes to reflect different types of activity (Varien 1999; Wilcox et al. 2007). Effective distances for agriculture range from as little as 2 km for intensive irrigation (Flannery 1982) to as much as 8 km or more for extensive strategies, with some ethnographic examples from the Southwest ranging even farther (Cushing 1979:249). Mark Varien (1999) used multiple distance values of 2, 7, and 18 km to model a range of agricultural and social activity. David Wilcox and colleagues (2007) considered values of 3, 9, and 18 km to reflect daily interaction, one-day round trips, and over-night trips between sites.

Our data lend themselves to empirical evaluation of social interaction distances by consideration of LCA proximity described above at intervals commonly hypothesized to structure human behavior. Examination of different intervals compared to social interaction distances shows an apparent inflection point at the 9-km radius. At smaller increments, the correlation between measures of spatial and social connectivity (using the full weighted matrix of similarities) declines gradually in a linear fashion, but beyond 9 km the relationship breaks down more

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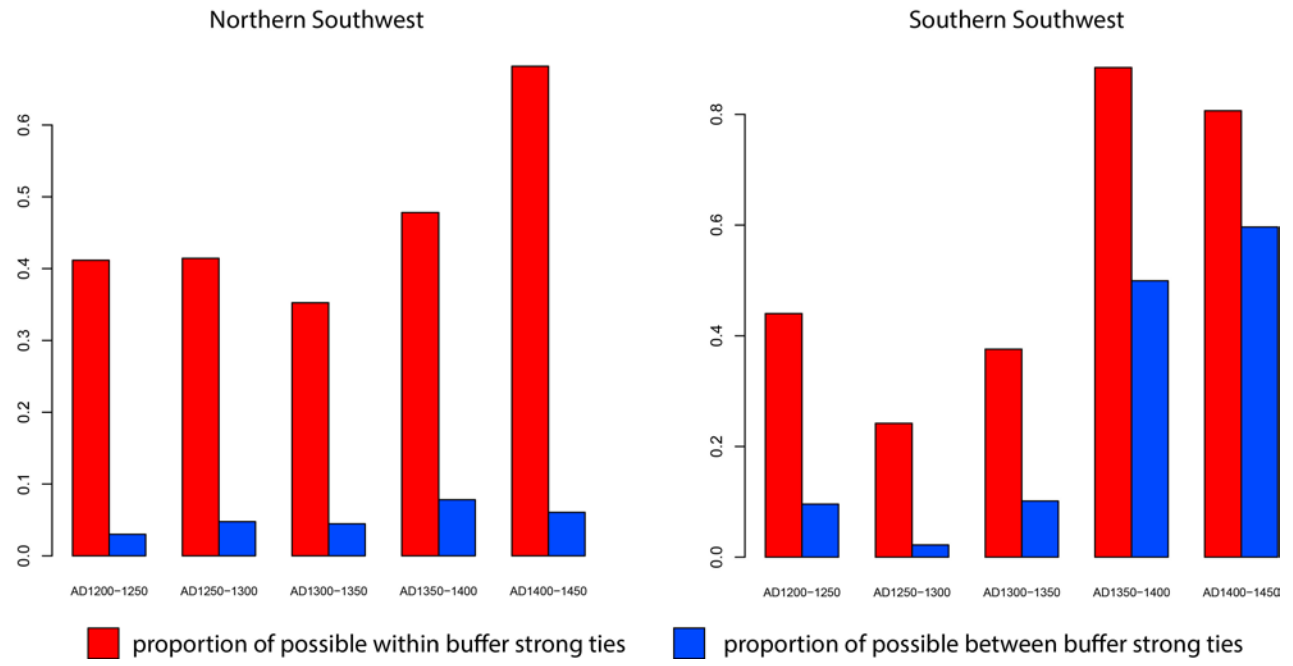


FIGURE 10. Proportion of strong ties within and between 9-km buffers.

rapidly. This suggests that the one-day trip estimate of 9 km has some empirical support. Overall, the number of single-day interaction groupings represented by these buffers declines through time, and the smaller and more isolated groups are the first to disappear.

To refine our analyses of the relationship between proximity and social connection, we calculated the total number of strong ties within and between the 9-km buffers (representing approximately one day of travel out and back from an individual site). As Figure 10 illustrates, for the northern Southwest, the proportion of all possible ties (known as network density) is far greater within the 9-km buffers than for sites in different buffers for all periods considered. This suggests that the spatial proximity of sites within the same buffers does play a major role in the distribution of the strongest ceramic similarities. Comparisons of within and between buffer strong ties for the southern Southwest again show that sites within the same buffer consistently have greater numbers of ties. The number of ties extending beyond the boundaries of individual buffers increases dramatically, however, in the southern Southwest for the last two intervals considered (A.D. 1350–1400 and A.D. 1400–1450). As this suggests, the late precontact period in the south is marked by a substantially greater frequency of strong connections that span greater distances (see also Mills et al. 2013b). Overall, these results suggest that spatial proximity does play a major role in the distribution of strong ties among settlements in our study area (particularly in the northern Southwest), but that pattern diminishes in the last 150 years considered in the southern Southwest, after the arrival of substantial numbers of migrant populations in the region, possibly as a result of increasingly distant connections spanning diasporic communities across the region.

CONCLUSIONS

Our analyses indicate that the northern and southern Southwest experienced quite different trends in community structure throughout the late precontact period. We employ a novel GIS approach that measures potential connectivity as a function of cost distance to illustrate relatively equal patterns of potential connectivity in the north and south through about A.D. 1300. By 1350, a pattern emerges of much higher potential connectivity in the Lower Salt/Middle Gila drainages of the Hohokam region. Furthermore, during the late thirteenth and early fourteenth centuries, the most spatially isolated sites are located along the Mogollon Rim and Upper Gila regions, between the two major zones of occupation.

The relationship between site proximity and social connectivity is complex. Looking first at overall connectivity in the north, we do not find the expected inverse correlation between site isolation and social connectivity, nor any other obvious pattern. In the south, on the other hand, we see that many isolated sites have low social connectivity, with one interesting exception. Isolated sites in the Tonto Basin, situated between the north and south, have high degrees of social connectivity with distant sites in both areas, suggesting that they fulfilled some intermediary role.

Looking more closely at strong social ties, we revisit previous investigations indicating an overall weak relationship between proximity of neighbors and total social connectivity. We find that strong social ties are much more likely to connect sites within approximate days-walk distances. Interestingly, however, this relationship between proximity and social connectivity breaks down in the southern Southwest by the late fourteenth century. We attribute this pattern, initially, to the spread of Puebloan immigrants from the north to the south. Immigrant communi-

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ties in diaspora maintained social ties across great distances. Later, the relationship between proximity and social connectivity broke down even more as Roosevelt Red Ware ceramics associated with the spread of Salado religious practices and hybrid identities (Clark et al. 2013) became more widespread. Studies have shown that Roosevelt Red Ware was made in most of the places it is found (for example, see Crown and Bishop 1991; Hill 1998; Lyons 2003, 2012; Mills et al. 1999; Neuzil 2008; Ownby et al. 2014; Zedeño 1994), and its initial production is linked to Puebloan immigrants and their descendants (Clark and Lyons 2012; Crown 1994; Lyons 2003; Lyons and Clark 2012; Lyons and Lindsay 2006). Interestingly, many areas marked by high frequencies of Roosevelt Red Wares also see other changes, such as increased frequencies of obsidian, in particular from sources in the Upper Gila where migrant sites are common (Mills et al. 2013a). Taken together, our analyses, along with these past studies, suggest the increasing importance of long-distance ties in the construction of communities across the southern Southwest in the fourteenth century and later.

Our analyses also demonstrate the potential of using spatial and social network analyses to quantify changes in social connections through time. We propose that changes in social connectivity may have played a role in the subsequent decline of common material culture traditions that have historically been used by archaeologists to identify the Hohokam and other groups.

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Data Availability Statement

The site data in the Coalescent Communities Database are available online from Archaeology Southwest through a formal user agreement (http://www.archaeologysouthwest.org/hswdb). This user agreement asks users to agree to keep locational information confidential and also asks that they collaborate with or cite researchers responsible for any specific datasets they choose to use. Qualified users will include academic researchers, archaeologists within contract firms, and independent researchers with access to databases such as AZSITE (Arizona database for site information) and/or ARMS (New Mexico database for site information), which also contain sensitive site locational information.

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NOTES

1. A ware, in the Southwest, is defined as a broad technological tradition usually associated with a particular time period and geographic location. A ware includes multiple types, each with a particular style or design configuration.
2. Because we focus on the *overlap* among individual buffers around sets of sites, this measure of spatial proximity is undirected and symmetrical (i.e., pairs/sets of sites are defined as "neighbors" when their buffers overlap at a given distance, irrespective of which site is treated as an origin). Thus, this measure is comparable to the undirected/symmetrical measures of ceramic similarity.

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