Spatial modeling of archaeological site locations based on summed probability distributions and hot-spot analyses: A case study from the Three Kingdoms Period, Korea

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Highlights
- Radiocarbon ages model site locations from the Three Kingdoms Period, Korea
- Historical/archaeological hypothesis has been that Baekje abandoned Gyeonggi >AD475
- Spatial autocorrelations of radiocarbon-based SPDs test historical interpretations
- Baekje residential settlement shifts south circa the AD475 Korguryeo invasion
- Attribute-based hot spot tests of SPDs nuance history with archaeological data
Abstract

Archaeologists typically use radiocarbon ages to date human activities on archaeological sites. However, radiocarbon ages can also serve as independent proxies for human demographic patterns through space and time. Spatial modeling of archaeological data often involves taking diachronic datasets and developing synchronic views of the distribution of cultural patterns. Here, we evaluate spatial dynamics of human activity areas assayed by radiocarbon ages in the Baekje Kingdom of Korea before and after the invasion of Koguryeo, which is historically documented as occurring in AD 475. The statistical techniques used in this research apply spatial autocorrelations on archaeological sites with weighted attributes from summed probability distributions (SPDs) to evaluate regional scale diachronic changes from radiocarbon datasets. Ripley’s K analysis shows an increasing tendency toward clustering of weighted SPD attributes from sites after AD 325. The Getis-Ord Gi* statistic shows the changing hot spots of Baekje settlement shift prior and concurrent to the establishment of a military zone in northern Gyeonggi Province, South Korea. The settlement systems realign from clusters in the north and south of the province to clusters in the southeast with avoidance of the north.

Keywords Temporal-spatial modeling of archaeological sites; SPDs of radiocarbon ages; Ripley’s K; Getis-Ord Gi*; Protohistorical Period of Korea
1. Introduction

The use of radiocarbon dating in archaeological studies has continued to grow over the past few decades as the relative costs have decreased while the accuracy and precision of the method have increased (Bronk Ramsey, 2008, Taylor and Bar-Yosef, 2014, Wright, 2017). Nevertheless, all radiocarbon ages have some degree of statistical uncertainty due to collection, storage, taphonomic or laboratory errors that can be introduced at any point in the process (Kim, et al., 2016, Polach, 1992, Scott, et al., 2010). Statistical uncertainties related to the production and uptake of atmospheric $^{14}$C is accommodated by means of calibration between well-dated varve sediments or corals created by an international research consortium (the most recent is published in Reimer, et al., 2013), but also imbue radiocarbon ages with an inherent imprecision.

Archaeologists use radiocarbon ages to create diachronic datasets out of material culture that can appear spatially synchronic. That is, human artifacts can be in overlapping or cumulative contexts, which may be separated by tens, hundreds or thousands of years, depending on the depositional and taphonomic circumstances. Mapping artifacts in a spatial context using a Geographic Information System (GIS) can create an impression of simultaneity in use or discard, an assumption which radiocarbon dating is used to test. Once a radiocarbon chronology is created, relationships between material objects and environments can be established, which is essential to understand the circumstances under which the evolution of human technology occurred. Similarly, human material cultural manifestations can be compared on regional or even global scales to show commonalities and/or
differences in the ways human cultures have developed over time. For example, distributions of radiocarbon ages within robustly sampled regional contexts have been used as proxy data to model population dynamics (Manning and Timpson, 2014, Park, et al., 2017, Riede, 2009, Timpson, et al., 2014).

The use of radiocarbon ages to model prehistoric demographic patterns has both advocates and critics. Those who are in favor of using the method argue that radiocarbon ages collected from archaeological contexts definitively represent human activity regardless of the social circumstance, and there is no inherent bias to the results since the purpose of submitting an age is that there is no conclusive a priori knowledge of the temporal setting, otherwise the age would not have been generated in the first place (Peros, et al., 2010, Rick, 1987). In the world of “Big Data” analysis, bias is presumed to be eliminated vis-à-vis rich, longue-durée datasets, which accumulate over time to produce an even distribution of results as knowledge sets grow (Tallavaara, et al., 2014). On the other hand, critics can point out that time periods in regions with good relative dating potential (e.g., well-established ceramic seriations, historical texts) will have patchy outputs in which time periods that lack historical or serial typologies will be oversampled, distorting the interpretative value of radiocarbon-based results (sensu Bevan, et al., 2013, Finkelstein, 2016). Changing mobility and consumption patterns over time can also skew population estimates because more mobile people and cultures that consume less fuel leave lighter archaeological traces than sedentary, highly consumptive people (Freeman, et al., 2017, Naudinot, et al., 2014). The most commonly leveled criticisms are that some archaeological regions and time periods are subject to
taphonomic bias due to diagenesis, visibility of the archaeological material or research intensity bias (Bird and Frankel, 1991, Contreras and Meadows, 2014, Hiscock and Attenbrow, 2016, Mökkönen, 2014, Surovell, et al., 2009, Torfing, 2015). In order to find common ground, datasets that use multiple proxies to supplement radiocarbon ages, improved statistical simulation tools such as summed probability distributions (SPDs) or refined points of analysis (such as ages generated only from house features) are argued to be more robust than studies using uncritically selected or modeled big datasets (Crema, et al., 2017, Crombé and Robinson, 2014, Palmisano, et al., 2017, Robinson, et al., 2019, Shennan, et al., 2013, Tallavaara, et al., 2010, Timpson, et al., 2014). Furthermore, the use of historical texts or oral traditions can anchor probabilistic radiocarbon proxy models by providing a priori scaffolding upon which interpretations about past cultural activities can be constructed (Edinborough, et al., 2017).

This paper tests whether settlement dynamics shift in relation to an a priori date of AD 475, which is the historically documented invasion of Baekje by Korguryeo during the Three Kingdoms Period of Korea (57 BC to AD 688). Although settlement studies using calibrated radiocarbon ages have become standard research tools for reconstructing population dynamics, using radiocarbon ages to test the veracity of historical texts center primarily on confirming or refuting the occurrence of specific events (Izdebski, et al., 2016, Lee, 2002, Levy, et al., 2007). To fill in gaps pertaining to the effect of such events on the lives of ordinary denizens of society, the use of spatial autocorrelation techniques can be used to statistically
model settlement dynamics in relation to historical documented events (e.g., Park, et al., 2017).

2. Research Questions

The historically documented invasion and relocation of the Baekje capitol has prompted historians to hypothesize that the whole Gyeonggi Province (henceforth, Gyeonggi-do) was depopulated immediately after AD 475, as all of Baekje’s local populace is thought to have moved southwards (henceforth, “AD 475 Hypothesis”; Choi, 2008, Kwon, 2011, Yeo, 2013). Accepting this hypothesis, some archaeologists have conventionally predicated that all the settlements with Baekje style pottery found in Gyeonggi-do had been abandoned immediately after AD 475 and thus must date to before AD 475 (Park, 2001). In order to test this hypothesis, we pose the following research questions:

(1) Can radiocarbon ages demonstrate changes in spatio-temporal patterns in a probabilistic way?
(2) Can regional differences in settlement distributions using material culture be detected in the archaeological record?
(3) Was northern Baekje (i.e., Gyeonggi-do) depopulated after AD 475?

This archaeological example from the Three Kingdoms Period of Korea uses distributions of radiocarbon ages as population proxies to understand changing settlement dynamics in response to the rise and fall of a state for which there is associated historical documentation. We divided our study into four main periods,
and distributions of radiocarbon ages were binned according to posterior distributions of conditional probability of occurrence. Simulated distributions of points in space were generated in a Ripley’s K analysis to show increasing tendency of sites to cluster over time. Furthermore, we used the Getis-Ord Gi* statistic (Getis and Ord, 1992, Ord and Getis, 1995) to identify clusters of settlement from these bins to evaluate whether the invasion of Koguryeo affected population distributions within Baekje territory. GIS hotspot-type analyses using posterior distributions of summed probability distributions represent a conditionally probabilistic way to test archaeological or historical hypotheses.

3. Background to the Study Area

Beginning in the 1st century BC, the degree of social complexity increased rapidly in Korea as iron technologies were applied to agricultural tools and weaponry, which facilitated the development of three ancient states in the mid-3rd century AD. According to both historical and archaeological records, Koguryeo was located in the northern part of peninsula, Baekje in the central part and Silla in the southeastern part (Figure 1). Material culture between the political entities was distinct (Figure 2), which has allowed archaeologists to distinguish between the respective economic zones (Park, 1999). Historical records indicate that Baekje, originated as a small polity in Hanseong (located in the modern city of Seoul), gradually developed to a centralized state in the mid-3rd century and actively expanded its territory by conquering and consolidating neighboring polities (Kim, 1998 [1145], Noh, 1987). The expansion of Baekje is archaeologically supported by
the spread of Baekje style pottery to the surrounding areas (Park, 1999). In the late 4th century AD, due to Baekje’s continuous territorial expansion, wars between Koguryeo and Baekje broke out (Kim, 1998 [1145]). In AD 475, Koguryeo attacked Baekje and captured Hanseong, and Baekje transferred its capitol to Ungjin, located 150 km to the south. Korean historians have interpreted that this event represented the effective, permanent surrender of political authority of Baekje to Koguryeo in the north of its territory (Kwon, 2011, Yeo, 2013), which is located in the modern-day province of Gyeonggi-do in South Korea.

*Figure 1. Location of the study area within the Three Kingdoms period of Korea.*
Figure 2. Representative ceramic material culture from (a) Baekje and (b) Koguryeo kingdoms, ca. 4th century AD, Korea.

4. Research Methods

4.1. Bayesian model construction of radiocarbon ages

To test research questions outlined above, archaeological data and radiocarbon ages were assembled in the Archaeometry Laboratory at Seoul National University. Inclusive of the suburbs of Seoul and environs, sampling in Gyeonggi-do is one of the highest in Korea with approximately 0.27% of the province area having been subject to archaeological survey and/or excavation. In South Korea, archaeological data are archived according to their material culture affiliation, and, in this case, the separation between Baekje-type artifacts and other archaeological traditions is generally not in dispute. After a critical assessment of reported radiocarbon ages, a total of 409 radiocarbon ages from 60 settlements were calibrated for atmospheric variability in the production of $^{14}$C in OxCal 4.3.2 to 2-σ. A probability density function (PDF, Bronk Ramsey, 2017, Bronk Ramsey and Lee, 2013) was calculated from the calibrated ages. The criteria for rejecting radiocarbon ages from 450 BC to AD 650 (>2400 and <1300 cal. BP) from raw data were made
on the basis that these ages are interpreted as coming from non-Baekje or uncertain cultural contexts; or they are believed to be spurious or statistical outliers considering previous chronology, archaeological knowledge and/or historical background. For single-occupation dwelling structures that contained two or more radiocarbon ages, the $R_{\text{combine}}$ function with the Outlier parameter in OxCal was used to derive the age. After the combination of selected radiocarbon ages, 276 proxy points attributed to Baekje settlement features were used for statistical analysis (Supplementary Material 1).

Summed probabilities (sensu Balsera, et al., 2015, Crema, et al., 2010, Porčić, et al., 2016) from each archaeological site were generated to bin occupations into two categories (AD 25–475, 476–625) and four subcategories (AD 25–175, 176–325, 326–475, 476–625) (Supplementary Material 2). Summed probabilities estimate the number of occupation events within a specific bin (McLaughlin, 2019, Williams, 2012). SPDs of the presence or absence of settlement at specific locales (sites) within the designated bins are not a reflection of overall population densities at those sites relative to the entire dataset.

Our application of the analytical dataset was designed to test posterior distributions of temporal data with spatial autocorrelation techniques. A polygon file of Gyeonggi-do (including Seoul and Incheon administrative zones) was added to the GIS to create a hard analytical boundary for the study. Point shapefiles of the 60 archaeological sites from Gyeonggi-do were created in ArcGIS 10.2.2 in which the binned SPDs of radiocarbon ages were added as attributes (Figure 3). Each binned category was assigned an attribute value that related to the SPD on a scale of 0-
100(%) based on the relative proportion of the SPD within the bin. Four weighted mean geographic centers of site locations were calculated using binned SPD values as the weight.

**Figure 3.** Example of summed probability distribution (SPD) binning for Bayesian modeling of site probability locations. The Gangnae-ri site has 23 radiocarbon ages from features with diagnostic Baekje material culture. The PDF is divided into four bins, which are subdivided from AD 25 to 625 and the probabilities are percentages that occupation of the site occurs within one of those bins based on the total statistical distribution.
4.2. Spatial statistics of the SPD-modeled radiocarbon ages

4.2.1. Ripley's K multi-distance spatial cluster analysis

Four independent Ripley's K multi-distance spatial cluster analyses were performed in ArcGIS to determine whether the locations of sites exhibit statistically significant clustering or dispersion over a range of distances. In ArcGIS, the K statistic is determined based on the expected number of random points surrounding a given point given the total number of points in a dataset, and it assigns clustering or dispersion values based on the actual data distribution (ESRI, 2018). The K function can simply be expressed as \( K(t) = \lambda^1E \) where \( K \) is the characteristics of point processes at different scales, \( t \) represents the variance of those scales, \( \lambda \) is the density of events and \( E \) is the number of extra events that occur within \( t \) relative to random permutations of that event (Dixon, 2013). ArcGIS calculates \( t \) as \( d \), which is the Euclidean distance between points within the random distribution of points based on Markov chain Monte Carlo (MCMC) simulations within a bounded area. The \( L(d) \) function is the expected distance of points within a completely random distribution at the scale of analysis. In ArcGIS, the formula is as follows:

\[
L(d) = \sqrt{\frac{A \sum_{i=0}^{n} \sum_{j=1, j \neq 1}^{n} k_{i,j}}{\pi n(n-1)}}
\]

In this formula, \( A \) is the total bounded area of the features and \( n \) is the total number of features. Spatial weight can be applied \((k_{i,j})\) where the weight is 1 if the distance between two given features \((i \text{ and } j)\) are \( \leq d \), and the weight is 0 when \( \geq d \) if no boundary correction is applied (ESRI, 2018). Attribute values can also be analyzed
against a range of identical values relative to the number of analyzed points simulated in a normal (Gaussian) distribution.

For the present analysis, all archaeological site locations were reprojected into UTM coordinates and a total of 10 distance bands were generated. Confidence intervals of each distance band were computed based on 99 MCMC permutations of randomly distributed points within a bounding polygon based on the site universe. Features were weighted based on the percent probability of site occurrence within the total SPD (range = 0 to 0.13484). Beginning and ending distances of the analyses were executed unsupervised with a simulated outer boundary correction to accommodate the potential for sites to occur outside the study region to ensure that MCMC neighbors were not undersampled.

4.2.2. Getis-Ord Gi* spatial autocorrelation

Spatial modeling of archaeological site distributions using SPDs traditionally use Kernel Density Estimates (KDEs) which map Gaussian distributions of attributes between points (Collard, et al., 2010, Grove, 2011, Manning and Timpson, 2014, McLaughlin, 2019). However, such tests can under- or overestimate local attribute variability determined from radiocarbon data, which are predicted on patchy research intensity along modern political boundaries and are strictly visual tools in most cases (Crema, et al., 2017). Getis-Ord Gi* is a spatial statistic in which attribute weights are modeled locally as z-scores relative to the total distribution of data: positive numbers indicate that there is a clustering of high values around a high attribute value and low numbers represent clustering around low attribute values (Getis and Aldstadt, 2004). Getis-Ord Gi* differs from KDE methods because the
former statistic does not follow a Gaussian distribution, but creates correlation matrices based on z-scores at points (archaeological sites) that exceed the 90%, 95% and 99% confidence thresholds exclusively.

The Getis-Ord Gi* equation (Ord and Getis, 1995) has been revised over the years into its current form, which is published by ESRI (2018) as:

$$G_i^* = \frac{\sum_{j=1}^{n} w_{ij} x_j - \bar{X} \sum_{j=1}^{n} w_{ij}}{S \sqrt{\frac{n \sum_{j=1}^{n} w_{ij}^2 - (\sum_{j=1}^{n} w_{ij})^2}{n-1}}}$$

In this formula, $x_j$ is the attribute value of a given feature ($j$), $n$ is the total number of features, $w_{ij}(d)$ is a binary spatial weighted matrix, $\bar{X}$ is the sample mean and $S$ is the sample variance. When the locations of two features ($i$ and $j$) are within the fixed distance threshold ($d$), $w_{ij} = 1$; if the features exceed the threshold, $w_{ij} = 0$ (Ord and Getis, 1995). The other variables structured into the equation are:

$$\bar{X} = \frac{\sum_{j=1}^{n} x_j}{n}$$

and

$$S = \sqrt{\frac{\sum_{j=1}^{n} x_j^2}{n} - (\bar{X})^2}$$

For analytical purposes, a fishnet polygon of $6.15 \pm 0.05$ km$^2$ units (based on 0.0025 radian degrees) was joined to the SPD value attributes from the point shapefiles and Gi* statistics were generated within that matrix. As introduced above, the Gi* value is derived as a z-score based on the clustering of attributes (highs with highs and lows with lows, which with 2-σ thresholds are traditionally set between $+1.65$ and $-1.65$, respectively) (ESRI, 2018). The p-value is the probabilistic
posterior distribution of the relationship between the attribute values. For the purposes of the analysis of settlement practices between AD 25–625, the distance threshold was set to 1800 m automatically by the ArcGIS software to ensure that every feature had at least one neighbor. The attributes were the SPD values from each site within the assigned bin. Thus, sites with high probabilities of occurring within the specified bins clustered with each other (high-high), while sites with low or no probability of occurring within the bin would cluster with each other (low-low). The use of the Getis-Ord Gi* in this manner is designed to circumvent sampling bias within such a large dataset by assigning weight to clusters of high or low probabilities of settlement within a large region. Getis-Ord Gi* maps reflect relative localized proportionality of attribute values across a study region, and therefore hotspots and cold spots do not show absolute population increases or decreases.

5. Results

The overall SPD results indicate that in the 100 years preceding Korguryeo invasion of Baekje, there is a significant decline in the probability density of house features with Baekje material culture (Figure 4). The capture and execution of Baekje’s King Kaero in AD 475 at the hands of Korguryeo was a significant defeat for Baekje, but was not the end of the political power of the kingdom, much less cultural traditions (Park, 2017). SPDs indicate more significant depopulation of areas north of the Han River compared to the south following the initiation of Korguryeo raiding in the late 4th century AD.

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1 A Python plugin called “Hotspot Analysis” in QGIS can also perform Getis-Ord Gi* and other spatial autocorrelation analyses (Oxoli, et al., 2016).
Gyeonggi-do was subdivided into contexts north and south of the Han River and the analysis was re-run showing more significant depopulation of regions north of the Han River ca. AD 400.

To further contextualize the impact of military actions on settlement processes in Gyeonggi-do, the SPD of radiocarbon ages from archaeological sites modeled using Getis-Ord Gi* indicate that high probabilities of settlement in northern Baekje preceding the Koguryeo invasion in AD 475, while the probabilities of settlement shift southward in the run up to the invasion and period following it.
There is an apparent depopulation of the northern Baekje frontier following AD 475 in favor of settlement in the southern portion of Gyeonggi-do.

**Figure 5.** Mapped probability function distributions of calibrated radiocarbon ages from 60 sites located in Gyeonggi-do within four temporal bins.

Ripley’s K analysis of weighted distributions of points shows that site locations demonstrate weak dispersion relative to the expected K (MCMC random permutations within the site universe) beyond the 8000 m threshold prior to AD 325 (Figure 6a-b). From AD 326 to 625, the weighted site distributions match the expected K values until 18,000–20,000 m above which they show dispersion (Figure 6c-d). After AD 325, the central tendency of the data points trend toward more clustering at greater scales relative to earlier periods, generally according with a more random orientation at all scales up to 27,000 m.
Figure 6. Ripley’s K analysis in meters of SPD weighted distributions of 60 sites located in Gyeonggi-do within four temporal bins.

Getis-Ord Gi* maps reflect the SPDs showing hotspots of settlement focused northward in the pre-AD 475 period (Figure 7a-c). In the period between AD 326–475, the focus of Baekje settlement appears to shift southward to the Hanseong region. In contrast, there is a distinct decline in the probability of settlement in the northern area as the concentration of settlement shifts to the area south of the Han River following AD 475 (Figure 7d). A weighted mean geographic center calculation of SPD detects a shift in settlement of 20 km to the south-southeast from the first bin (AD 25–175) to the last bin (AD 476–625).
Figure 7. Getis-Ord Gi* smoothed kernel distributions of attributes derived from SPDs at 60 sites located in Gyeonggi-do within four temporal bins. Known locations of Koguryeo fortresses constructed after AD 475 provides a potential explanation for the shift in site occupation probabilities shown in the southward shift of the weighted mean center.

6. Discussion

Historical records document that after its development to a state level society in the mid-3rd century AD in the Han River Valley, Baekje expanded its territory to surrounding areas (Noh, 1987, Park, 2001). The demographic dynamics illustrated by the Getis-Ord Gi* clearly demonstrate that this historical event correlated with a significant shift in the spatial distribution of Baekje sites. The presence of Baekje settlements in the northern and southern portions of the study region (Figure 7a, 7b) accord with similar scales of clustering to 8000 m and weak
tendencies toward dispersion or a spatially random orientation thereafter illustrated in the Ripley’s K (Figure 6a, 6b). These trends indicate spatially homogenous expansion of settlements between AD 176 and 325 in which there is a geographic expansion of territory without changing the relative degree of population aggregation. Later, Ripley’s K Bayesian simulations vs. actual weighted distribution of sites demonstrate increasing clustering of sites after AD 325, but do not nuance the directional distribution of this tendency. The SPD demonstrates a significant decrease radiocarbon ages associated with Baekje household debris (a proxy for population) near the beginning of the 5th century AD (Figure 4). The SPD-derived Getis-Ord Gi* clearly illustrates a southward demographic shift in Baekje settlement concurrent to the overall depopulation, ultimately with focal settlements located south of the Han River in Gyeonggi-do (Figure 7). It is likely that had more southern provinces been included in the analysis, a stronger pattern of southward-shifting settlement would be apparent in the post-AD 475 period.

The methodological approach used to arrive at these conclusions employed spatially local autocorrelations to derive the most efficacious explanation for probabilistically derived (Bayesian) temporal and spatial data. SPDs allow observed data to be fit to a smooth distribution model to accommodate statistical uncertainty associated with measurements (Burr, 1942, Williams, 2012). SPDs can be used as tools to understand relationships among vertical (e.g., temporal, stratigraphic) occurrences of large datasets (e.g., Crema, et al., 2016, Macklin, et al., 2010), but have been criticized for not accommodating data scatter and temporal lags inherent in calibrated radiocarbon data (e.g., Chiverrell, et al., 2011, Torfing, 2015). This
criticism has been challenged as favoring descriptive over analytical approaches (Timpson, et al., 2015) and ultimately to effectively evaluate spatial (horizontal) distributions, a null hypothesis relating to the suitability of proxy data must be accepted or rejected (Shennan, et al., 2013, Smith, 2016). Without explicitly advocating for one approach over another, we use Getis-Ord Gi* to test temporal probability occurrences within a hot-spot visual environment. Hot spots enhance user comprehension of vast quantities of information based on proxy data. By binning sufficiently large sets of data into sufficiently large temporal categories and anchoring data to historically known events, SPDs and MCMC spatial data can provide prior information for assessing the consequences of historical events on the spatial distribution of sites over time (Crema, et al., 2017, Oh, et al., 2017, see also Smith, 2016).

SPDs and Ripley’s K analyses combined with Getis-Ord Gi* probability models indicate that the settlement structure of Baekje shifted in accordance with political consolidation and disintegration throughout the study period. Consolidation of Baekje authority related to territorial expansion in the 3rd to 4th centuries AD suggested by historical studies (Kim, 2014, Ku, 2010, Noh, 1987, Park, 2017) is reflected in the occurrence of Baekje material culture in archaeological assemblages in Gyeonggi-do.

However, analysis of post-AD 475 radiocarbon ages does not support the historically driven hypothesis that argues for a complete evacuation of Baekje populace in the whole Gyeonggi area immediately after the relocation of Baekje capitol from Hanseong to Ungjin (e.g., Choi, 2008, Kwon, 2011, Park, 2001, Yeo,
2013). Instead, our results indicate a more nuanced settlement model than the AD 475 Hypothesis would suggest, although significant depopulation of Gyeonggi-do beginning ca. AD 400 is implied in the SPD model. Koguryeo-related sites located in Gyeonggi-do are mostly fortresses, and no Koguryeo settlements have been found in the area. This evidence leads us to the hypothesis that Koguryeo did not fully colonize Gyeonggi-do after AD 475 and its northern portion was transformed into a military zone. When plotted simultaneously in the GIS, the locations of Koguryeo fortresses are suggestive of a population reorientation away from the active military frontier, especially south of the Han River (Figure 7d). We interpret these results as indicating not a depopulation of the region in its entirety but as an avoidance of Baekje denizens of the locations in which Koguryeo was specifically expanding. The probabilistic model indicates that Baekje material culture (houses with pottery) continue to be found outside the active military zone, particularly in the southeast portion of the Gyeonggi-do study area.

7. Conclusion

The use of Bayesian statistical models of Baekje settlement on the Korean Peninsula (ca. AD 25–625) to construct SPDs and Ripley’s K analyses that were tested using Getis-Ord Gi* does not support the previously accepted AD 475 Hypothesis that the region that is now Gyeonggi-do was completely depopulated following the relocation of the Baekje capitol from Hanseong to Ungjin in AD 475. Instead, we propose an alternative hypothesis on the weight of the evidence, which is that settlement shifted away from the active military zone in the north toward the
southeast portion of the province. Our hypothesis represents a more nuanced understanding of the exertion of political and cultural influence in the face of a military defeat.

The methods developed for this study involve testing spatial distributions of probabilistically derived data in order to better contextualize changing human settlement patterns through time. Probability-based statistical methods are ways to test interpretations of when and where human settlements occurred in the past that accommodates varying degrees of statistical uncertainty. Assembling radiocarbon data into a GIS that have been aggregated as proxies is possible due to advanced spatial statistic toolkits such as Getis-Ord Gi* and other autocorrelation methods (Shekhar, et al., 2011). Ultimately, the use of such methods are modes of evaluating the “weight of evidence” toward understanding the past (Duke and Steele, 2010). Bayesian-based probabilistic models are argued to be preferable to blanket statements of conjecture regarding temporal data because they are flexible, descriptive evidence which accommodate a priori archaeological knowledge (Cowgill, 2015). They also allow for the construction of agent-based models in which human choice and behavior can be assessed based on the extenuating environmental or social variables (Whitley, 2005). However, the use of spatial autocorrelations with z-scores like Getis-Ord Gi* provide a clear and concise maps for visualizing probabilistic data distributions.

There will always be some degree of uncertainty associated with archaeological datasets, but Bayesian probabilistic methods represent an efficacious way of aggregating large sets of data into a spatial statistical environment. Such
datasets should be subject to continuous reanalyses. As such, our interpretation from Gyeonggi-do, South Korea based on archaeological data is subject to further refinement and revision. For example, ongoing cultural resource management projects will augment the database of radiocarbon ages, which will further serve to augment statistical uncertainty within SPDs and the associated spatial model. In doing so, we ultimately gain deeper insight into the past and the relationship between historical and archaeological sets of information (see also Choi, et al., 2017).

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Supplementary Material

Supplementary material is publically archived at the following link: https://figshare.com/articles/_/10069094

References


Kim, B., 1998 [1145]. Samguksagi (in Korean), National Institute of Korean History, Gwacheon

https://doi.org/10.1017/RDC.2015.10.


https://doi.org/10.25024/kj.2010.50.2.158.


https://doi.org/10.1163/156852302322454639.


https://doi.org/10.1016/j.quascirev.2009.06.010.

http://dx.doi.org/10.1016/j.quascirev.2014.07.003.


https://doi.org/10.1017/RDC.2017.122.


