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Geostatistical analysis of historical contingency and land use footprints in the prehistoric settlement dynamics of the South Carolina Piedmont, North America

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ABSTRACT

We present a high-resolution geostatistical analysis of prehistoric archaeological site locations and land use footprints for the South Carolina Piedmont of North America using archaeological survey data, multivariate logistic regression techniques, and fuzzy set theory. Our analysis uses archaeological site locations and generalizations about prehistoric economic systems to quantitatively model land use footprints and to test hypotheses derived from the archaeology of human-environment interactions. Specifically, we test the differential influence of landscape suitability and historical contingency as factors differentially influencing site location in immediate and delayed return economies. Our results highlight temporal variability in the influence of material factors (landforms and the residuum of previous occupations) on the selection of settlement and land use locations over the long term. We argue that our results indicate high potential for land use legacies beginning with the introduction of ceramic technologies. These landscape legacies were likely positive for human populations in that they improved the quality of ecosystems services and the reliability of provisioning.

1. Introduction

Statistical models of archaeological site locations can provide significant insights about settlement and land use processes, i.e. behavioral and systemic contexts in which archaeological material was deposited (Kellett and Jones, 2016; Kvamme, 2006; Schiffer, 1972), but they are also critical to the formulation of long-term perspectives on the co-evolution of landscape and society (Butzer, 1996). Archaeological perspectives are gaining increasing attention in the environmental sciences, because archaeological investigations offer a means to empirically test hypotheses concerning sustainability of long-term human-environment interactions (Redman, 2005; Dearing et al., 2010; Contreras, 2016). In this paper, we extend this work and present a high-resolution geostatistical analysis of long-term prehistoric settlement and land use dynamics in the South Carolina Piedmont of North America using archaeological survey and site location data, multivariate logistic regression techniques, and fuzzy set theory.

Our work specifically addresses two significant factors, one spatial and one temporal, involving settlement and land use processes that remain largely unexplored in the literature. Firstly, ecologically significant behaviors associated with subsistence occur mostly offsite, in the territorial vicinity surrounding archaeological sites (Zedeño, 1997). The specific geospatial footprint of offsite prehistoric land use has received remarkably little attention in archaeology (Erickson, 2006; Orengo et al., 2018; van Andel et al., 1990). Secondly, the behaviors guiding settlement and land use locations are differentially distributed across space, and through time (Rossignol, 1992). Indeed, few archaeologists would dispute the notion that past events influence settlement and land use for any given time and place, yet this factor is conspicuously absent in statistical models of site locations.

In terms of the spatial factor, the potential constraints that landscape places on land use and provisioning are key parameters in debates surrounding the coevolution of society and landscape. The evolving spatial footprint of land use is of particular interest to research on the causes of economic intensification and the transition from immediate to delayed return economies (Weitzel and Codding, 2016; Smith, 2015; Zeder, 2012). Nevertheless, many studies of settlement-land use dynamics provide only qualitative descriptions of land use strategies hypothesized to have occurred within vaguely or arbitrarily defined catchment areas. For the temporal factor, long-term, repetitive subsistence activities have the potential to leave cultural and ecological legacies that can influence future use (Smith and McNees, 1999;

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Redman, 2005; Dearing et al., 2010). The relative influence of such legacies in the settlement process is a measure of the degree to which past activities either constrain or facilitate future use. Indeed, spatial characteristics of sites with antecedent occupations may be more optimally aligned with the settlement-land use dynamics of the preceding period. Thus, where landscapes exhibit legacies and contingencies of antecedent settlement and land use, "memory" is a potentially important component of the settlement and land use system (Dearing et al., 2010).

The analysis presented here uses archaeological site locations and generalizations about prehistoric economic systems to statistically test the hypotheses relating to (1) relationships between the intensity of economic activities and the size of their land use footprint (the spatial factor) and, (2) the importance of historical contingency (the temporal factor) to settlement dynamics in the transition from immediate to delayed return economies. We use the term "land use footprint" to refer to a spatially explicit model of the potential for material effects of offsite subsistence behaviors on the physical landscape (e.g. Kay and Kaplan, 2015). Land use footprint models have the potential to significantly improve empirically informed explanations of settlement processes and the co-evolution of society and landscape because they explicitly quantify the amount of the landscape potentially utilized by people during specific settlement and land use periods. We operationalize this spatial factor by statistically modeling the influence and relative abundance of key landscape characteristics within different catchment sizes for each site location.

We use the term "historical contingency" to refer to the conditional influence of antecedent occupation events (Gould, 1999) on settlement and land use outcomes at any given moment in time. We argue that land use footprints represent the spatial expression of at least one form of historical contingency influencing settlement dynamics. Thus, with an archaeological site representing the minimum land use footprint, we operationalize the potential for historical contingency as the presence of antecedent occupation. In order to account for chronological uncertainty inherent in the data, but retain key inferences about land use and its co-evolution with settlement we redefine the archaeological site typology for the South Carolina Piedmont using fuzzy sets (Jarosław and Hildebrandt-Radke, 2009). We account for the presence and absence of antecedent occupations as part of a multivariate logical regression analysis.

2. Methods and materials

2.1. Research location and context

Our analysis models the type, intensity, and spatially explicit distribution of prehistoric Native American land use (~10,000 BP – 400 BP) in a 1256 Km^2 landscape. This research was conducted within the context of a US National Science Foundation funded Critical Zone Observatory project (CZO), an interdisciplinary network examining environmental processes that effect the Earth's surface and that support terrestrial life (i.e. the Earth's Critical Zone). Our project, located on the Sumter National Forest, South Carolina, is part of the Calhoun CZO (Fig. 1.). Processes at the Calhoun CZO have been heavily shaped by long-term human-critical zone interactions, notably by land degradation attributed to 19th and early 20th century cotton farming (Coughlan et al., 2017; Richter and Markewitz, 2001). Situated between the Coastal Plain and the Appalachian Mountains, Sumter National Forest is located on the Southern Piedmont, a landscape made of low ridges, shallow valleys, and narrow, incised tributaries. The Southern Piedmont is characterized by a humid temperate climate with approximately 1250 mm of precipitation annually and average temperatures ranging from −5 °C in winter to 40 °C in summer. Although now predominantly a mixed hardwood-pine secondary forest, historically the Piedmont vegetation was a hardwood-dominated forest with an Oak-Hickory (*Quercus spp.*, *Carya spp.*) community in upland locations and Sweetgum (*Liquidambar styraciflua*) and mesic oak forests in valley bottomlands.

2.2. Overview of piedmont archaeology and prehistoric land use

Archaeological finds consisting mostly of isolated stone tool artifacts suggest that the human settlement history of the South Carolina Piedmont began sometime after the transition from Pleistocene to Holocene vegetation ca. 12,800 BP (Goodyear et al., 1990). These "Paleoindian" period sites are rare in the Sumter National Forest area and all are associated with the Late Paleoindian, Hardaway Dalton tradition dated elsewhere to approximately 10,500 to 9500 BP (Benson et al., 2006). However, given the paucity of evidence, investigations of the earliest occupations of the Piedmont remain few. By ca. 9500 BP, the postglacial climate continued to warm and biota were shifting toward a mixed oak and pine dominant forest similar to current conditions (Delcourt and Delcourt, 1987). This shift, along with megafaunal extinctions, is associated with a new technological assemblage and subsistence strategy labeled "Early Archaic". Early Archaic lifeways were characterized by a generalized and relatively mobile foraging economy. Evidence for use of the Sumter NF resources by Early Archaic peoples is much more numerous than that of the previous period. Humans were likely beginning to effect animal populations and vegetation in specific locations and may have left long-term legacies in soils where large and persistent camps were located. However, land uses during both the Paleoindian and Early Archaic were low intensity, immediate-return economic systems with social organization adapted to providing for short-term needs (Woodburn, 1982).

The arrival of the Middle Archaic tool assemblages and feature types as early as 8000 BP points to intensifying resource use, increasingly complex social organization, and diversifying cultural traditions (Anderson et al., 2007). Typical Middle Archaic artifacts include increased frequency of locally sourced quartz projectile points and cutting and scrapping tools, grindstones, and fire cracked rock (Benson et al., 2006). Storage pits also appear hinting at efforts to offset temporal variability in the availability of key resources. In some areas, mounds and mound complexes point to increasing social complexity (Anderson et al., 2007). However, in the South Carolina Piedmont, the Middle Archaic economic system could still be described as an immediate-return system.

The widespread adoption of ceramic technologies in the Late Archaic period marks a significant shift toward a delayed-return economic system. Delayed-return economies are characterized by investments that anticipate future yields (e.g. planting crops or raising livestock), accumulation and curation of labor intensive technical facilities, more permanent and fixed residency, processed and stored foods and materials, and institutions governing property and inheritance (Woodburn, 1982). The Late Archaic move into productive bottomlands is hypothesized to have initiated a cycle of reinforcing feedbacks between land use, landscape, and socioeconomic organization that contributed to a delayed-return socioeconomic pathway (Smith and Yarnell, 2009). These processes led to increased sedentism, the domestication of specific cultivars, and intensive agricultural land use during the late Woodland and Mississippian periods.

2.3. Research approach

Our proxy for settlement and land use is the archaeological site and its artifactual assemblage. Due to its designation as a National Forest, much of the study area has been systematically surveyed and shovel tested for archaeological remains in order to comply with cultural resource management laws such as the National Historic Preservation Act of 1966. We obtained the archaeological survey boundaries, archaeological site locations, and descriptive reports for the entire Enoree District of the Sumter National Forest from South Carolina Archsite (http://www.scarchsite.org/).

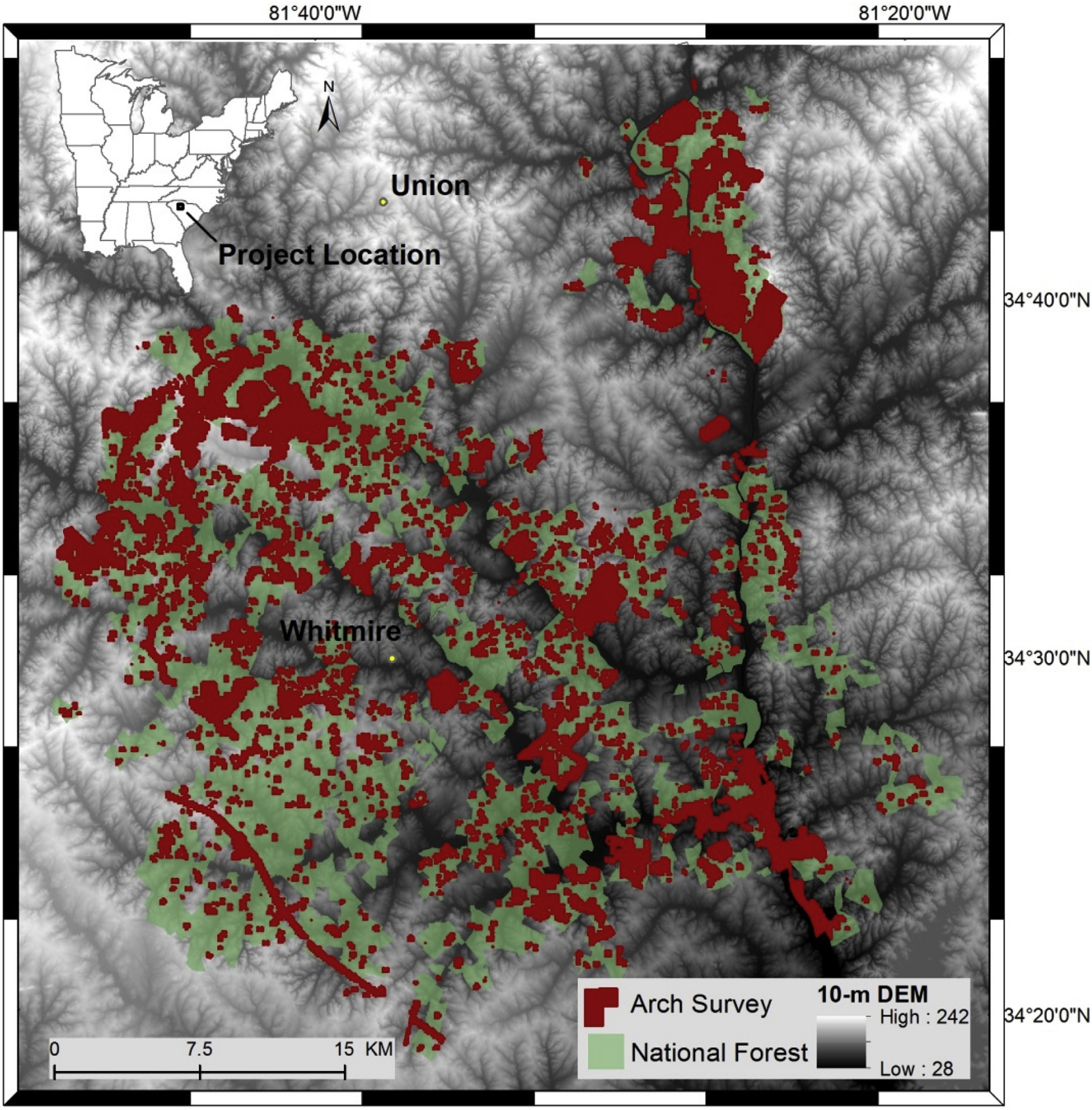

Fig. 1. Location of project area showing Sumter National Forest (Enoree District) boundary and extent of archaeological survey coverage.

To represent the biophysical landscape, we constructed hydro-geomorphic factor layers (topographic position, topographic wetness, slope, aspect, and exposure) from a 10 m resolution digital elevation model (DEM). We merged the survey and site data together into 100 m^2 sampling grid, with sites represented as their own shape and non-site areas as 100 m^2 units (Fig. 1). Non-surveyed areas within the national forest and surrounding areas were entirely excluded from the analysis. For each 100 m^2 unit, we extracted values corresponding to the hydro-geomorphic factor layers.

Geostatistical analysis took the form of an iterative process alternately using a Firth Logistic Regression model (Firth regression model), fuzzy set theory, and fuzzy GIS overlay techniques (Fig. 2). We used Firth regression models to determine the statistical relationships between archaeological sites, antecedent occupations (historical contingency), land use suitability, and the overall quality and size of the resource catchment. For additional details on the analytical steps used to create the data set used in the Firth regression analyses presented here please see supplemental material (Appendix A in Supporting Information).

2.4. Archaeological sites and fuzzy set theory

Information gathered by surface survey and limited subsurface testing may indeed offer insight into past human behavior, but the resulting archaeological site typologies present a perennial problem for modeling settlement and land use because of the uncertainty in specific

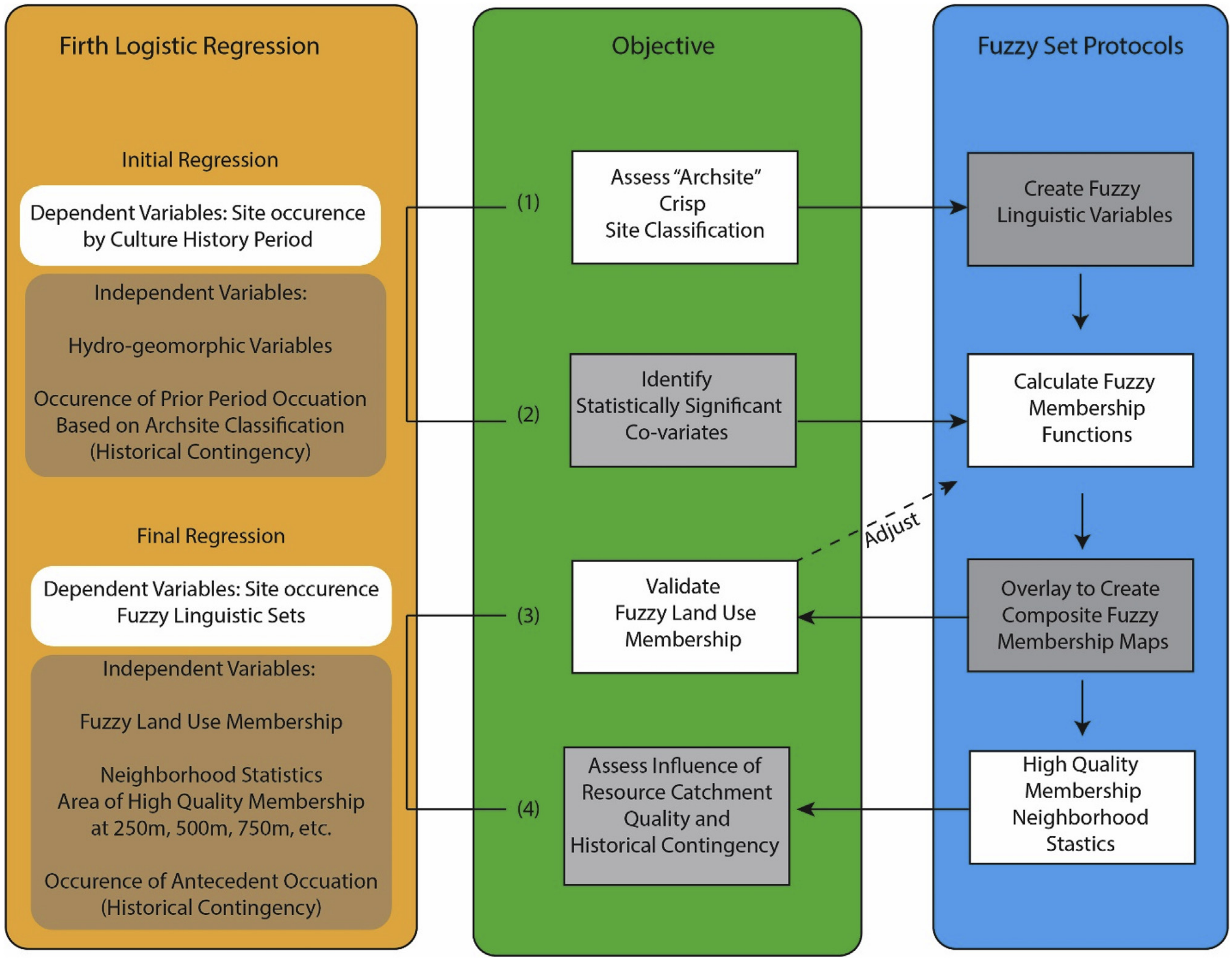

Fig. 2. Analysis process showing relationships between data, objectives, and fuzzy set protocols.

function, form, and chronology (Kohler and Parker, 1986; Kvamme, 2006). Indeed, even for well documented excavation contexts, typologies are informed by artifact and site data where membership to a specific class is uncertain, multivalent, or partial (Hatzinikolaou, 2006; Hatzinikolaou et al., 2003; Jarosław and Hildebrandt-Radke, 2009; Roberts, 1986). In short, archaeological data does not tend to fall seamlessly into a binary categorization of true versus false. In the terminology of fuzzy set theory, archaeology does not make very good "crisp" sets.

As a consequence, we argue that archaeological sites recorded in cultural resources inventories are best represented as fuzzy sets (Hatzinikolaou, 2006; Hatzinikolaou et al., 2003; Jarosław and Hildebrandt-Radke, 2009; Lock, 2000). In fuzzy set theory (Zadeh, 1973, 1996) complex, poorly bounded data are represented with algorithms and linguistic variables that classify relationships between data points by means of conditional statements that correspond with degrees of membership in a set (i.e. a fuzzy set) with uncertain or overlapping boundaries. In this analysis we are interested in distilling land use type and intensity from two sources of information, archaeological site descriptions (artifacts, features, etc.) and site locations. Aside from two large Mississippian period sites with earthen mounds, sites with visible surface features were rare in the project area. Many sites did have temporally diagnostic lithic material and many fewer contained ceramic types indicative of specific cultural periods. We took the presence of ceramics or lithic diagnostic of the "ceramic period" as indicative of the "delayed-return" end of the economic land use spectrum and lithics that were diagnostic of the "pre-ceramic" period as more indicative of the "immediate-return" end. For this initial stage, we deliberately excluded prehistoric archaeological sites with no diagnostic materials (e.g. lithic scatters). As a consequence, our initial target linguistic variables (fuzzy sets) were (1a) "immediate return settlement and land use" and, (1b) "delayed return settlement and land use" (Table 1, Fig. 3).

2.5. Firth regression model and hypotheses

Geostatistical modeling in archaeology commonly makes use of logistic regression analysis (Carrer, 2013; Hatzinikolaou, 2006; Warren and Asch, 2003). In a logistic regression analysis, occurrence and

Table 1
Relationship of Culture History Period classifications to initial fuzzy sets and their inferred land use type.

Culture History Period	Simplified Site Typology	Initial Fuzzy Set
Unknown Lithic	Excluded	Excluded
Paleoindian	(1a) Pre-Ceramic	Immediate Return
Early Archaic		
Middle Archaic		
Late Archaic (Lithic only)		
Late Archaic (incl. ceramic)	(1b) Ceramic Period	Delayed Return
Early Woodland		
Middle Woodland		
Late Woodland		
Mississippian		

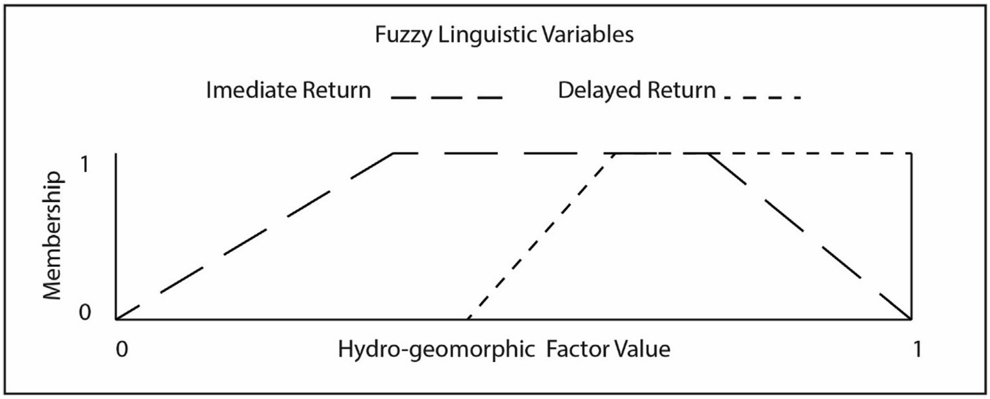

Fig. 3. Hypothetical membership functions of hydro-geomorphic factor values for preliminary fuzzy sets: Immediate and Delayed Return Settlement and Land Use.

absence of archaeological sites across a given landscape are represented as binary data where a one represents occurrence and a zero represents absence. Logically, then, in order to understand where sites are likely to occur, it is necessary to understand where they do not occur (Kohler and Parker, 1986; Kvamme, 2006). In the spatial context of an archaeological survey, archaeological site occurrences are often rare. For example, archaeological data from the Sumter National Forest in South Carolina show a site occurrence to total area surveyed ratio of approximately 0.13 sites per ha (2828 sites/22,185 ha). In terms of spatial area, the site occurrence rate equates to 921 ha of positive archaeological site occurrences and 19,357 ha where no site was located (e.g. site absence). The Firth regression model, also known as a Penalized Maximum Likelihood Estimation method, is a logistic regression model designed for the analysis of "rare events" (or rare occurrences in spatial terms) (Firth, 1993). In technical terms, rare occurrences have many times fewer occurrences than absences and when represented as a binary dependent variable, the zeros (absences) outnumber the ones (occurrences) by one or more orders of magnitude (King and Zeng, 2001). Conventional logistic regression techniques underestimate the probability of rare occurrences and this underestimation results in negative bias on the intercept (King and Zeng, 2001). The Firth regression model reduces the bias introduced by rare occurrences and therefore allows retention of the full data set (Firth, 1993).

To assess the suitability and quality of the resource catchment, we used the probability distributions of significant hydro-geomorphic variables (derived from a 10 m resolution digital elevation model) at known archaeological site locations to define fuzzy membership functions for a set of hydro-geomorphic factor maps (Jarosław and Hildebrandt-Radke, 2009) (See Appendix A1, Fuzzy Membership Methods, in Supporting Information). Factor maps were then combined using ArcGIS Fuzzy Overlay into two composite topographic indices representing immediate-return (IR) and delayed-return (DR) land use suitability (See Appendix A1.6, Fuzzy Overlay Methods, in Supporting Information). We then created a binary variable to represent "high quality delayed-return" (HQDR) from the highest quantile IR and DR suitability values (e.g. 0.96 to 1) marking presence, and the remaining values (e.g. < 0.96) indicating absence of HQDR. We further limited the high quality delayed return map to bottomland floodplains of the highest order streams and rivers where relatively frequent flood regimes exist (e.g. riverine terraces). High quality immediate-return (HQIR) land was not limited to bottomlands. In order to test for offsite land use footprints, we used neighborhood statistics to sum the area of HQDR and HQIR land within 250 m, 500 m, 750 m, 1 km, and 2 km concentric catchments of each sample unit.

We tested Firth models with 7 different fuzzy dependent variables (labeled 2a-2f), making use of the entire range of our prior knowledge pertaining to inferred land use gradients (Fig. 4). The first fuzzy set is comprised of sites with lithics only (set 2a). The second set is the original IR Fuzzy set comprised of pre-ceramic period lithics (2b). We split the Delayed Return fuzzy set (1b) into three non-mutually exclusive categories: (2c) All ceramic period sites, (2d) Lithic only ceramic period sites (e.g. no ceramics present), and (2e) ceramic period sites with ceramics. Because we had 25 sites with positively identified Mississippian component, we further split set 2e: (2f) sites with no positively identified Mississippian ceramics, and (2 g) sites with positively identified Mississippian ceramics. These fuzzy sets represented three more hypothesized land use types: (2d) Lowest intensity delayed return economy hunting/collecting camps, (2e) moderate intensity delayed return sites and (2 g) highest intensity delayed return sites (i.e. agricultural settlements).

We hypothesized (**H1**) that fuzzy set (2d), lithic-only, would have stronger association with the IR land use suitability map while (**H2**) fuzzy set (2 g), Mississippian ceramic sites, would have the strongest associations with the DR land use suitability map. We also reasoned (**H3**) that the suitability of the site location itself would be more important to less intensive land uses and conversely that more intensive land uses would have stronger associations with larger amounts of highly suitable land in the catchment surrounding the site. In theory, lower mobility associated with higher land use intensity would increase the need for a larger, higher quality resource catchment surrounding a settlement. Therefore, the importance of offsite land use suitability to settlement location would be reflected with statistically significant influence of high quality land at successive distances (e.g. 250 m, 500 m, 750 m, etc.) until the transport and defense costs associated with distance to the site became too high. Lastly, we hypothesized (**H4**) that the influence of historical contingency (presence of antecedent occupation) would increase with land use intensity since people making delayed return investments in their environment would have greater incentive to stay and defend those investments. Because the fuzzy set "preceramic lithic sites" combines Paleoindian, Early Archaic, and Middle Archaic, we could not test this set for historical contingency. For sets 2c through 2f, we used the presence of 2b (confirmed pre-ceramic period sites) to test for the effects of historical contingency. For set 2 g, (Mississippian ceramics sites), we used the presence or absence of any positively identified pre-Mississippian ceramic period component as indicated in the original crisp sets Late Archaic, Early-, Middle-, and Late Woodland. Processed data used in the final Firth logistic regression is included in the supplemental material (See Appendix A2, Table A2.1, in Supporting Information).

3. Results

3.1. Fuzzy overlay and validation of fuzzy membership

The Fuzzy IR and the Fuzzy DR maps showed considerable spatial overlap (Fig. 5.). However, each fuzzy set in the final Firth regression showed a differential influence of Fuzzy IR and Fuzzy DR maps. For example, sites with lithic material only ("All Lithics", Set 2a) displayed

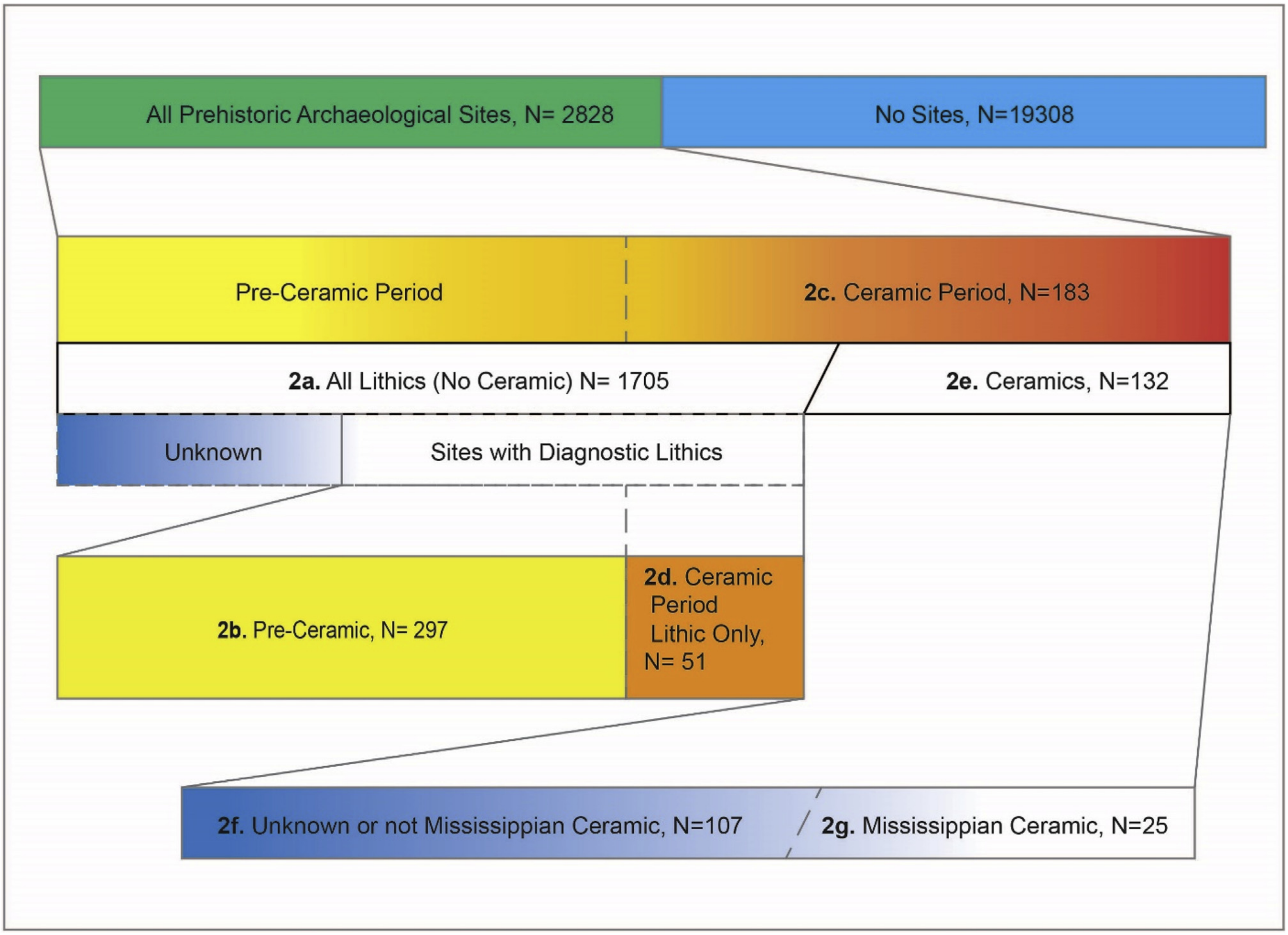

Fig. 4. Final Fuzzy dependent variables (2a-2g), showing relationships and polyvalence.

strong significant positive effects of Fuzzy IR membership value and significant negative effects of Fuzzy DR membership value (coefficients of 13.04, $P < 0.001$ and -14.37, $P < 0.001$ respectively), confirming our **H1** hypothesis. Sites positively identified as pre-ceramic lithic sites (2b) showed considerable dispersal across the landscape, yet when tested against Fuzzy IR and Fuzzy DR overlay, pre-ceramic sites show the significant positive effect of Fuzzy IR membership (coefficient of 8.26, p value < 0.001). This contrast with the significant, negative effect of the Fuzzy DR overlay map (coefficient of -3.85, p value < 0.001).

Overall, ceramic period sites (2c) had a Fuzzy DR membership of > 0.7. Fuzzy DR showed significant positive effect (5.01, $P < 0.001$) on ceramic period site location. Again, historical contingency played a role, but the effect was slightly diminished in comparison to lithic only sites (2.51, $P < 0.001$). Ceramic period sites with lithic material only (2d) showed positive and significant influence of Fuzzy IR membership (4.89, $P = 0.041$) while Fuzzy DR membership was not significant. The influence of historical contingency is also a considerable factor showing a significant positive effect (3.013, $P < 0.001$) and indicating a preference for the reoccupation of pre-ceramic period sites.

While non-Mississippian ceramic sites were strongly correlated with the Fuzzy DR Overlay, Mississippian ceramic sites (2 g) were not significantly correlated with Fuzzy DR membership values. This result was contrary to our hypothesis **H2**.

3.2. Neighborhood statistics and quality of resource catchment

The amount of HQIR land surrounding the site was not a significant positive predictor for any of the site types, supporting our hypothesis **H3** that the quality of the site location itself would be more important than the quality of the surrounding catchment for immediate return land use. In fact, HQIR at the 250 m interval was a significant negative predictor (coefficient of -0.255, $p < 0.001$). Thus, the immediate return land use footprint constitutes only the footprint of the site themselves, or about 3% of systematically surveyed area (~550 ha). If this figure is extrapolated to the entire project area, it translates to approximately 3800 ha of immediate return land use footprint.

On the other hand, HQDR at the 250 m interval was significant for all sites with ceramics (Table 2) supporting hypothesis H3 for delayed return land use. Mississippian ceramic sites displayed the strongest relationship (0.229 coefficient, $P < 0.001$) with the area amount of HQDR within 250 m of the archaeological site. However, historical contingency in the form of antecedent ceramic sites not identified as Mississippian (e.g. Late Archaic or Woodland era) had the strongest significant effect for Mississippian ceramic sites with a coefficient of 4.289, $P < 0.001$, supporting hypothesis H4 that historical contingency increases in importance with land use intensity. A total of 18,680 ha of the project area is HQDR and approximately 1997 ha (just over 10%) of that amount was within 500 m of a ceramic period site. However, less than 9% of the area defined as HQDR (1662 of 18,680 ha) had been systematically surveyed for archaeological sites. All ceramic sites had > 1.6 ha of HQDR within a 250 m catchment. Within a 500 m catchment of ceramic period sites, HQDR made up at least 25% (19.26/78.51ha) of the landscape. This was true even for ceramic period sites that had low amount of HQDR within the 250 m catchment (See Appendix B1, Table B1, in Supporting Information). HQDR comprised at least 40% of the 250 m and the 500 m catchments of ceramic period sites that had long-term occupations (e.g.

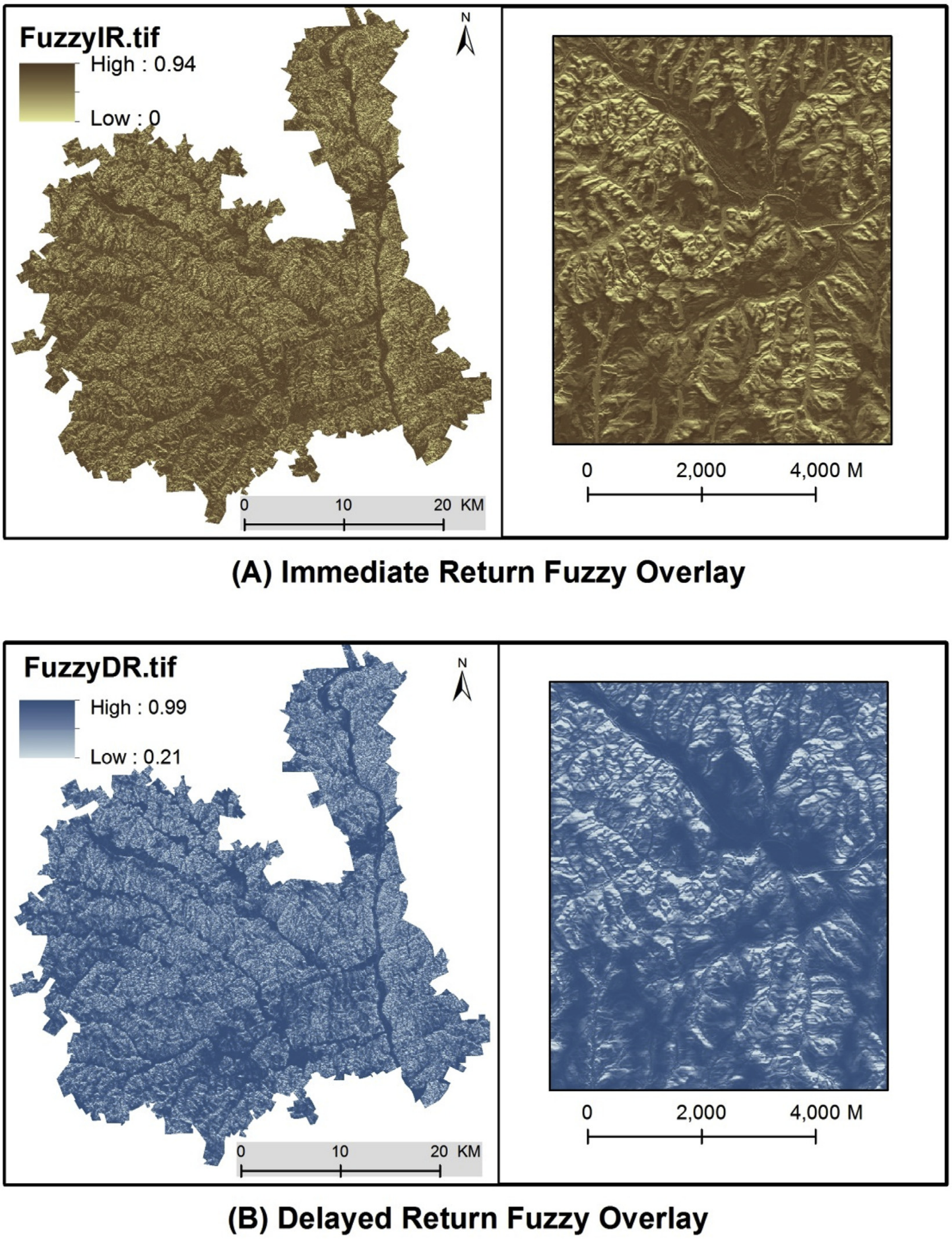

Fig. 5. Immediate Return (A) and Delayed Return (B) fuzzy overlays for the project area (left hand maps) with detailed close-up (right hand maps).

Table 2
Odds ratios for the final Firth logistic regressions, significant variables shown (**P < 0.001, *P < 0.05). Note that for odds ratios, values less than 1 indicate a negative influence.

Dependent Variable (Crisp Site Type)	Independent Variable – (odds ratio)				
	Fuzzy IR	Fuzzy DR	HQDR 250 m	HQIR 250 m	Historical Contingency
2a. All Lithic	458,630.43**	0.000**			
2b. Pre-Ceramic	3869.96**	0.02**		0.77**	
2c. All Ceramic Period		149.9**	1.13**		12.30**
2d. Ceramic Period, Lithic Only	132.69*				20.35**
2e. Ceramic Period Ceramic Only		44.61*	1.16**		7.87**
2f. Ceramic Period Non-Mississippian Ceramics		54.33*	1.14**		8.47**
2g. Ceramic Period Mississippian Ceramics			1.26**		72.89**

Mississippian sites with confirmed Woodland components). For the three major Mississippian sites in the project area (including 2 mound sites and a "village" (Green and Bates, 2003)), HQDR constituted greater than 97% of the landscape within a 250 m catchment and > 90% of the landscape within the 500 m catchment. These sites had the highest concentration of adjacent HQDR land for all prehistoric sites. Two village-sized Mississippian ceramics sites had lower amounts (< 90%) of HQDR within 250 m of the site. These may have been suboptimal for settlement growth. Of the area surveyed, there are 38 landscape patches with > 95% (18.6) ha of contiguous HQDR within a 250 m catchment. 16 of these patches (around 40%) are within 100 m of a ceramic period site. There are 13 partially surveyed patches with > 85% (66.7 ha) of contiguous HQDR within a 500 m catchment, 6 of which have ceramic period sites and 5 of which have "village-sized" (ca. 4 ha or greater) ceramic period sites.

4. Discussion

4.1. Land use suitability and footprints

Although our analysis failed to reveal a footprint for offsite land use for the pre-ceramic period, we were able to delimit site location suitability for immediate return economies (**H1**). This reinforces the notion that immediate return economies exhibit low intensity land use whose legacies are limited to the material residuum of predominantly ephemeral habitation and resource processing activities. Further, we were able to show that ceramic period sites that lack ceramics are more correlated with the immediate-return than the delayed-return land use activity. Thus, our fuzzy overlay using hydro-geomorphic landscape characteristics helped to discriminate between functionally differentiated site types even within the same cultural time period (Kohler and Parker, 1986). For immediate return land uses, archaeological sites are arguably the most intensively used places on the landscape. The site is the location where tools are manufactured, repaired, and cached. It is also the location where resources were processed, cooked, consumed, and where waste items were deposited. As a consequence, we suggest that for the pre-ceramic, immediate return economic period, the archaeological site itself works well as a proxy for a land use footprint.

As representatives of the most intensive prehistoric land uses, we hypothesized (**H2**) that Mississippian ceramic sites would have the strongest association with the delayed return fuzzy overlay (Fuzzy DR). However, this was not the case. Instead, Mississippian ceramic sites showed the strongest associations with historical contingency (**H4**) and secondarily with the amount of high quality delayed return land (HQDR) within the 250 m resource catchment (**H3**). The strength of the historical contingency factor may partly be an artifact of chronological uncertainty. However, the relationship of Mississippian ceramic sites to the amount of high quality delayed return land strongly suggests a commitment to a relatively intensive agricultural land use with considerably sized land use footprints. It seems likely that for pragmatic reasons, Woodland period sites that were well positioned with respect to proximity to HQDR bottomland were the sites that developed into Mississippian villages. Such sites would have been "pre-adapted" to accommodate intensifying agricultural endeavors simply by virtue of their biophysical template. However, nearby locations with large amounts of HQDR did exist, but were not occupied.

4.2. Historical contingency

Smith and McNees (1999) define four historically contingent factors that positively influence reuse and reoccupation of a particular location: (1) construction of facilities for shelter and storage, (2) accumulation of tools and raw materials, (3) disturbance investments that improve productivity or reliability of resource yield, and (4) accumulated knowledge (social memory). Of these factors, only the accumulation of tools and raw material has the potential to bridge a gap in archaeological periods. As Wandsnider and Camilli (1992) point out, facilities decay over time and thus have life spans. Their reuse is partly a factor of the cost of repair versus new construction. For example, Middle Woodland era people may have enjoyed the convenience of raw material (lithic) availability at a Middle Archaic camp abandoned from the Late Archaic through the Early Woodland period. However, given the time scale involved, (> 2500 years), it seems unlikely that resource enhancement activities by Middle Archaic foragers continued to provide subsistence benefits far into the future. Similarly, even if successive groups using the site shared common ancestry or cultural heritage, it seems unlikely that a social memory of that locale could remain after such a long period of disuse.

Historical contingency became an important factor during the Mississippian period, specifically for locations near large plots of HQDR land. Although Mississippian peoples clearly located sites adjacent to large swaths of HQDR floodplain lands, historical contingency was a stronger predictor for Mississippian settlement location than amounts of HQDR land within surrounding catchment areas. It seems that in South Carolina, Woodland period farmers were initially choosing settlement locations based on the quality of the landscape in the immediate proximity to their habitations. Mississippian farmers showed a preference for Woodland sites with proximal access to the largest amounts of HQDR lands regardless of the Fuzzy DR membership values of the sites themselves. In doing so, some of the settlements passed up opportunities to maximize their access to HQDR land by remaining on the site of antecedent Woodland period occupation.

4.3. Implications for late prehistoric human-environment interactions

We estimate that the minimum delayed-return land use footprint, as indicated by the introduction of ceramic technology, falls somewhere between 111 ha (site area only) and 1200 ha of the area immediately adjacent to a recorded ceramic site. The minimum land use footprint for Mississippian period is estimated to be a range of 412 ha (which includes all HQDR within 250 m of a Mississippian site) and 1200 ha (all HQDR within 500 m of a Mississippian site). Optimal locations for Mississippian village-type settlements were areas with > 97% of HQDR land within 250 m and > 90% of HQDR land within 500 m. Within the project area there were 66 potential village locations meeting these criteria. Only nine of these 66 are known to have been occupied.

Despite the fact that Mississippian peoples had the most intensive prehistoric economies, they do not appear to have been constrained by the availability of high quality agricultural lands in our project area. Consequently, it seems highly unlikely that prehistoric land use caused any significant landscape degradation in the project area or on the South Carolina Piedmont, more generally. If land use footprints did result in landscape legacies, they were likely conducive to long-term agricultural land use and therefore constitute an example of a sustainable socioecological system. Combined with the importance of historical contingency in Mississippian settlement, it seems likely that land use introduced positive ecological feedbacks that enhanced rather than degraded the agricultural potential of the landscape. Indeed, our analysis supports the hypothesis advanced by Smith and Yarnell (2009) that a cycle of positive feedback between land use, landscape, and socioeconomic organization produced a delayed-return socioeconomic trajectory.

5. Conclusions

In spite of the large amount of data amassed by archaeological survey, the discipline's preoccupations with material culture and its immediate depositional loci has led to a science dominated by inferences drawn from site-level investigations and relative dating. While this approach has been productive for understanding much about past societies, it often fails to produce substantive insights into landscape-level understandings of long term settlement and land use processes.

Conversely, ecologists and other biophysical scientists interested in how humans have influenced landscapes through long term occupation and use rarely address the social dynamics, settlement patterns, or decision processes fundamental to providing causal explanations for human-environment interactions (Contreras, 2016; Redman, 2005). Land use constitutes a main point of contact between social and biophysical systems, a fulcrum, upon which human behavior and social organization is significantly leveraged by and places the most weight upon the non-human environment.

Site persistence and demographic growth during the Mississippian period appears to have occurred on Late Woodland sites that were strategically located in close proximity to more optimal farmland. However, historical contingency, e.g. occupation of the site during the Woodland period, was a more important predictor than the amount of high quality flood-plain farmland surrounding the site. Our analysis thus supports the notion that reinforcing socioecological feedbacks have influenced the evolution of human-critical zone interactions in ways that enhanced the productivity of Mississippian land use. We argue that our results, which demonstrate the importance of historical contingency in settlement processes, indicates high potential for ecological legacies associated with the evolution of delayed return economies. These landscape legacies likely improved the quality of ecosystems services and the reliability of provisioning. Indeed, they appear to have encouraged the continuous settlement of sites even under the most intensive land use.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jas.2019.04.003.

References

Anderson, D.G., Russo, M., Sassaman, K.E., 2007. Mid-Holocene Cultural Dynamics in Southeastern North America. Climate Change and Cultural Dynamics: A Global Perspective on Mid-holocene Transitions. pp. 457–489.

Benson, R.W., Pluckhahn, T.J., Gresham, T.H., Atkinson, D.S., Payne, K., 2006. Cultural Resources Overview of the Sumter National Forest. Report by Southeastern Archaeological Services, Athens, GA, Submitted to Francis Marion and Sumter National Forests. USDA Forest Service, Columbia, SC.

Butzer, K.W., 1996. Ecology in the long view: settlement histories, agrosystemic strategies, and ecological performance. J. Field Archaeol. 23, 141–150.

Carrer, F., 2013. An ethnoarchaeological inductive model for predicting archaeological site location: a case-study of pastoral settlement patterns in the Val di Fiemme and Val di Sole (Trentino, Italian Alps). J. Anthropol. Archaeol. 32, 54–62.

Contreras, D.A., 2016. Correlation is not enough–building better arguments in the archaeology of human-environment interactions. In: Contreras, D.A. (Ed.), The Archaeology of Human-Environment Interactions: Strategies for Investigating Anthropogenic Landscapes, Dynamic Environments, and Climate Change in the Human Past. Taylor & Francis, New York, New York, USA.

Coughlan, M., Nelson, D., Lonneman, M., Block, A., 2017. Historical land use dynamics in the highly degraded landscape of the Calhoun critical zone observatory. Land 6, 32.

Dearing, J.A., Braimoh, A.K., Reenberg, A., Turner, B.L., van der Leeuw, S., 2010. Complex land systems: the need for long time perspectives to assess their future. Ecol. Soc. 15, 21.

Delcourt, P.A., Delcourt, H.R., 1987. Long-term Forest Dynamics of the Temperate Zone : a Case Study of Late-Quaternary Forests in Eastern North America. Springer-Verlag, New York.

Erickson, C.L., 2006. Intensification, political economy, and the farming community. Defense of a Bottom-Up Perspective of the Past.

Firth, D., 1993. Bias reduction of maximum likelihood estimates. Biometrika 80, 27–38.

Goodyear, A.C., Michie, J.L., Charles, T., 1990. The Earliest South Carolinians: the Paleoindian Occupation of South Carolina. Archaeological Society of South Carolina.

Green, W., Bates, J., 2003. The Broad River Chiefdom: A Possible Unrecognized Chiefdom in the Central South Carolina Piedmont Southeastern Archaeological Conference. Charlotte, North Carolina.

Gould, S.J., 1999. Introduction: the Scales of Contingency and Punctuation in History, Structure and Contingency: Evolutionary Processes in Life and Human Society, vols. ix-xxii. Leicester University Press, London, pp. ix–xxii.

Hatzinikolaou, E., 2006. Quantitative Methods in Archaeological Prediction: from Binary to Fuzzy Logic. In: GIS and Archaeological Site Location Modeling. CRC Press, Boca Raton, pp. 437–446.

Hatzinikolaou, E., Hatzichristos, T., Siolas, A., Mantzourani, E., 2003. Predicting archaeological site locations using GIS and fuzzy logic. Digit. Herit. Archaeol. 169–177.

Jarosław, J., Hildebrandt-Radke, I., 2009. Using multivariate statistics and fuzzy logic system to analyse settlement preferences in lowland areas of the temperate zone: an example from the Polish Lowlands. J. Archaeol. Sci. 36, 2096–2107.

Kay, A.U., Kaplan, J.O., 2015. Human subsistence and land use in sub-Saharan Africa, 1000BC to AD1500: a review, quantification, and classification. Anthropocene 9, 14–32.

Kellett, L.C., Jones, E.E., 2016. Settlement Ecology of the Ancient Americas. Taylor & Francis.

King, G., Zeng, L., 2001. Logistic regression in rare events data. Polit. Anal. 9, 137–163.

Kohler, T.A., Parker, S.C., 1986. Predictive models for archaeological resource location. Adv. Archaeol. Method Theor. 9, 397–452.

Kvamme, K.L., 2006. There and Back Again: Revisiting Archaeological Locational Modeling. GIS and archaeological site location modeling, pp. 3–38.

Lock, G.R., 2000. Beyond the Map: Archaeology and Spatial Technologies. IOS Press, Ravello, Italy.

Orengo, H.A., Knappett, C., Knappett, C., 2018. Toward a definition of minoan agro-pastoral landscapes: results of the survey at palaikastro (crete). Am. J. Archaeol. 122, 479–507.

Redman, C.L., 2005. Resilience theory in archaeology. Am. Anthropol. 107, 70–77.

Richter, D.D., Markewitz, D., 2001. In: Richter Jr.Daniel D., Markewitz, Daniel, Foreword, Reiners and Pedro Sánchez, William A. (Eds.), Understanding Soil Change. Understanding Soil Change. Cambridge University Press, Cambridge, UK, pp. 272 ISBN 0521771714. June 2001 1.

Roberts, D.W., 1986. Ordination on the basis of fuzzy set theory. Vegetatio 66, 123–131.

Rossignol, J., 1992. Concepts, methods, and theory building. In: Rossignol, J., Wandsnider, L. (Eds.), Space, Time, and Archaeological Landscapes. Plenum Press, New York, N.Y. USA, pp. 3–16.

Schiffer, M.B., 1972. Archaeological context and systemic context. Am. Antiq. 37, 156–165.

Smith, B.D., 2015. A comparison of niche construction theory and diet breadth models as explanatory frameworks for the initial domestication of plants and animals. J. Archaeol. Res. 23, 215–262.

Smith, B.D., Yarnell, R.A., 2009. Initial formation of an indigenous crop complex in eastern North America at 3800 BP. Proc. Natl. Acad. Sci. Unit. States Am. 106, 6561–6566.

Smith, C.S., McNees, L.M., 1999. Facilities and hunter-gatherer long-term land use patterns: an example from southwest Wyoming. Am. Antiq. 64, 117–136.

van Andel, T.H., Zangger, E., Demitrack, A., 1990. Land use and soil erosion in prehistoric and historical Greece. J. Field Archaeol. 17, 379–396.

Wandsnider, L., Camilli, E.L., 1992. The character of surface archaeological deposits and its influence on survey accuracy. J. Field Archaeol. 19, 169–188.

Warren, R.E., Asch, D.L., 2003. A Predictive Model of Archaeological Site Location in the Eastern Prairie Peninsula, Practical Applications of GIS for Archaeologists: a Predictive Modelling Toolkit. Taylor & Francis London, pp. 5–32.

Weitzel, E.M., Codding, B.F., 2016. Population growth as a driver of initial domestication in Eastern North America. R. Soc. Open Sci. 3, 160319.

Woodburn, J., 1982. Egalitarian Societies. Man 17, 431–451.

Zadeh, L.A., 1973. Outline of a new approach to the analysis of complex systems and decision processes. EEE Trans. Syst. Man Cybern. 1100, 38–45.

Zadeh, L.A., 1996. Fuzzy Sets, Fuzzy Sets, Fuzzy Logic, and Fuzzy Systems: Selected Papers by Lotfi A Zadeh. World Scientific, pp. 394–432.

Zedeño, M.N., 1997. Landscapes, land use, and the history of territory formation: an example from the puebloan southwest. J. Archaeol. Method Theory 4, 67–103.