

Go Your Own Least Cost Path

Spatial technology and archaeological
interpretation

Proceedings of the GIS session at EAA 2009, Riva del Garda

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Incorporating GIS Methodological Approaches in Heritage Management Projects

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Abstract

There has been a long-standing debate in academic archaeology on how to study the surface archaeological record. The debate has centered around whether to interpret the record as consisting of discrete sites and isolates or as continuous distributions of artifacts, features, and deposits. Historic preservation laws, however, focus on discrete sites as the properties that need to be discovered, recorded, and evaluated. As more research is done within a heritage management framework, the outcome has been to focus on the site as the unit of analysis almost to the exclusion of the study of spatial behaviors that transcend discrete sites. To achieve the objectives of heritage preservation and to examine spatial human behavior that is unconstrained by the site concept, new methodologies are needed. As a move in this direction we use GIS to create hypothetical archaeological landscapes based on assumptions of human behavior that can be tested and refined with survey and excavation data. In this process we collect detailed surface data that GIS algorithms use to define discrete sites and, at the same time, to analyze continuous distributions of cultural materials. We illustrate this approach with a several examples from North America and West Africa using different field methodologies.

Introduction

In heritage management, archaeologists are often asked to answer three basic questions: How many sites are in a project area? Where are these sites located? And, which sites are important enough to be investigated more thoroughly? Answering these questions requires us to use existing information on culture and the environment to design surveys, incorporate new data as they are obtained from the field to assess survey adequacy, and to infer cultural behaviors from settlement and resource locations. GIS technology provides a single platform from which these three endeavors can be performed in an efficient, objective, and replicable manner. Much of what follows has been placed under the rubric of predictive modeling. As we demonstrate, however, the term now encompasses a much wider array of models and modeling techniques than in the past. One of the uses of predictive modeling is to guide inventory effort. The basic approach is to use archaeological data collected from a part (i.e., sample) of a specified region (the sample universe) to create an environmental signature of where sites tend to be located and generalize it to the rest of the sample universe. Using multiple regression or logistic regression, an equation can be created by which independent environmental variables are statistically related to predict the likelihood that a particular area will contain an

archaeological site (ROSE/ALTSCHUL 1988). The advantage of using environmental variables is that the variable states of interest can be continually mapped across the surface of the sample universe. For interval scale data, such as elevation, a unique score can be assigned to any particular parcel. For categorical variables, like landforms, the sample universe can be divided into a series of polygons, each representing a particular landform, and each parcel within the polygon receiving the same "landform" score. Predictive statements tend to become more accurate as archaeological surveys cover more area and become more representative of the range of scores for each environmental variable used to predict site location. In essence, confidence in a model's predictions increases as the sample fraction of the entire universe increases and more diverse environmental settings are surveyed.

Regression models as well as simpler intersection, or correlative, models became extremely popular with the advent of GIS technology. GIS software provided the means for dividing areas into small cells that could adequately capture environmental variation affecting human behavior as well as making the enormous number of calculations required by multivariate statistical techniques quickly and easily. Generally, the main output of GIS software is graphic in nature; sensitivity maps which show the likelihood that a particular parcel contains an archaeological site have become standard fare in archaeological management.

Regression and correlative models are based on the assumption that human behavior is patterned. Decisions about where to establish settlements or conduct activities are conditioned by a set of cultural "rules," such as how close to be to specific resources, how best to shield oneself from enemies, and so on. Archaeologists are generally not privy to these rules. If these decisions are patterned, however, the resulting behaviors will yield a particular distribution of archaeological sites and materials. Archaeologists, then, can infer the basis of these settlement decisions by associating site locations with their environmental settings. This logic is the basis for many types of archaeological investigations, ranging from site catchment analysis of single site locations to regional settlement pattern analysis.

Like site catchment or regional analyses, most predictive modeling begins with the assumption that human behavior is patterned according to environmental variables. Predictive modeling differs from other analytical approaches to studying human spatial behavior by stopping short of developing or requiring a framework for explaining observed patterns. Humans may adapt to their environment in complex ways, but the result is that archaeological sites tend to

be associated with particular environmental settings. Even if we do not understand the underlying adaptation, we can still predict site location. By the same token, finding associations between environmental characteristics and site location can lead to unexpected insights regarding the factors influencing settlement decisions. Altschul and his colleagues (ALTSCHUL ET AL. 2005, 49) present the logic of using environmental variables to predict human use of a landscape in southeast New Mexico as follows:

- The environmental variables used in predictive models are best viewed as proxy variables.
- Humans use a complicated “calculus” in assessing potential locations in which to live, obtain and process resources, and commune with their gods.
- People do not generally measure the slope of the land where they place their houses or measure the exact distance to water, but they do choose land that is flat and near water.
- The indigenous people of Loco Hills probably did not know, much less care, at what elevation they placed their camps, but they certainly knew where the stands of black grama and tobosa grasses occurred.
- Elevation, though not part of the prehistoric “calculus,” is strongly correlated with the vegetative communities of southeast New Mexico and thus can be used as a predictor of site location.

For some planning and management purposes, just knowing where sites are located, or are likely to be located, is enough. For example, the locations of well pads used to explore for oil and gas can be moved so as to avoid sites. Hence, by adopting a “flag and avoid” strategy, archaeologists working with oil and gas producers do not need to know anything about a site other than its boundaries. Similarly, during the initial stages of planning a road, it is probably sufficient to know the relative likelihood that each possible alignment will cross archaeological sites as opposed to the exact number and nature of the potentially affected sites.

In many cases, however, we need to know more. Decisions about which archaeological sites to protect, which ones to disturb, which sites need to be investigated, and how much of each site needs to be excavated, require that we distinguish between sites on the basis of their scientific importance. To accomplish this, we need to develop and test hypotheses about why sites are located where they are, which means we need to understand the adaptation underlying settlement decisions.

In areas with long archaeological traditions, human adaptations have generally been explored with some rigor so that the patterns expressed in predictive models can be readily incorporated into theoretical models of settlement and subsistence. Combining empirically based projections of settlement trends with theoretical notions about subsistence practices often leads to the selection of samples of sites to excavate that have a strong potential to advance

our understanding of the past. Such is not the case, however, in regions that have been largely ignored by archaeologists. In these situations, we must use the initial survey data to tease out broad trends in settlement and to hypothesize about the kinds of land-use behaviors that could have resulted in the observed pattern. These dual requirements are even more critical for development projects for which the time between survey and excavation is compressed, so that information needs to be developed quickly about which sites or site components are important enough to warrant further investigation and/or protection. Instead of relying less on models, these situations cry out for a greater reliance on tools that not only help archaeologists interpret survey results but also help communicate to regulators and other stakeholders what we think is important about the past and how many sites, and how much of each site, we need to excavate, so that appropriate heritage decisions can be made.

Cultural heritage is not simply about saving vestiges of the past; it is also about ensuring that traditions and traditional ways of life are preserved and enhanced in the face of modern development. Often, decisions about social impacts of development are made without properly taking into account a region’s culture history or traditional socioeconomic adaptation. The result is that economic development is commonly followed by disruption of traditional social institutions. The lives of many of the individuals that the “aid” is designed to improve are actually made worse. Archaeologists are in a unique position to address this problem. By studying how humans adapt to a particular environment over long periods and how changes in these adaptations affect social, economic, and political institutions, archaeologists can provide insights into how a particular culture might react to proposed changes.

GIS technology has led to the development of a powerful tool, agent-based modeling, which provides a framework for testing different theories of adaptation. Unlike regression or correlative predictive models in which patterns of settlement are inductively derived from generalizing patterns from the known (i.e., surveyed areas in the sample universe) to the unknown (i.e., non surveyed areas in the sample universe), agent-based modeling begins with a linked set of logical statements about how human actors (either individuals or groups) behave in a particular landscape. The model unfolds as actors respond to environmental events (i.e., drought, fish runs, etc.) and the consequence of their own actions (e.g., overgrazing, surplus harvest for trade, etc.). By running each adaptive scenario numerous times, and then again under slightly different rules or parameters, the range in settlement variation for each adaptation can be documented.

Comparing the results of correlative predictive models of archaeological site location and agent-based models of human adaptation can lead to interesting insights. In theory, the two should be linked because human land-use behavior will be related to the distribution of archaeological materials. Although postdepositional processes can account for



Figure 1. The Sabodala Project Area.

some of the discrepancies between the results from the two types of models, more fundamental differences – such as the same environmental zone being considered favorable for settlement by inductively based models and unfavorable by the deductive agent-based models – probably signifies that one or more of the proxy variables in the correlative models is not related to human behavior and/or that one or more of the adaptive “rules” in the agent-based models is wrong. Regardless, these discrepancies point to fruitful lines of future research.

As our ability to explain the connections between the two modeling approaches increases, we will be in a better position to predict how future development will impact a particular society. Instead of being viewed as interesting, but not terribly useful, archaeology can become an important element in discussions of socioeconomic development. Ultimately, understanding the past will assist in shaping a positive future.

In this paper, we present our approach to one such case of economic development from the Sabodala region of east Senegal. We begin with a brief discussion of the area, its archaeology, environment, and culture. We then present the results of correlative predictive models of surface sites and a geomorphic predictive model of buried sites. Next, we discuss our approach to agent-based modeling for the study of long-term human adaptation to the region. We close with a statement about modeling in development contexts.

Sabodala

Our study area is a 240 km² region at the upper reaches of the Senegal River and Gambia River drainages (*figure 1*). The Senegal and Gambia Rivers both rise in the highlands of Guinea and flow northwest to the Atlantic Ocean. The Senegal River flows along the eastern and northern borders of Senegal, dividing it from Mali and Mauritania. The Gambia River flows through southern Senegal, with its lowest reach contained within the tiny country of The Gambia. Ephemeral streams flow north from the project area merging with the Falemme River, a major tributary of the Senegal River, about 40 km to the northeast on the Senegal-Mali border. Similar streams flow into the Senegal plains to the west and south before being captured by the Gambia River about 100 km to the southwest of the project area. Several mining concessions have been defined, and we are engaged in completing the cultural heritage component of the economic and social impact assessment of one of those concessions. In 2009, we conducted the first phase of ethnographic research, compiled historic maps and documents, and created the initial predictive models of archaeological site location. Archaeological monitoring of exploration activities began in 2010; archaeological and ethnographic field surveys are scheduled for later this year.

The Sabodala region is hilly and volcanic and receives on average a little more than a meter of rain per year, mostly in the wet season from June until September. Rainfall, however, is extremely variable, and the well-drained volcanic and sedimentary rock regime ensures that outside

of the rainy season surface water is scarce. Paleoclimatic evidence suggests that except for relatively brief periods, the region has been hot and dry for most of the Holocene (THIAW 1999). This is particularly true for the last 500 years. It is not the aridity, however, that is of most concern to human settlement. More important are the large interannual fluctuations in climate and the periodic long intervals of drought conditions.

No systematic archaeological work has been performed in the general area. In the early twentieth century, fascination with Acheulean hand axes and Neolithic stone axes fueled interest in the archaeology of eastern Senegal. LAFORGUE (1923, 1925) mentions the Sabodala region in an early review of the prehistory of the Sahara and West Africa. Professional archaeological research in Senegal, however, only took root after the foundation of IFAN (Institut Français d'Afrique Noire, or French Institute for Black Africa) in 1936. IFAN sponsored inventories throughout West Africa that resulted in a number of syntheses of the massive database (GUITAT 1970; MAUNY 1961; RAVISÉ 1970). Sites in eastern Senegal were reported, although none were recorded in the project area or its immediate surroundings. The closest systematic work consisted of a 50-km survey and limited testing at three sites performed by THIAW (1999) as part of his dissertation on the lower Falemme River, located more than 100 km to the north. Ceramic and other artifact classifications applied to Sabodala derive from the Middle Senegal Valley Project of 1990–1992, which focused on large sites on the Senegal River, located more than 200 km to the north (MCINTOSH ET AL. 1992). Both of these studies focused on alluvial settings of major drainages, not upland areas, and the suitability of generalizing existing results to the upper Senegal and upper Gambia drainages has not been demonstrated.

Today, agriculture and pastoralism are the main subsistence activities in the region, with artisanal gold mining another major economic activity. Agriculture is largely dependent on rainfall. Unlike the better studied areas of the Senegal River and its major tributaries, such as the Falemme, where recession agriculture predominates, Sabodala has no perennial streams, and the floodplains that exist are extremely narrow. Soils are deepest and best suited for agriculture in constrained alluvial settings; however, soil development also has occurred on plateau-like areas on the tops of hills. Slash and burn is the most common technique to clear farmland; it is also used to hunt game and to stimulate fresh grass and clear out thorny vegetation for cattle and goats.

Although today pastoralism is very important, it is unlikely that such was the case in the more distant past. The climate in West Africa was sufficiently wet that the tse tse fly would have impeded the development of pastoralism until about 500 years ago.

Artisanal gold mining has been practiced in the hills of Senegal since at least the rise of Islam in West Africa (THIAW 1999).

For the most part, gold mining was an adjunct to other subsistence activities. The gold mine trade has historically been controlled by North African traders who maintained the trade routes through the Sahara and local brokers and merchants known as Juula, who were generally Soninke or Malinke people. This practice continues today, with much of the gold being bought by traders based in the adjoining country of Mali. Gold mining is practiced through an intricate social organization in which the mining is completed by male task groups that sell the excavated “dirt” to family-based groups, who in turn sluice and process the gold.

The Sabodala region is occupied presently by a variety of ethnic and linguistic groups. Communities of two linguistic groups – Malinke and Peul – dominate the region and exert the greatest influence on social and political institutions. Malinke and Peul societies are typically stratified and are subdivided into three classes: nobles, “castes,” and slaves. Although these classes are still recognized, they have been subverted and reshuffled in complex ways. For example, slavery is outlawed in Senegal; yet, because status is ascribed, the term “slave” is still used to refer to descendants, and master/slave relations have been largely transformed into relations of clientage (THIAW 1998).

The ethnographic evidence we collected indicates that the communities in the Sabodala region are likely uprooted and have emigrated from neighboring regions of Senegal, Mali, and Guinea. Lands suitable for agriculture are quite restricted and are controlled by the elites who are predominantly of the Cissoko lineage. The Cissoko control most of the chieftaincies in the local villages of the region. The agricultural potential of other lands is poor, although they are plentiful; lands poorly suited to agriculture are left to the lower classes. Land is inherited within the lineage, which means it is collective in theory; but in practice, members of the lower classes and junior members of elite classes do not have access to quality land. The result is high mobility among these people, who are constantly in search of better land. Much of the tension both within communities and within elite families is related to access to land.

Each village considers the lands within 8–10 km as “theirs” with regard to agriculture and use rights for lands up to 50 km from the village for such activities as herding and hunting. Villages tend to be located adjacent to or near agricultural land and in locations where potable water is near the surface and available year-round. Villages are spaced relatively far apart, separated by vast tracts of land of marginal quality for agriculture. In an absolute sense, therefore, land is never in short supply. Movement is not greatly restricted, and the sociogeographic history of the region is of social groups continually fragmenting and starting new communities. The current population generally claims origin in Mali (either from Tomara, Marena, or Maraka), Guinea (primarily from Fuuta and Djallon), and Senegal (from Bundu and the Middle Senegal valley). It is likely that these immigrants made it to the Sabodala

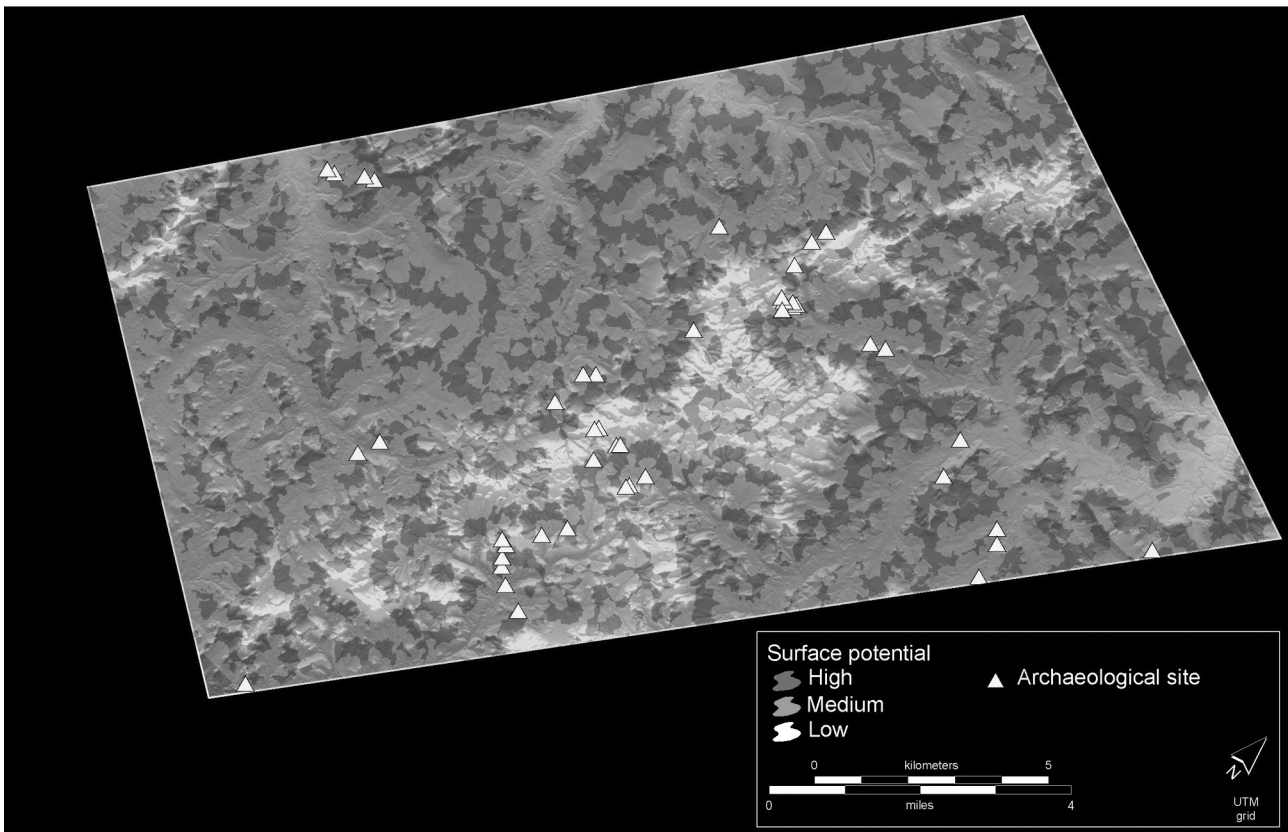


Figure 2. Predictive model of surface archaeological sites, showing locations of known archaeological sites.

area no earlier than the eighteenth or nineteenth centuries, where they established the villages of Mamakono, Sekhoto, and NioMadina. These villages in turn grew and fragmented into the 10 current villages in the nineteenth and twentieth centuries. Whether these groups would have continued to grow and fragment or whether population movement would have continued on further west is unknown. The development of industrial gold mining along with other infrastructure developments, such as irrigation in the Senegal River Valley (PARK 1993), have altered the traditional economic base in fundamental ways.

Correlative Models

The ethnographic survey was designed primarily to identify sacred and traditional places of importance to local residents. In the course of our fieldwork, we identified archaeological sites found along the way. This initial effort resulted in recording 50 traditional sites and identifying 49 archaeological sites. The archaeological sites discovered range from Neolithic villages with associated field houses and activity areas to upper Paleolithic artifact scatters (ca. 40,000–10,000 years ago). Although the survey was cursory and opportunistic, it certainly demonstrated the archaeological and cultural richness of the area.

Our next task is to design a sample that adequately assesses the nature of the archaeological record: the number and types of sites and the time periods represented. In de-

velopment projects, it is not uncommon for only the direct impact zones to be surveyed. Without a regional context in which to place the sample of sites, however, the results of even very intense investigations are highly restricted. In these cases, we select some arbitrary sampling fraction of nonimpact areas for survey, such as 5, 10, 20, or 50 percent, in addition to the impact zones. Often, this strategy leaves archaeologists and nonarchaeologists alike wondering if the survey captured enough archaeological and environmental variation to characterize the archaeological record sufficiently to make sound decisions about heritage. ALTSCHUL ET AL. (2005) have demonstrated that statistical models can be powerful tools in assessing survey results. As more survey is completed, new models can be calculated and compared statistically and visually with previous ones. Particularly for nonarchaeologists, visual comparisons showing site sensitivity zones converging in size and shape as more data are added can be very powerful in decisions about when basic settlement trends are reliably established. By having the GIS model parameters already established at the outset of fieldwork, we can add survey results on an iterative basis and make decisions of survey sufficiency without recourse to a fixed, arbitrary sample fraction. For example, regulators, project sponsors, and archaeologists might agree prior to the survey that high-sensitivity zones should contain 85 percent of the sites in less than a third of the sample universe. The model can be recalculated periodically and the survey continued until the desired model parameters are met.

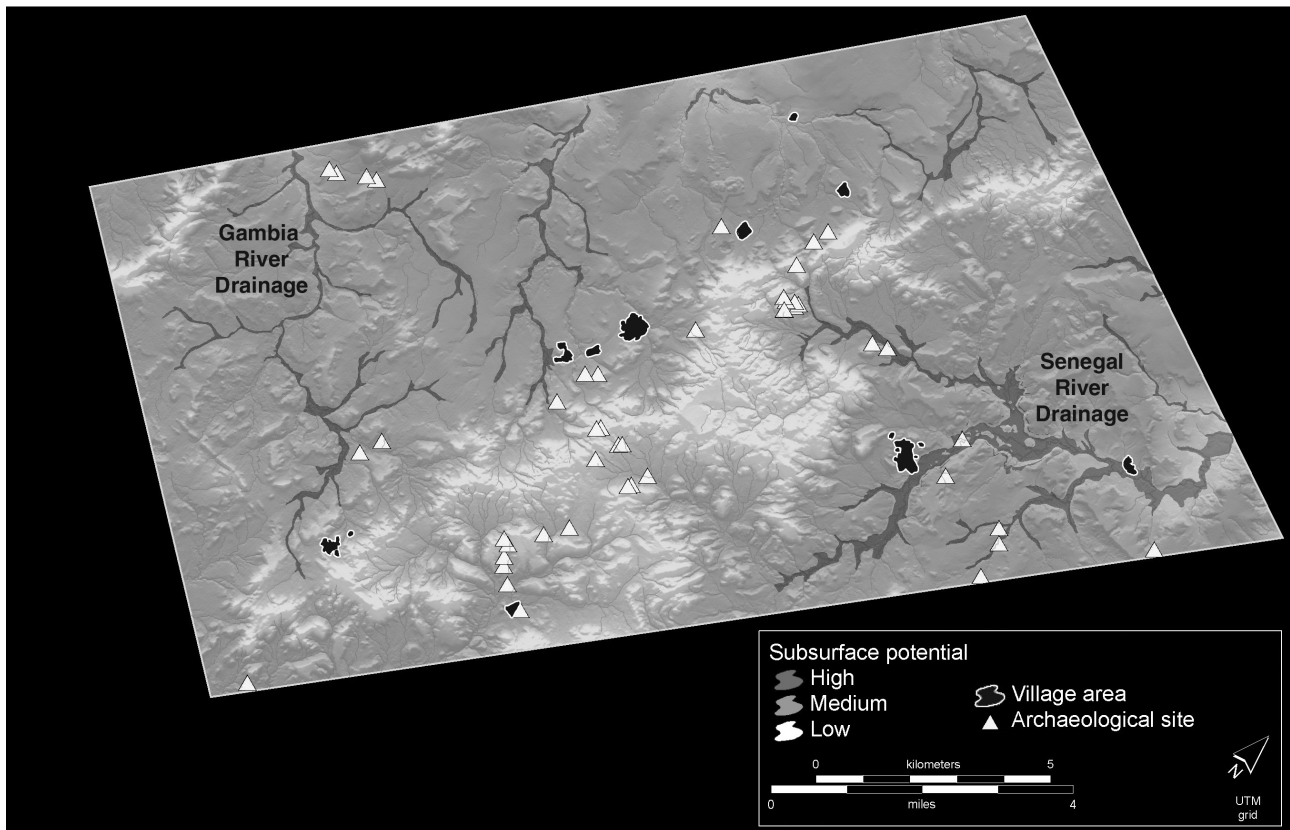


Figure 3. Predictive model of buried archaeological sites, showing locations of known archaeological sites and modern villages.

To create a model of surface archaeological locations, we first determined which environmental variables were associated with known site locations. The sample universe was divided into a large number of small grid cells of equal size and shape that serve as the unit of analysis. We compared the characteristics of five variables – aspect, elevation, flow length (a proxy for runoff accumulation), soil type, and slope – in cells containing archaeological sites with those for the project area as a whole to develop the initial model. It is important to note that we were not able to correlate nonsite locations with environmental variables, as is generally the case with predictive modeling, because we have not systematically surveyed for sites. Thus, we only know where the 49 sites were found, not where archaeological sites have not been found. Consequently, we could not use logistic regression or similar techniques, which distinguish “site” and “nonsite” cells based on their probabilities of belonging to the respective classes. Instead we created a model based on a supervised classification using the IDRISI software package. Using the five environmental variables, we created three categories and ranked them according to the proportion of sites contained in each category to the proportion of cells of the category and to the total number of cells in the sample universe. We then cross-checked the result by computing a Principal Components Analysis (PCA) on the selected variables and performing a supervised classification of the PCA results; the results of the two techniques were very similar.

We found that one of the categories is positively correlated with site locations; we termed this category the high-sensitivity zone. Statistically, high-sensitivity cells were distinguished from cells in the other two categories primarily because they had short flow lengths (180 m average), were facing south, and were lying on greater slopes. High-sensitivity lands accounted for about a third of the project area but nearly half the sites. A second category, termed the low-sensitivity zone, covered nearly 13 percent of the project area, but contained only two sites. Cells of this category were distinguished from the others because they had long flow lengths (850 m average), were facing north, and were on relatively flatter land. The vast area in the middle, called the moderate-sensitivity zone, accounted for just over half the project area and about 46 percent of all site locations.

Figure 2 presents the surface model. Low-sensitivity zones are concentrated in the hills of Sabodala, whereas the high-sensitivity zones cover hill slopes and knolls overlooking watercourses. The vast unknown is pretty much everywhere in between. Because the model is fitted to the data, it is best viewed as a reflection of where we have looked and not necessarily where sites are located. Sites have mostly been found along sections of roads that cross the floodplain and below the hills. We have found a surprising number of sites in these areas, which are properly marked as high sensitivity. The relative sensitivity of the other two zones is very much in doubt. For example,

the model classifies most alluvial settings in the moderate-sensitivity zone. Yet, these are precisely where many activities, such as those involving gold mining sluices, agricultural plots, corrals for goats and cattle, soccer fields, and sacred trees, are concentrated. These areas flood periodically, and there is little surface evidence of activities known to be performed there. Beneath the surface, however, may be a different story. Storage features, middens, and other, more-permanent features, such as stone rubble mounds that mark graves, should withstand the scouring of floods and the colluvial deposits washed in from the adjacent hill slopes. Even during the ethnographic survey, when we were not looking very hard, we found one buried site in an alluvial setting.

Detecting buried deposits requires subsurface probing, which is expensive and time consuming. To guide this process, we created a preliminary model of buried site probability for the Sabodala project area based on slope elements and associated landforms that could be inferred from topographic maps (1-m contour interval). This model is based primarily on RUHE's (1975) descriptive slope elements: summits, shoulderslopes, backslopes, footslopes, and toeslopes. These slope elements are associated with geomorphic processes that occur in different landscape positions and so they are useful for predicting where archaeological sites may be buried. The dominant geomorphic processes for each slope element are: (1) summits—water infiltration and soil formation; (2) shoulderslopes—erosion; (3) backslope—transportation of eroded sediment; (4) footslope—deposition of colluvial and slopewash sediments; and (5) toeslope—deposition of alluvial sediment. Buried archaeological sites are most likely in the lower landscape positions (i.e., footslopes and toeslopes), and surface sites are most likely on summits, shoulderslopes, and backslopes.

High-, medium-, and low-probability areas were drawn by hand on the topographic maps and then digitized. High-probability areas include the toeslopes of floodplains and alluvial terraces that are less than about 1 m above the active floodplain. Medium-probability areas were defined as the juncture of footslopes and toeslopes in valley margin positions (mainly colluvial footslopes and alluvial fans) and alluvial terraces that are more than about 1 m above the active floodplain. Low-probability areas consist of the elevated landforms of summits, shoulderslopes, and backslopes, places where archaeological deposits are most likely surficial. Small pockets of colluvium may occur in the medium- and low-probability areas that cannot be distinguished on the topographic maps, and so it is possible that sites may be buried in these localities.

Figure 3 presents the preliminary subsurface predictive model. High-sensitivity areas lie along the larger watercourses; it is interesting that the two areas with the highest buried site potential are the major streams flowing into the Gambia and Senegal Rivers in the southwest and northeast portions of the project area, respectively. Plotted in

figure 3 are the locations of current villages and the archaeological sites known in the project area. Three of the 13 residential polygons lie completely or partially in high sensitivity areas for buried sites, with another 3 polygons lying reasonable close to these areas. It is important to note that the current location of villages is likely influenced by industrial mining operations, which are centered in the northwestern sector of the project area. We suspect that pre-mining village locations are located either in areas susceptible to site burial or adjacent to them.

Not surprisingly, the archaeological sites found during the ethnographic work, which were all detected from the surface during brief examinations of particular areas, are not located in areas likely to produce buried sites. The strong indirect nature of the correlation of known archaeological sites and likely locations of buried sites shows the folly of designing surveys solely based on past archaeological surface survey results.

This preliminary buried site model will aid the survey design regarding the intensity of survey and necessity for subsurface testing by shovel pits in different parts of the project area. Geoarchaeological field investigations (coring, trenching, soil profile description and interpretation, and radiocarbon dating) will be used to test and refine this preliminary model. A reconnaissance will document the range of landforms present in the project area and will examine the stratigraphy of existing subsurface exposures. We will obtain cores and document the profiles of backhoe trenches and existing subsurface exposures. Subsurface examinations will concentrate on areas where the reservoir, mining areas, and roads are planned. Cores will be extracted from alluvial landforms, especially in the area of a proposed reservoir. Backhoe trenches will be placed to sample representative landforms (e.g., alluvial floodplains and terraces, alluvial fans, and colluvial footslopes) in the high-, medium-, and low-probability areas, spread across various small to large drainage systems. The stratigraphy of cores and backhoe trenches will be described and interpreted in terms of their potential for buried cultural deposits. Samples of the fill of backhoe trenches will be collected in 30-cm intervals and placed in discrete piles so that 5 to 10 5-gallon buckets of soil can be screened to search for buried artifacts. Charcoal and organic-rich samples will be saved for radiocarbon dating.

There has been a trend recently to try to combine surface and subsurface models into one all-encompassing predictive model. We have been disappointed with the results (see ALTSCHUL ET AL. 2005). In our opinion, these models conflate two factors influencing the composition of the archaeological record. Surface models assume that human land-use behavior is related to the distribution of natural resources. Associating environmental variables that serve as proxies of resources sought by humans with a sample of sites is designed to train a statistical technique to identify and then generalize an environmental signature to the sample universe. The major problem with surface models

is that they tend to be statistically overmodeled. The proxy variables that are designed to encompass the entire suite of behaviors involved in settlement actually are so intricately intercorrelated that they explain the same statistical variation. The result is that these models appear very strong (i.e., they accurately predict a very high percentage of the cases used to create the model), but in reality have very little predictive power (i.e., they do not accurately predict site locations of cases not used to create the model).

Subsurface models, in contrast, are designed to identify areas that were favored by human settlement but because of postdepositional processes yield no indication of past use on the surface. Subsurface models are difficult to test by any other means than fieldwork. Even then, testing subsurface models is difficult because the time and expense required to excavate sufficient subsurface probes to evaluate the model is prohibitive.

Combining surface and subsurface models makes little logical sense. Moreover, we suspect that many combination models yield a false sense of confidence in the resulting model's performance. Because the training set of sites used to develop the predictive equations is composed primarily of surface sites, it probably is not a good predictor of buried sites; a fact that will not be discovered until development uncovers archaeological sites where they are least expected.

We have found that a better approach is to develop two predictive models; one for surface sites and one for buried sites (ALTSCHUL ET AL. 2008). The two models will be used to design and assess the survey efforts. From the survey we intend to estimate how many sites are in the project area, what types of sites are present, and when they were occupied. Based on these results we can infer population trends, settlement patterns, and subsistence activities. Surface and subsurface models, however, will be of limited help in explaining these trends. For that, we need to turn to from data driven models to theoretical ones.

Agent-Based Modeling

The Sabodala region is an arid environment where in the recent past people have subsisted largely on dry farming and herding, which has been supplemented with a cash economy of limited gold mining and slaving. What characterizes the economies of arid land societies, like those in Sabodala, is their near universal focus on minimizing risk; an orientation that is fundamentally different from market-based, western economies in which the goal is to maximize return. This difference is often associated with behaviors that have been interpreted as inefficient or irrational (LEGGÉ 1989, 86), such as planting more fields than one has labor to harvest or buying more livestock than can reasonably be fed. Anthropologists have shown that each of these apparently "irrational" behaviors makes perfect sense within the logic of the indigenous economic system.

Another key difference is that the unit within which wealth and power is held and that makes key decisions is not the individual as in classical economic theory, but instead, a group such as a lineage or clan. Sustaining these larger organizations may involve having individuals make decisions that do not benefit themselves. This is particularly the case in stratified societies, in which there are classes of individuals, such as slaves, whose main purpose is to ensure the viability of other classes.

There are a wide variety of socioeconomic adaptations to arid environments. Which ones apply to Sabodala? It is tempting to project ethnographic practices back indefinitely into the past. We know, however, that the ethnographic present has shallow historical roots, probably on the order of no more than 200 years. Nevertheless, the archaeological and historical records suggest that the area has been occupied throughout the Neolithic, or between 1,500 and 2,000 years ago, and more sporadically during the upper Paleolithic. While it is possible that the current adaptation replaced a similar one, it is also possible that present-day society has been shaped in large part from the colonial experience of the nineteenth and twentieth centuries.

We are in the process of developing two agent-based models to help us understand the archaeological survey results better and to select sites in the project area that require further investigation. We are using a beta-version of Agent Analyst to create individual agents, or actors, that will interact with the spatial data developed for the correlative predictive models and each other (see <http://www.institute.redlands.edu/AgentAnalyst/>). Each agent makes decisions based on a "rulebook" which tells them how to behave under certain circumstances: for example, how much to plant and where to locate fields; what to do if crops are highly successful, only moderately successful, or destroyed; how many goats and cattle to purchase with their surplus; when to sell their herds; and when to move them. The rules governing the model also specify when the group is allowed to grow (i.e., have children, how many children will survive each year), when each group needs to split into two groups, what a group does when it comes into contact with another (e.g., form a village, fight, or move away from each other), and when a group either dies or moves out of the area.

We have developed two "rulebooks." The first we term the egalitarian model. Inspired by the work of Kohler and his colleagues at the Santa Fe Institute modeling the prehistory of portions of the Colorado Plateau of the American southwest (e.g. KOHLER ET AL. 2007), each agent represents an individual farming unit. Each agent has access to all types of agricultural land. Climatic data are spatially and temporally highly variable so that agents are rewarded for planting in diverse settings with the expectations that only one or two plots will be successful. We plan to run the model with and without herding as a secondary economic focus in recognition that pastoralism was not available to residents of Sabodala until about 500 years ago. Each agent, however, will also allocate a certain amount of its

human resources to gold mining activities, which will be redeemed by outside agents (i.e., agents not in the simulation) for cash, which in turn will be used in times of shortages to purchase food (measured in calories).

We also will create a stratified model. Using the ethnographic present as our guide, agents will consist not of individual economic units, but collectives mirrored on present-day lineages. Each agent will consist of a small number of nobles and a larger number of commoners, with a disenfranchised class at the bottom paralleling slaves or serfs attached to each noble. Each agent will have access to lands of variable quality. A disproportionate amount of each harvest will flow to nobles with lesser amounts going to commoners and the balance, if any, flowing down to slaves or serfs. Additionally, each agent will be required to tithe some percentage of its wealth to an outside agent (e.g., we will run the model with 10 percent, 20 percent, and 30 percent levels of taxation). Simulations will again be run with and without pastoralism as an economic component; gold mining will again supply an auxiliary source of cash.

The goals of the agent-based modeling are twofold. First, which, if either, model best fits the archaeological record and for what periods? Second, which, if either, model is sustainable in the Sabodala region and at what population levels?

Although both questions are of archaeological interest, answers to these questions also may be helpful in decisions regarding economic and social development. For example, we may find that an agropastoral economy is sustainable in the region but only with a society based on social fissioning and high population mobility. Development aid focused on large infrastructure investments assuming a sedentary village-based society is likely not only to be wasteful, but socially destabilizing. Similarly, we may find that a society based on a hierarchical social structure is viable as long as artisanal gold mining is an important economic activity. Encouragement of family-based craft production, which might discourage communal participation in gold mining, could undermine the office of the village chief, whose authority and power are based on his ability to trade small quantities of artisanal gold to traders from Mali and other parts of North Africa. Agent-based modeling rooted in archaeological data may provide insights into the organization and structure of existing communities, which may prove valuable in designing social and economic development programs.

GIS Modeling and Development

We are mindful that our work in Sabodala has dual purposes. We are reconstructing the past of Sabodala as part of enriching the heritage of Senegal. GIS technology has become a particularly powerful tool in this endeavor by providing the platform for compiling, organizing, and ana-

lyzing archaeological data. Correlative predictive models have been particularly useful as means of visualizing where we have found archaeological sites and where we can expect to find others. Importantly, they provide us the means of assessing how confident we can be in the results to date, where we still have gaps in our data, and how best to fill these gaps.

At the same time that we are learning about the past, our work is part of a larger socioeconomic effort to enhance the conditions of the present and future generations of the region's residents. We are mindful that many such efforts have failed in the past not only to improve conditions but have had unintended consequences that have actually made conditions worse. The decision to shift the Nigerian economy from a traditional to a cash basis, which was based on the Western assumption that individuals would act "rationally" and prosper, led to the collapse of traditional relationships and a concomitant dependence of most of the population on government subsidies (LEGGE 1989). Similarly, the development of irrigation along the middle Senegal River in Mauritania, which was intended to enhance and stabilize agriculture, ended up concentrating wealth among particular groups and disenfranchising most of the population so that the country nearly fell apart as a functioning nation (PARK ET AL. 1993). Of course, there are many more examples of programs designed to make things better having exactly the opposite effect. All these programs were based on certain assumptions regarding human behavior and left sponsors surprised when things did not turn out the way they were supposed to.

Rather than trying to make West Africans into Westerners, a better approach may be to make sure our actions do not replace, but instead enhance, traditional socioeconomic adaptations. To do so we need to look back before we go forward. Agent-based modeling provides a means of testing ideas about human adaptation derived from archaeology. We may find that in the last 2,000 years, no adaptation was successful in the Sabodala region for the long term; i.e., people moved in for a time and then were forced to move out because they could not make a living. We may also find out that the only historically viable system is morally reprehensible, in that it requires forcible migration and enslavement in order to be sustained. Alternatively, we may find that an agrarian society is possible to sustain, but only at much lower population levels than currently exist. This information can then be run forward, examining how traditional adaptations and social conventions will react to proposed development schemes. Government and development agencies will be forearmed with ideas about what the land can be expected to produce and how people need to be organized to produce it.

Cultural change has proven exceedingly difficult to predict in development projects. Human response to change tends to be viewed in simplistic terms. If we do X (e.g., build a road, improve the water supply, provide electricity), then people will do Y (e.g., be free to travel to opportunities,

grow more crops and achieve economic independence, be better connected and participate in democracy); the bigger the improvement, the better the result. But cultures are conservative, having developed institutions and practices adapted to long-term historical and environmental trends. Archaeologists are unique among social scientists in recognizing the time depth and the singular social histories responsible for shaping a particular cultural adaptation. We have learned that cultures respond to major change not by completely reshuffling their component parts and internal relations but through traditional practices and established relationships.

Development projects that disrupt traditional institutions and practices may achieve the desired economic result, but at an unacceptable social cost. In contrast, development projects that enhance traditional institutions at the same time that they improve economic conditions have the best chance of being sustainable. Archaeological studies of human adaptation and culture change, which have generally not been incorporated into development projects, may help alleviate some of the persistent problems that plague these projects by identifying how modern institutions and practices are related to traditional adaptations, how these adaptations have responded to changes in the past, and most importantly, how these adaptations are likely to respond to proposed changes (see also PIKIRAYI 2009, 126).

Cultural heritage has traditionally been about finding and saving vestiges of the past. GIS technology allows archaeologists to do much more. We are no longer simply stewards of the past; our knowledge can help guide present decisions and mold the future. We owe it to future generations not to shrink from this responsibility, but to embrace it.

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References Cited

- ALTSCHUL, J. H. – GREEN, P. – TAGG, M. – HEILEN, M. – HOMBURG, J. – NAGLE, C. – KLEIN, T. – SEBASTIAN, L. – VAN WEST, C. – CUSHMAN, D. 2008: Issues in Constructing Archaeological Predictive Models, (poster presented at the 2008 Partners in Environmental Technology Technical Symposium & Workshop, Washington, D.C.).
- ALTSCHUL, J. H. – SEBASTIAN, L. – ROHE, C. M. – HAYDEN, W. F. – HALL, S. A. 2005: Results and Discussion: The Loco Hills Study Area. In: Ingbar, E. – Sebastian, L. – Altschul, J. – Hopkins, M. – Eckerle, W. – Robinson, P. – Finley, J. – Hall, S. A. – Hayden, W. F. – Rohe, C. M. – Seaman, T. – Taddie, S. – Thompson, S.: *Adaptive Management and Planning Models for Cultural Resources in Oil and Gas Fields in New Mexico and Wyoming*, Preservation Research Series 5, Albuquerque, 49–76.
- ESRI 2010: ArcGIS 9.2 Desktop Help: How Iso Cluster Works. <http://webhelp.esri.com/arcgisdesktop/9.2/index.cfm?TopicName=How%20Iso%20Cluster%20works>, (accessed July 26, 2010).
- GAFFNEY, V. – VAN LEUSEN, P. M. 1995: Postscript—GIS, environmental determinism and archaeology: a parallel text. In: Lock, G. – Stančić, Z. (eds.): *Archaeology and Geographical Information Systems: A European Perspective*, London, 367–382.
- GUITAT, R. 1970: Carte et répertoire des sites néolithiques du Sénégal, *Bulletin de l'Institut Fondamental d'Afrique Noire*, Série B, No 4, 1125–1135.
- KAMERMANS, H. – VAN LEUSEN, M. – VERHAGEN, P. (EDS.) 2009: *Archaeological Prediction and Risk Management: Alternatives to Current Practice*, Archaeological Studies Leiden University, Leiden.
- KING, L. C. 1957: The uniformitarian nature of hillslopes, *Transactions of the Edinburgh Geological Society* 17, 81–102.
- KOHLER, T. A. 1988: Predictive locational modeling: history and current practice. In: Judge, W. J. – Sebastian, L. (eds.): *Quantifying the Present and Predicting the Past: Theory, Method, and Application of Archaeological Predictive Modeling*, Denver, 19–59.
- KOHLER, T. A. – JOHNSON, C. D. – VARIEN, M. – ORTMAN, S. – REYNOLDS, R. – KOBTI, Z. – COWAN, J. – KOLM, K. – SMITH, S. – YAP, L. 2007: Settlement Ecodynamics in the Prehispanic Central Mesa Verde Region. In: Kohler, T. A. – van der Leeuw, S. E. (eds.): *The Model-Based Archaeology of Socionatural Systems*, Santa Fe, 61–104.
- LAFORGUE, P. 1923: Essai sur l'influence de l'Industrie saharienne en Afrique occidentale au cours de la période

néolithique, *Bulletin de la Société Préhistorique Française* 20, 61–166.

LAFORGUE, P. 1925: État actuel de nos connaissances sur la Préhistoire en Afrique Occidentale française, *Bulletin du Comité Historique et Scientifique de l'A.O.F.* 8, No 1, 105–171.

LEGGE, K. 1989: Changing Responses to Drought Among the Wodaabe of Niger. In: Halstead, P. – O'Shea, J. (eds.): *Bad Year Economics: Cultural Responses to Risk and Uncertainty*, Cambridge, 81–86.

MAUNY, R. 1961: Tableau Géographique de l'Ouest Africain au Moyen Age, *Mémoires de l'Institut français d'Afrique Noire*, No 61.

MCINTOSH, S. K. – MCINTOSH, R. J. – BOCOUM, H. 1992: The Middle Senegal Valley Project: Preliminary Results from the 1990-91 Field Season, *Nyame Akuma* 38, 47–61.

PARK, T. K. (ED.) 1993: *Risk and Tenure in Arid Lands: The Political Ecology of Development in the Senegal River Basin*, Tucson.

PARK, T. K. – BARO, M. – NGAID, T. 1993: Crisis in Nationalism in Mauritania. In: Thomas K. P. (ed.): *Risk and Tenure in Arid Lands: The Political Ecology of Development in the Senegal River Basin*, Tuscon, 87–121.

PIKIRAYI, I. 2009: What can Archaeology do for Society in Southern Africa?, *Historical Archaeology* 43 (4), 125–127.

ROSE, M. R. – ALTSCHUL, J. H. 1988: An Overview of Statistical Method and Theory for Quantitative Model Building. In: Judge, W. J. – Sebastian, L. (eds.): *Quantifying the Present and Predicting the Past: Theory, Method, and Application of Archaeological Predictive Modeling*, Denver, 173–255.

RAVISÉ, A. 1970: Industrie néolithique en os dans la région de Saint Louis (Sénégal), *Notes Africaines* 128, 97–102.

RUHE, R. V. 1975: *Geomorphology: Geomorphic Processes and Surficial Geology*, Boston.

SCHOENBERGER, P. J. – WYSOCKI, D. A. – BENHAM, E. C. – BRODERSON, W. D. (EDS.) 2002: *Field Book for Describing and Sampling Soils* (Version 2.0), Lincoln.

THIAW, I. 1998: The Built Environment and the Expansion of Social Dependence in Eighteenth-Nineteenth Centuries Inland Senegambia (Upper Senegal River), *Society of Historical Archaeology Newsletter* 31 (4), 28.

THIAW, I. 1999: Archaeological Investigation of Long-Term Culture Change in the Lower Falemme (Upper

Senegal Region) a.d. 500–1900, (unpublished Ph.D. Dissertation, Department of Anthropology, Rice University, Houston).

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