The Evolution of Social Behavior in the Prehistoric American Southwest

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Long House Valley, located in the Black Mesa area of northeastern Arizona (USA), was inhabited by the Kayenta Anasazi from circa 1800 B.C. to circa A.D.1300. These people were prehistoric precursors of the modern Pueblo cultures of the Colorado Plateau. A 100-percent archaeological survey of the valley, supplemented with limited excavations, has yielded a rich paleoenvironmental record, based on alluvial geomorphology, palynology, and dendroclimatology, permitting accurate quantitative reconstruction of annual fluctuations in potential agricultural production (kg maize/hectare). In particular, the archaeological record of Anasazi farming groups from A.D. 200-1300 provides information on a millennium of sociocultural stasis, variability, change, and adaptation. We report on a multi-agent computational model of this society that closely reproduces the main features of its actual history, including population ebb and flow, changing spatial settlement patterns, and eventual rapid decline. The agents in the model are monoagriculturalists, who decide both where to situate their fields as well as the location of their settlements. Nutritional needs constrain fertility. Agent heterogeneity is demonstrated to be crucial to the high fidelity of the model.

A central question that anthropologists have asked for generations concerns how cultures evolve or transform themselves from simple to more complex forms. Traditional study of human social change and cultural evolution has resulted in many useful generalizations concerning the trajectory of change through prehistory and classifications of types of organization. It is increasingly clear, however, that four fundamental problems have hindered the development of a powerful, unified theory for understanding change in human social norms and behaviors over long periods of time.

The first of these is the use of whole societies as the unit of analysis. However, such group-level effects must themselves be explained. Sustained cooperative behavior with people beyond close kin is achieved in most human societies, and increasingly hierarchical political structures do emerge through time in many cases. Successful explanation and the possibility of developing fundamental theory for understanding these processes depend on understanding behavior at the level of the individual or the family (DeVore 1988). Among the advantages of such an approach is that it allows for specific modelling of peoples' behavioral ranges and norms, and their strategies as community size and structure changes.

Secondly, traditional analyses are aggregated not only over individuals, but also over space. Current research indicates that stable strategies for interpersonal interactions in a heterogeneous, spatially- extended population may be very different than in a homogeneous population in which space is ignored (e.g., Lindgren and Nordahl 1994). Most social interactions and relationships in human societies before the recent advent of rapid transportation and communication were local in nature.

Third, cultures have been considered homogeneous tending towards maximization of fitness for their members. Little consideration was given to historical processes in shaping evolutionary trajectories or to non-adaptive aspects of cultural practice.

Finally, most discussions of cultural evolution have failed to take into account the mechanisms of cultural inheritance and the effects of changes in modes of transmission through time (Boyd and Richerson 1985; Cavalli-Sforza and Feldman 1981). Understanding culture as an inheritance system is fundamental to understanding culture change through time.

The Artificial Anasazi project is at the juncture of theory building and experimentation. We use agent-based modelling to test the fit between actual archaeological and environmental data collected over many years and simulation using various rules about how households interact with one another and with their natural environment. By systematically altering demographic, social, and environmental conditions, as well as the rules of interaction, we expect that a clearer picture will emerge as to why the Anasazi followed the evolutionary trajectory we recognize from archaeological investigation. Our long range goal is to develop agent-based simulations to understand the interaction of environment and human behavior and their role in the evolution of culture.

The Study Area

The test area for exploring the use of agent-based modelling for understanding social evolution is the prehistoric American Southwest from about A.D. 200 to 1450 using a culture archaeologists refer to as the Anasazi and a locality called Long House Valley. The Anasazi are the ancestors of the present day Pueblo peoples, such as the Hopi, Zuni, and the various groups along the Rio Grande in New Mexico. A commonly held view is that technological, social, and linguistic complexity co-evolves. The Anasazi (Ancestral Pueblo) culture underscores the interdependence of these aspects of culture. The Anasazi were, in many respects, technologically a simple agricultural society whose major food source was maize. In the A.D. 200 to 1450 period the only technological major change that is archaeologically verifiable is the introduction of a more efficient system for the grinding of maize. During this time, however, there is evidence of greatly increased social complexity. Contemporary Pueblo people have a complicated social system made up of sodalities (or distinct social associations). There are clans, moieties (division of the village into two units), feast groups, religious societies and cults (68 different ceremonial groups have been recorded), war societies, healing groups, winter and summer governments, and village governments. Details of the groups come from historical documents and contemporary ethnographies. The economic, religious, and social realms of Pueblo society are so tightly integrated it is difficult to understand them as separate elements of the society.

Long House Valley, a 180 km^2 land form in northeastern Arizona, provides a realistic archaeological test of the agent-based modelling of settlement and economic behavior among subsistence-level agricultural societies in marginal habitats. This area is well suited for such a test for a number of reasons. First, it is a topographically bounded, self-contained landscape that can be realistically reproduced on a computer. Second, a rich paleoenvironmental record, based on alluvial geomorphology, palynology, and dendroclimatology, permits the accurate quantitative reconstruction of annual fluctuations in potential agricultural production (in kg of maize per hectare)(Dean et al. 2000). Combined, these factors permit the computerized creation of a dynamic resource landscape that accurately replicates actual conditions in the valley from A.D. 200 to the present. The agents of the simulation interact with one another and with their environment on this landscape. Third, tree-ring chronology provides an annual calendrical date. Fourth, intensive archaeological research, involving a 100% survey of the area supplemented by limited excavations, creates a database on human behavior during the last 2,000 years that constitutes the real-world target for the modelling (Dean et al. 1978). Finally, historical and ethnographic reports of contemporary Pueblo groups provide data on prehistory.

Between roughly 7000 and 1000 B.C., the valley was sparsely occupied by people who depended on hunting and gathering. The introduction of maize around 2000 B.C. began the transition to a food producing economy and the beginning of the Anasazi cultural tradition, which persisted until the complete abandonment of the region around A.D. 1300. Long House Valley provides archaeological data on economic, settlement, social, and religious conditions among a localized Anasazi population. These archaeological data provide evidence of stasis, variability, and change against which the agent-based simulation of human behavior on the dynamic, artificial Long House Valley landscape can be judged.

We have tested a large number of hypotheses about the Long House Valley Anasazi (Dean et al. 2000; Axtell et al. 2002), but we will focus on only two here—the role of environment in explaining the population dynamics of settlement placement, the large population increase after A.D. 1000 and the complete abandonment of the region at A.D. 1300; the second hypothesis tests the size of simulated and actual settlements that were selected and abandoned under various environmental, demographic, and social conditions in different years.

Methods

The Artificial Anasazi Project is an agent-based modelling study based on the Sugarscape model created by Joshua M. Epstein and Robert Axtell (1996). The project was created to provide an empirical, "real world" evaluation of the principles and procedures embodied in the Sugarscape model and to explore the ways in which bottom-up, agent-based computer simulations can illuminate human behavior in a real world setting. The landscape (analogous to Epstein and Axtell's Sugarscape), is created from reconstructed environmental variables and is populated by artificial agents consisting of families or households. Agent (household) demographic and marriage characteristics and nutritional requirements were derived from ethnographic studies of historical Pueblo groups and from other subsistence agriculturists.

The simulations take place on this landscape of annual variations in potential maize production values based on empirical reconstructions of low- and high-frequency paloenvironmental variability in the study area. The production values represent as closely as possible the actual production potential of various segments of the Long House Valley environment over the period of study. On this landscape, the agents of the Artificial Anasazi model play out their lives, adapting to changes in their physical and social environments.

The first step was to enter relevant environmental data, and data on site location and size. Simulations using these landscapes vary in a number of ways. The initial population of the agents can be scattered randomly or placed where they actually existed at some initial year. The environmental parameters may be left as they were originally reconstructed or adjusted to enhance or reduce maize production. Finally, and most importantly, the rules by which the agents operate may be changed.

Households must identify both farm and residential land. Movement rules for agents are triggered when a new household is created or when a household cannot produce enough maize to maintain itself. Standard demographic tables for subsistence agriculturalists are used to determine population growth and household fissioning.

There are three sufficiency criteria for selection of farmland: 1) The site must be currently unfarmed; 2) the site must be currently uninhabited; and 3) the site must have an estimated potential maize production of 160 kg of maize per household member. There are also three sufficiency criteria for selecting residential sites: 1) The site must be within 2 km of the farmland; 2) the site must be unfarmed; and 3) the site must be less productive than the farmland site identified in the steps for selecting farmland. If more than one site meets the sufficiency criteria, the site selected is the one with closest access to domestic water.

How closely the simulations mimic the historical data provides the most obvious test of model adequacy, or the "generative sufficience" in the terminology of Epstein (1999). We must ask: Do these exceedingly simple rules for household behavior, when subjected to the parallel computation of other agents and reacting to a dynamic environment, produce the complex behavior that actually did evolve, or are more complex rules necessary? When it is free to vary, does the population trajectory follow the reconstructed curve, and does the population aggregate into villages when we know the population actually did? Does the simulated population crash at A.D. 1300, as we know it did? Do the simulated settlement sizes and population densities closely associated with hierarchy known for the area emerge through time?

The agents use simple rules to locate their residences and farm plots calculated on caloric requirements, location of potable water, and land productivity. Nutrition determines fertility and population dynamics. The simulation has 22 user-controlled variables that govern both agent interactions and interaction with the annually changing environment. While we have reconstructed annual environmental changes for each hectare for each year, the reconstructed environment for maize agriculture can be characterized as dramatically improving about A.D. 1000, suffering a deterioration in the mid 1100s, and improving until the late 1200s when there is a major environmental disruption that included the "Great Drought."

Discussion

While potentially enormously informative, agent-based simulations remain theoretical constructs unless their outcomes are independently evaluated against actual cases that involve similar entities, landscapes, and behavior. The degree of fit between the results of a simulation and comparable real-world situations allows the explanatory power of the sociocultural model encoded in the simulation's structure to be objectively assessed. Lack of fit implies that the model is in some way inadequate. Such "failures" are likely to be as informative as successes because they illuminate deficiencies of explanation and indicate potentially fruitful new research approaches. Departures of real human behavior from the expectations of a model identify potential causal variables not included in the model or specify new evidence to be sought in the archaeological record of human activities.

The most appropriate comparisons begin at A.D. 400 with the same number of households in random locations as in that year's actual historical situation, as well as the environmental situation as it has been reconstructed for each year. The simulation of household and field locations, as well as the size of each community (the number of households at each site), runs on an annual basis, operating under the movement rules on the changing resource landscape. A map of annual simulated field locations and household residence locations and sizes runs simultaneously with a map of the actual archaeological and environmental data so that the real and simulated population dynamics and residence locations can be compared (Figs. 1, 2, 3). In addition we have generated time series plots and histograms that illustrate annual simulated and actual population numbers, aggregation of population, and location and size of residences by environmental zone, and in the simulated amounts of maize stored and harvested and the number of households that fission, die out or leave the valley.

<u>Real Long House Valley</u>: Sometime after 1150, largely in response to changes in productive potential, the inhabitants began to aggregate in localities particularly suitable for farming under the changing hydrologic and climatic conditions. This change in population distribution initiated a trend toward increasing sociocultural complexity, a development drawn by problems resulting from increasing settlement size and population density. Among these problems are coordinating the activities of larger groups of people, task allocation, conflict resolution, and the accumulation, storage, control, and redistribution of critical resources such as food and water. An important outcome of this trend was the development of a settlement size hierarchy that, by A.D. 1250, involved four levels of organization: the individual habitation site, the "central pueblo," the site cluster of 5 to 20 sites, and the valley as a whole. This settlement system is evident in the concentration of sites in favorable localities with "empty" areas in between, the structured spatial and configurational relationships among sites without clusters, and line-of-sight relationships between clusters' central pueblos.

<u>Artificial Long House Valley</u>: The simulation exhibits the demographic markers of the real situation. The greatest similarity is the development of site clusters in the same localities as the actual ones (Figs.1, 2) and the replication of the location and size of the location of the site of Long House itself (Fig. 1). In the Artificial Anasazi source code proper, hierarchy is not explicitly modelled. However, in the historical record there is an extremely high correlation between hierarchy and settlement clustering. Clustering is explicitly modelled, and on this basis we guardedly infer the presence of hierarchy. Rather than producing a site size hierarchy in which the population is distributed across several kinds of settlement unit, the simulation tends to pack people into a few large sites that constitute each cluster. Given the agent rules established for the simulations, this seems a reasonable fit, and population size and distribution similarities indicate that the artificial version of the complexity trajectory is in many ways equivalent to the actual situation. Another difference is that settlement clustering and size growth begin somewhat earlier in the model than in the actual Valley. This difference likely is due to lags in response of the real Anasazi to significant environmental changes.

By A.D. 1170 (Fig. 1), population concentrations have developed in the same localities in both the real and simulated valleys. In both cases a large unoccupied area has appeared in the middle of the valley, and site density is much reduced along the eastern margin of the valley floor. Large sites in the simulation are equivalent to groups of small sites in the real world. Early in the process, neither system exhibits a hierarchical settlement structure. By A.D. 1270 (Fig. 2), the actual Long House Valley was the locus of the fully developed settlement hierarchy. This development is evident in the spatial association of sites of different size (see legend) on the left image. The simulation (right image) shows less site size differentiation than the real valley, with most of the population packed into large sites. Nevertheless, some differentiation is evident along the northwestern margin of the valley. In addition, the simulation accurately captures the concentration of sites in the northern part of the valley, the clustering of sites, and the location and size of the largest actual site in the valley, Long House. All evidence suggests that by A.D. 1305, the real Anasazi (Fig. 3, left) had abandoned the valley. The Artificial Anasazi (right), however, survived by spreading out across the part of the valley that remained productive even under the worsened environmental circumstances of the post-1300 period. This difference accurately reflects the fact that the real Anasazi could have stayed on by altering farming the northern valley floor and dispersing into medium sizes communities.

Conclusion

In summary, agent-based models are laboratories where competing hypotheses and explanations about Anasazi behavior can be tested and judged in a disciplined, empirical way. The simple agents posited here explain important aspects of Anasazi history while leaving other important aspects unaccounted for. Site distribution and density are well approximated by the agent-based simulations. Countless simulations have been run and the results we report here are quite robust. The hierarchical structure identified in the archaeological context can be more closely approximated with some logical modifications to the settlement rules in the simulations. The explicit modelling of hierarchical social structures is a planned topic of future model development. The departure between real Anasazi and Artificial Anasazi in the final period of settlement is a fascinating challenge. The pattern of abandonment is observed in many regions of the prehistoric Anasazi at approximately this same time

With agent based modelling we can systematically alter the quantitative parameters or make qualitative changes that introduce completely new, and even unlikely elements into the artificial world of the simulation. In terms of the Artificial Anasazi model, we can experiment with agent attributes, such as fecundity or food consumption, and we can introduce new elements, such as mobile raiders, environmental catastrophes, or epidemics. Actual environmental constraints might have been the trigger to induce many of the Anasazi to abandon the region, however, social or ideological factors were responsible for the complete abandonment of the valley. Demographic and epidemiological models may be utilized to derive additional parameters for the agent-based modelling. We have also considered synergies among variables in the real context that we have not yet experimented with in the modelling efforts. In this analysis, using this “bottom up” approach to modelling prehistoric settlement behaviors, we have greatly improved our understanding of the underlying processes involved in the population dynamics.

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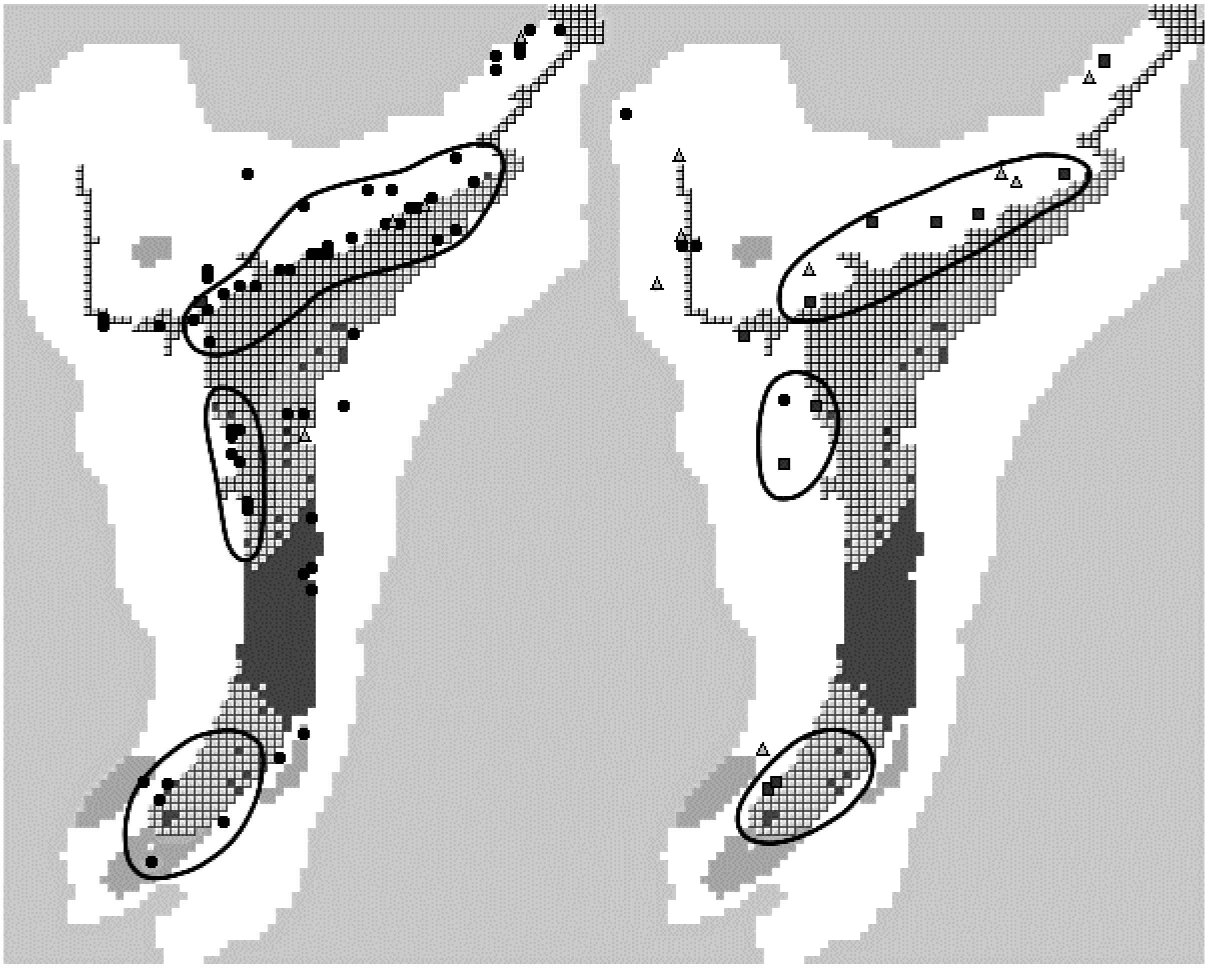

Figure 1. Simulated population distribution on the reconstructed environment on the right, the actual situation on the left in A.D. 1170. Hatching on both sides is the simulated land under cultivation. Grey represents the depth of the water table. Darker grey represents higher water table, lighter grey represents lower water table. White is unfarmable. Dots, triangles, and squares represent settlements. Dots = settlements of 5 households or less. Triangles = 6 to 20 households. Squares = 21 and higher. Settlements tend to be clustered in the same places, but simulated settlements are more aggregated. The largest settlement in both simulated and actual situations is within 100 meters of each other – the square on the upper arm of the narrow canyon on the left. This is the actual site of Long House after which the valley was named.

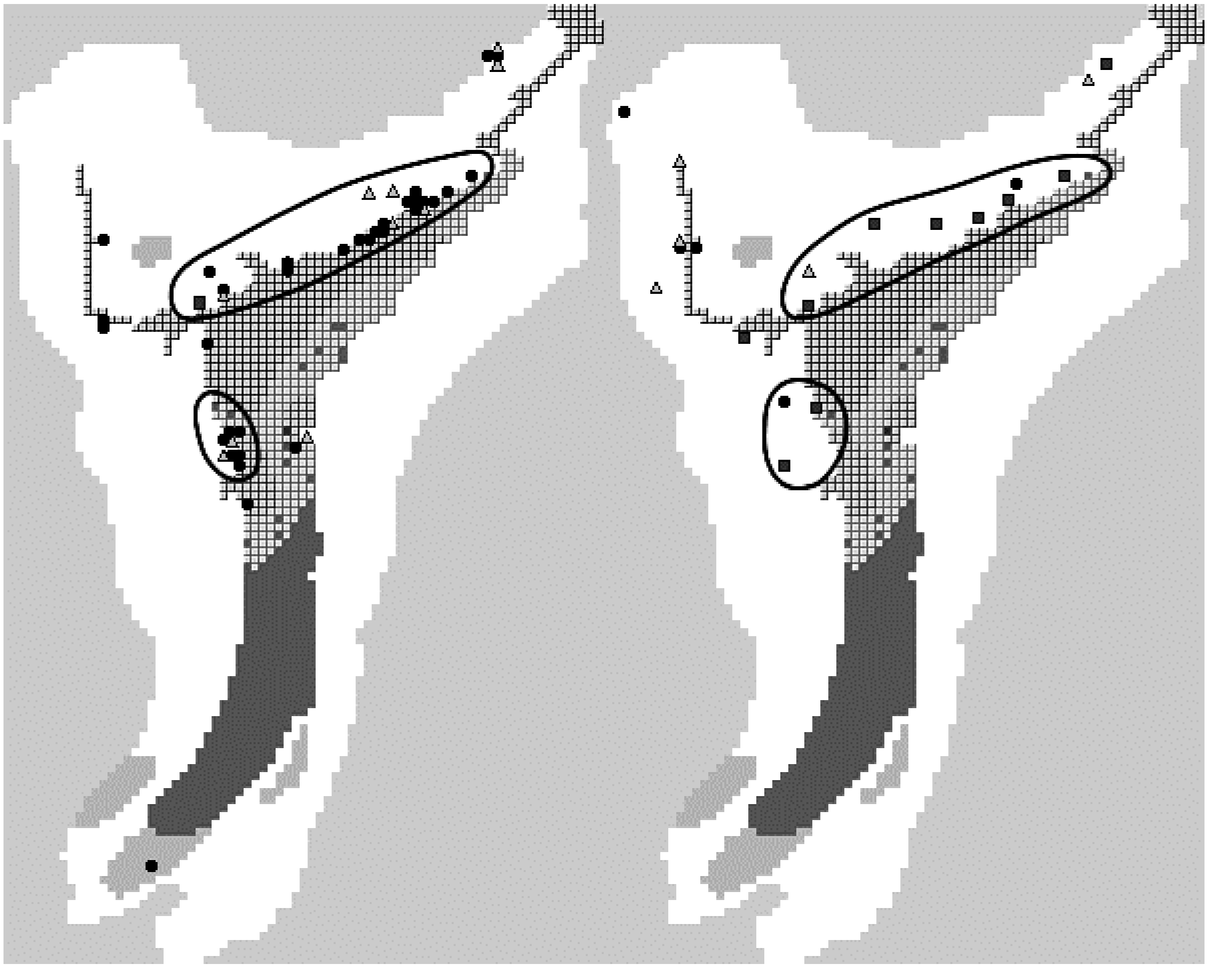

Figure 2. Simulated population distribution on the reconstructed environment on the right, the actual situation on the left in A.D. 1270. In both cases the population has begun to move out of the southern part of the valley because of erosion and a drop in the water table.

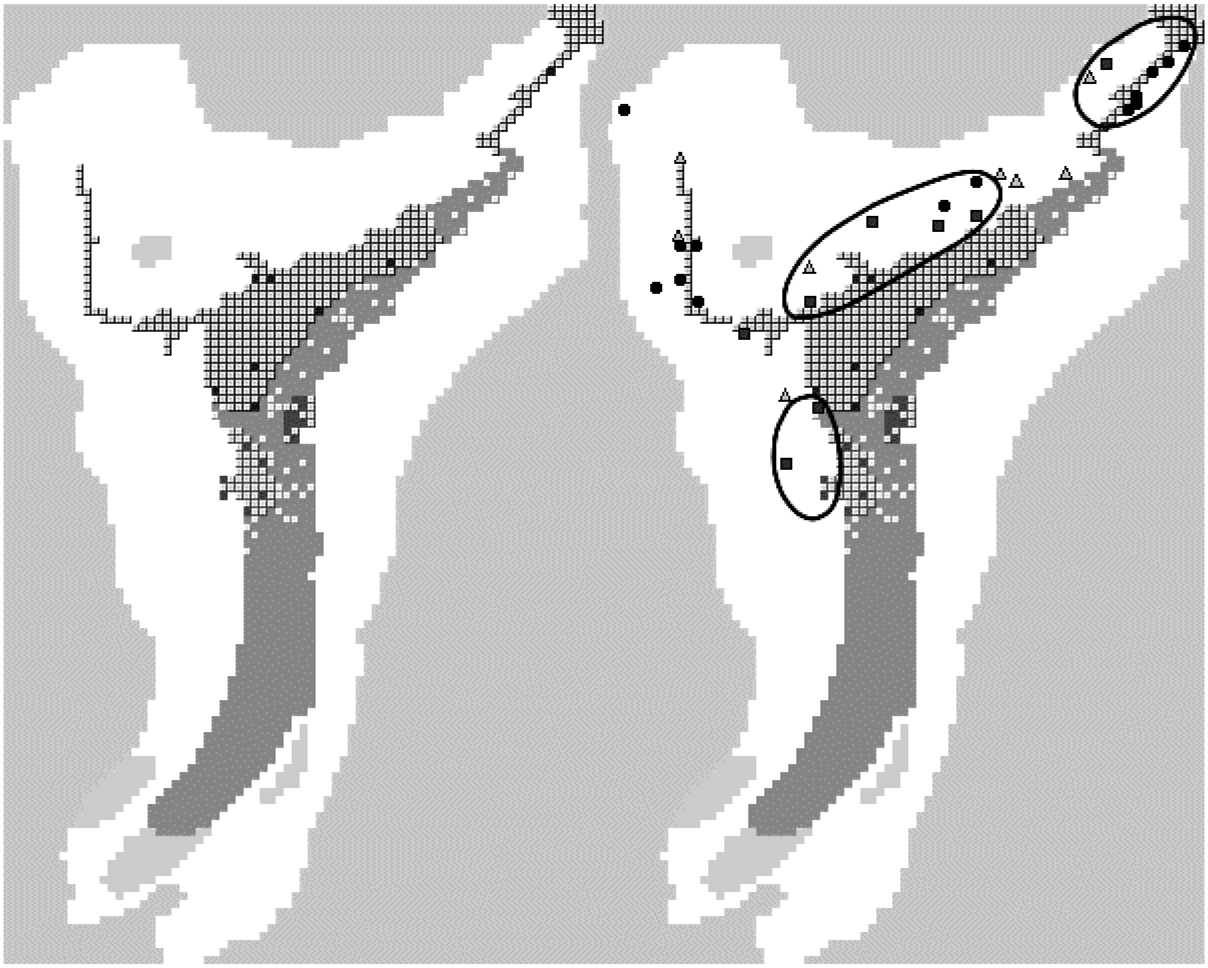

Figure 3. Simulated population distribution on the reconstructed environment on the right, the actual situation on the left in A.D. 1305. The actual population has abandoned the valley, but there are still settlements in the simulated version.

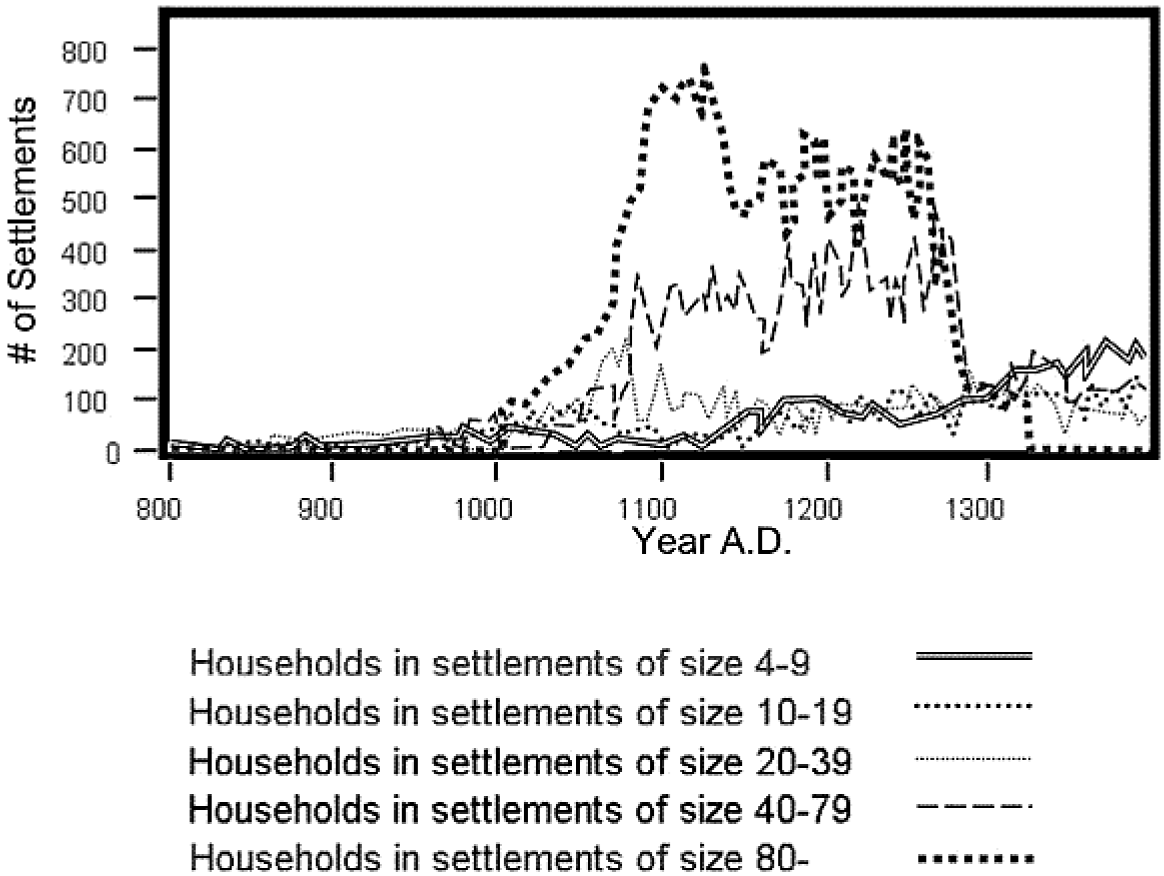

Figure 4. Changes in simulated settlement size. Large settlements (>80 + households) develop rapidly after A.D. 1050, fluctuate in size for 200 years and disappear abruptly after A.D. 1300.In sharp contrast, the number of smaller sites (4 to 9 households tend to increase gradually until after A.D. 1300 when their numbers increase. These relationships show some of the Anasazi could have remained in the valley had they dispersed to occupy favourable locations in the north (Fig. 3) and abandoned their large settlements for smaller dispersed ones.