The Evolution of Social Behavior in the Prehistoric American Southwest

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Abstract 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 rich paleoenvironmental record, based on alluvial geomorphology, palynology, and dendroclimatology, permits the accurate quantitative reconstruction of annual fluctuations in potential agricultural production (kg maize/hectare). The archaeological record of Anasazi farming groups from A.D. 200 to 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 and where to locate their settlements.

Keywords
Agent-based modeling, Anasazi, prehistory, American Southwest, environmental reconstruction, cultural evolution

1 Introduction

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 problems is the use of whole societies as the unit of analysis. Group-level effects, however, 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 [8]. Among the advantages of such base-level approaches is that they allow specific modeling of peoples' behavioral ranges and norms and their adaptive strategies as community size and structure change.

Second, in addition to subsuming the behavior of individuals within that of larger social units, traditional analyses integrate environmental variability over space. Current

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research indicates that stable strategies for interpersonal interactions in a heterogeneous, spatially extended population may be very different from those in a homogeneous population in which space is ignored [11]. 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 to be homogeneous, tending toward maximization of fitness for their members. Little consideration was given to historical processes in shaping evolutionary trajectories or to nonadaptive 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 [2, 3]. 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 modeling to test the fit between actual archaeological and environmental data collected over many years and simulations 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.

2 The Study Area

The test area for exploring the use of agent-based modeling 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, the Zuni, the Acoma, and the groups along the Rio Grande in New Mexico. A commonly held view is that technological, social, and linguistic complexity coevolve. Anasazi cultural development underscores the interdependence of these aspects of culture. The Anasazi were a technologically simple agricultural society whose major food source was maize supplemented by beans, squash, wild plants, and game. In the A.D. 200 to 1450 period the only major technological changes that are archaeologically verifiable are agricultural intensification (terracing and ditch irrigation) and the introduction of a more efficient system for grinding maize. During this time, however, there is evidence of greatly increased social complexity. Contemporary Pueblo people have complicated social systems made up of sodalities (distinct social associations) including 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 landform in northeastern Arizona, provides a realistic archaeological test of the agent-based modeling 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 kilograms of maize per hectare [6]. 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 annual calendric dating. 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 modeling [7]. Finally, historical and ethnographic reports of contemporary Pueblo groups provide anthropological analogs for prehistoric human behavior.

Between roughly 7000 and 1800 B.C., the valley was sparsely occupied by people who depended on hunting and gathering. The introduction of maize around 1800 B.C. began the transition to a food-producing economy and the beginning of the Anasazi cultural tradition, which persisted until the 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 [6, 1], but we focus on only two issues here: (1) 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 around A.D. 1300; and (2) the size of simulated and actual settlements that were selected and abandoned under various environmental, demographic, and social conditions in different years.

3 Methods

The Artificial Anasazi Project is an agent-based modeling study based on the Sugarscape model created by Joshua M. Epstein and Robert Axtell [10]. 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 Sugarscape) is created from reconstructed environmental variables and is populated by artificial agents—in this case households, the basic social unit of local Anasazi society. Agent demographic and marriage characteristics and nutritional requirements are derived from ethnographic studies of historical Pueblo groups and 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 paleoenvironmental 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. In general, 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 involving the Great Drought (1276–1299), falling alluvial water table levels, severe floodplain erosion, and changes in the seasonal patterning of precipitation [5]. 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 real site location and size. Simulations using these landscapes vary in a number of ways. The initial population of agents (households) can be scattered randomly or placed where they actually existed at some initial year. The simulations reported here were begun with the number of agents (households) actually present in the valley during the initial year with the households distributed randomly across the artificial landscape. 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. The simulation has 22 user-controlled variables that govern both agent interactions and interaction with the annually changing environment.

Agent (household) behavior on the production landscape is governed by agent attributes and a set of simple rules entrained sequentially. Standard demographic tables for subsistence agriculturalists are used to determine nutritional requirements, marriage ages and reproduction rates, and household fissioning and longevity. A household (agent) consists of five individuals, two parents and three children, each with nutritional requirements that are represented in the model by 160 kg of maize per person per year for a total requirement of 800 kg of maize per household per year. Because ethnographic data indicate that modern Puebloans try to keep at least two years' worth of corn on hand, our agents attempt to have at least two years' supply (1600 kg) in storage after the harvest in September. An internal clock tracks the amount of maize each household has in storage. This quantity is diminished each month by the amount consumed by the household and is replenished once a year by the amount harvested at the end of the growing season. The amount harvested equals the reconstructed potential production of the household's farmland minus a variable percentage that reflects fallowing, insect damage, and reservation of seed corn. Every April, each household assesses the status of its food supply, adding what it expects to have in storage by harvest time to the predicted yield of its farmplot for the coming growing season based on the previous year's production. If the expected stored amount plus the predicted yield exceeds 1600 kg, the household decides to maintain its current fields and stay where it is. If the sum is less than 1600 kg, the household decides to move to a more productive location where sufficient yield can be expected.

Movement rules for agents are triggered when a new household is created by the marriage of a resident female or when a household determines in April that the amount of stored maize plus the predicted maize production of its current farmplot cannot sustain it for the coming year. Once a household decides to move to a more productive location, it employs three sufficiency criteria for selecting new farmland: (1) the plot must be currently unfarmed; (2) the plot must be currently uninhabited; and (3) the plot must have a minimum 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 farmplot; (2) the site must be unfarmed; and (3) the site must be less productive than the selected farmplot. If more than one site meets the sufficiency criteria, the site selected is the one with closest access to domestic water. The fact that potential residential locations need not be unoccupied allows the development of multihousehold settlements.

How closely the simulations mimic the historical data provides the most obvious test of model adequacy, or "generative sufficiency" in the terminology of Epstein [9]. 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?

4 Results and 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 between the model and the real world begin at A.D. 400 with the same number of randomly located simulated households 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 (Figures 1, 2, 3). In addition, time series plots and histograms illustrate annual variation in simulated and actual population numbers, aggregation of population, location and size of residences by environmental zone, simulated amounts of maize stored and harvested, and the number of households that fission, die out, or leave the valley.

- *Real Long House Valley*: Around 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 driven 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 domestic water. An important outcome of this trend was the development of a settlement 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 habitation sites focused on a central pueblo, 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 within clusters, and line-of-sight relationships between the clusters' central pueblos.

- *Artificial Long House Valley*: 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 (Figures 1, 2) and the replication of the location and size of the site of Long House itself (Figure 2). In the Artificial Anasazi source code, hierarchy of any kind is not explicitly modeled. However, in the historical record there is an extremely high correlation between organizational hierarchy and settlement clustering. Clustering does emerge from the model, and on this basis we guardedly infer the presence of hierarchy. Rather than producing a site organizational hierarchy in which the population is distributed across several kinds of

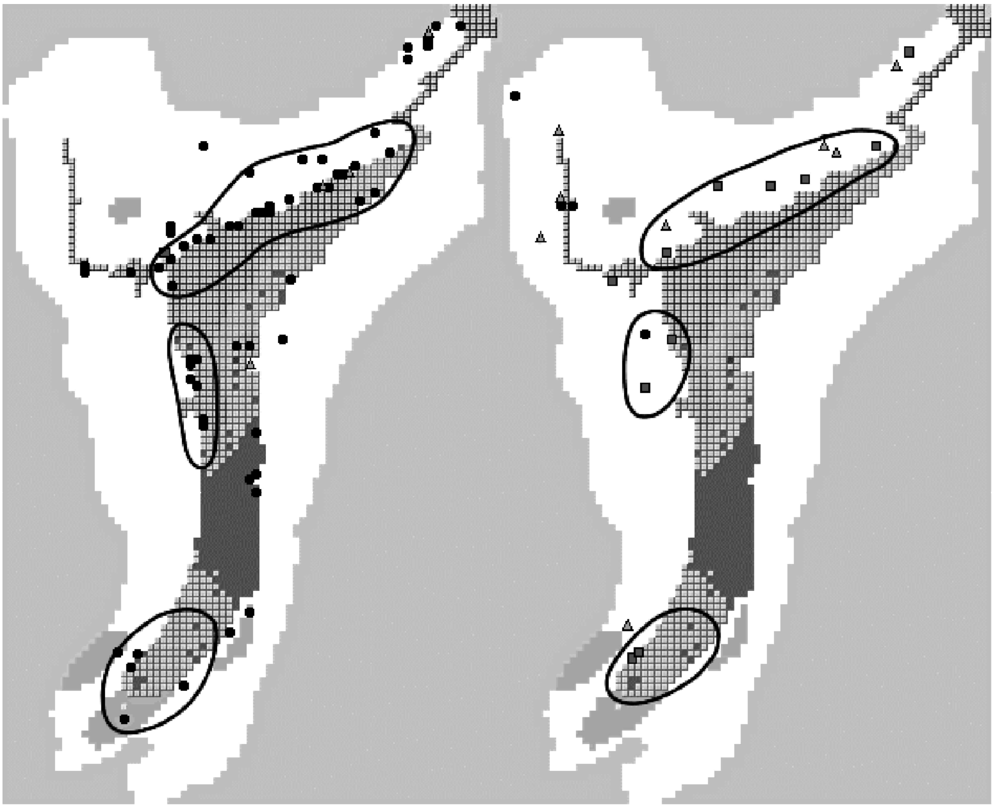

Figure 1. Simulated population distribution on the reconstructed environment (right) and the actual situation (left) in A.D. 1170. Hatching on both sides is the simulated land under cultivation. Gray represents the depth of the water table. Darker gray represents higher water table, lighter gray represents lower water table. White is unfarmable. Dots, triangles, and squares represent settlements. Dots = 5 or fewer households. Triangles = 6 to 20. Squares = 21 or more. Settlements tend to be clustered in the same places, but simulated settlements are more aggregated. The positions of the largest settlements in the simulated and actual situations are within 100 m of one another—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.

settlement unit, the simulation tends to pack people into a few large sites that correspond to each real site cluster (Figure 2). Given the agent rules, 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. As shown by the smaller sites and more scattered settlements in the real valley at A.D. 1100 (Figure 1), settlement clustering and size growth begin somewhat earlier in the model than in the actual valley. This difference likely is due to lags in the response of the real Anasazi to significant environmental changes.

By A.D. 1170 (Figure 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. Also in both cases, the settlement distributions result from combinations of three environmental factors: (1) the valley floor, which is subject to alluvial deposition and erosion and is therefore a poor place to establish residences; (2) arable land near which settlements can be located; and (3) domestic water resources

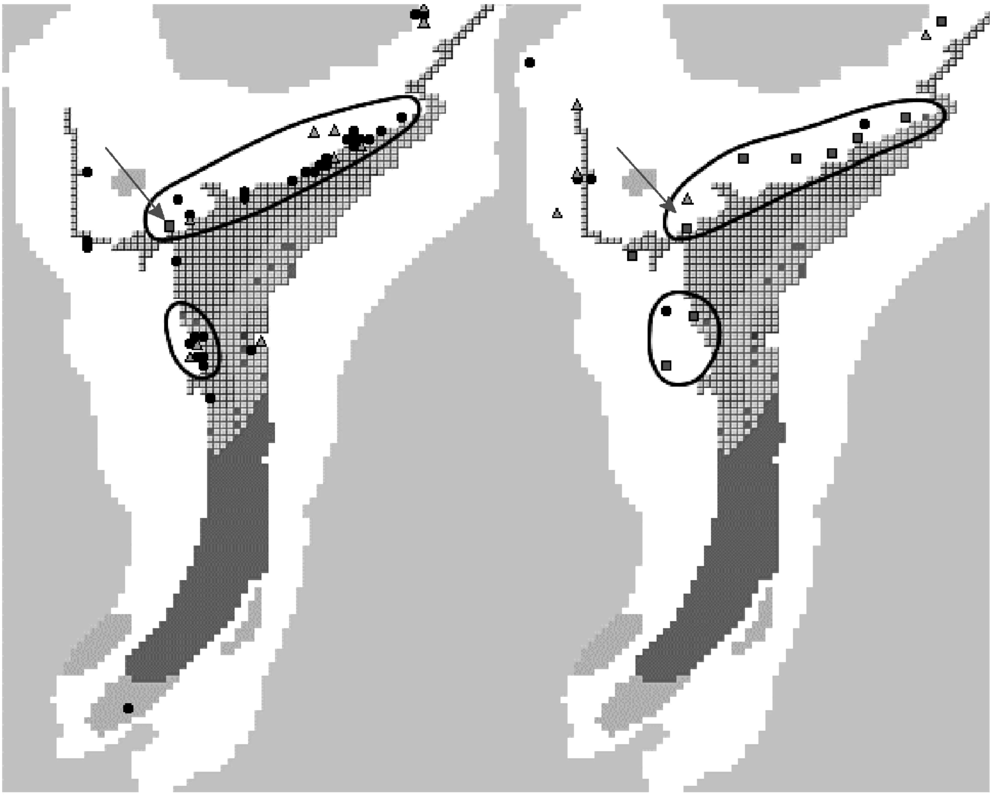

Figure 2. Simulated population distribution on the reconstructed environment (right) and the actual situation (left) in A.D. 1270. Symbols are the same as in Figure 1. In both cases the population has begun to move out of the southern part of the valley because of erosion and a drop in the water table.

that were concentrated along the northwestern margin of the valley floor between A.D. 1130 and 1180 and after A.D. 1250. 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 (Figure 2), the actual Long House Valley was the locus of the fully developed settlement organizational 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.

Comparing the simulated (Figure 4) and real time trajectories of site sizes generates some provocative inferences. The number of simulated sites with more than 39 households peaks around A.D. 1100, remains high for nearly two centuries, and drops precipitously at the end of the 13th century, with the largest sites disappearing shortly after A.D. 1300. In contrast, simulated sites with fewer than 40 households maintain a fairly stable profile and increase in number after the late 13th-century population crash and demise of the large settlements. While the rapid decline of the large sites mirrors the Anasazi abandonment of the real valley around A.D. 1300, the persistence of small to medium sites in the simulation contrasts sharply with the abandonment of all real sites at that time.

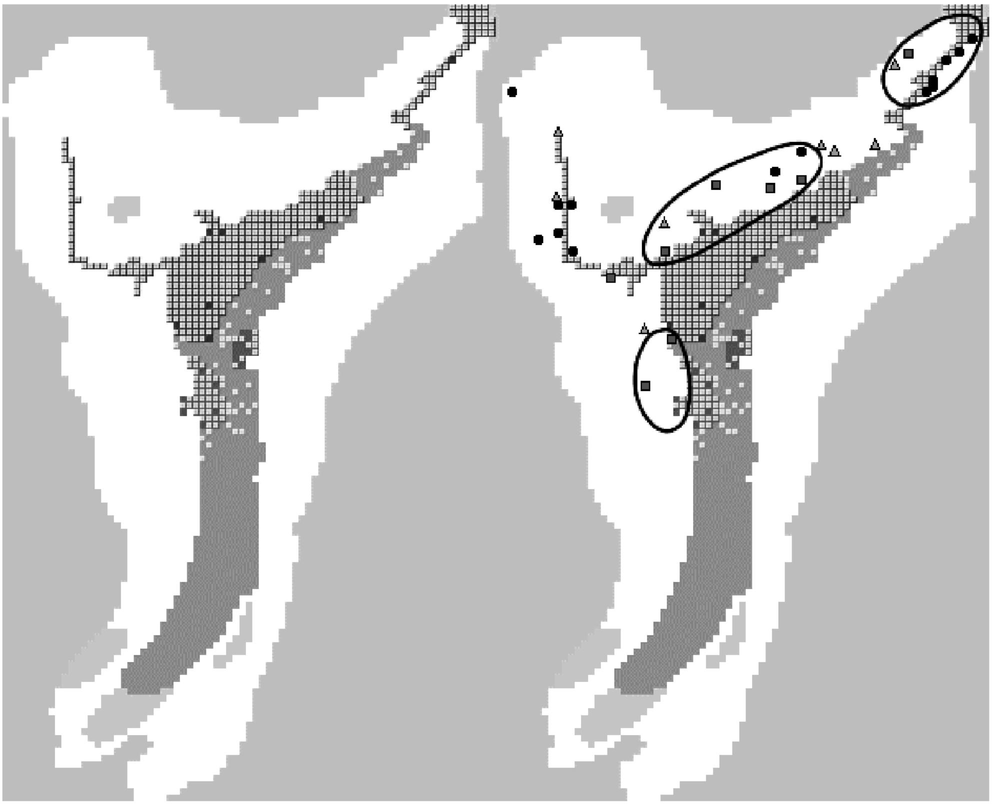

Figure 3. Simulated population distribution on the reconstructed environment (right) the actual situation (left) in A.D. 1305. Symbols are the same as in Fig. 1. The actual population has abandoned the valley, but there are still settlements in the simulated version.

The different responses by the simulated and real Anasazi to the environmental crisis of the late 13th century have important explanatory implications. It has long been clear [4] that even the seriously degraded post-A.D. 1275 environment of the valley could have supported a certain number of people and that the deleterious environmental conditions would not have forced all the Anasazi to depart. A smaller population could have sustained itself by abandoning large settlements and dispersing into smaller communities situated near the few locations that remained agriculturally productive. The Artificial Anasazi do precisely that, the reduced population shifting from large, aggregated communities into smaller settlements (Figure 4) scattered across the northern part of the valley where isolated pockets of farmable land still exist (Figure 3). That the real Anasazi employed a different option indicates that environmental degradation was not responsible for the complete abandonment of the valley and that other, undoubtedly social, factors were involved in the final emigration. That these social factors included the unwillingness or inability to forsake the relatively high level of social complexity embedded in the hierarchical settlement system of the late 13th century for a simpler, disaggregated social system is supported by the ready dispersion of the Artificial Anasazi, who, driven primarily by environmental constraints, lacked such cultural inhibitions.

All the evidence indicates that by A.D. 1305, the real Anasazi (Figure 3, left) had abandoned the valley. The Artificial Anasazi (Figure 3, right), however, survived by spreading out across the part of the valley that remained productive even under the

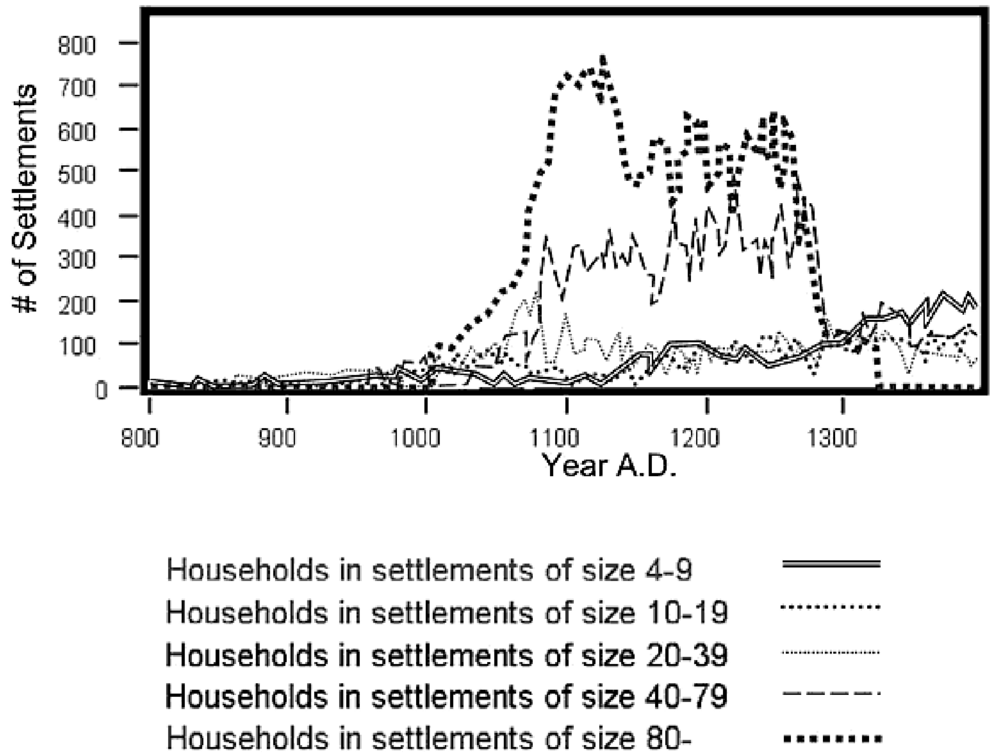

Figure 4. Changes in simulated settlement size. Large settlements ($\geq$ 80 households) develop rapidly after A.D. 1050, fluctuate in size for 200 years, and disappear abruptly after A.D. 1300. In sharp contrast, the number of smaller sites (4 to 9 households) tends to increase gradually until after A.D. 1300, when it increases more rapidly.

worsened environmental circumstances of the post-1300 period. This difference accurately reflects the fact that the real Anasazi could have stayed on by farming the northern valley floor and dispersing into medium-size communities [4]. The environmentally unnecessary total abandonment of the real valley undoubtedly reflects the pull of social factors drawing people to the distant communities established by previous emigrants from Long House Valley. Elements of this social attraction would have included maintaining a large enough pool of potential marriage partners, fulfilling ceremonial and social obligations to their former neighbors, and retaining achieved levels of sociocultural complexity.

5 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 modeling 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 modeling, 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 modeling. We have also considered synergies among variables in the real context that we have not yet experimented with in the modeling efforts. In this analysis, using this bottom-up approach to modeling prehistoric settlement behaviors, we have greatly improved our understanding of the underlying processes involved in the population dynamics.

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