7 Stories of the Past or Science of the Future? Archaeology and Computational Social Science

Michael Barton

Since it emerged as a formal field of study from 18th- and 19th-century antiquarianism, archaeology has focused on the past, a fact explicitly recognized in the Greek neologism adopted for its name. From its inception, archaeology has had as its primary goal the systematic (and, to many, scientific) reconstruction of past societies; that is, the most common outcome of archaeological practice has long been the construction of narratives that recount in history-like fashion some aspect of past human lives and societies. Within the past half-century, this basic aim has been expanded to encompass explanations why people and societies in these archaeological reconstructions acted and changed in the way they did—although debate continues within archaeology as to the relative importance of reconstruction (or history) and explanation and about what constitutes adequate explanation (Barton and Clark, 1997; Dunnell, 1982; Hegmon, 2003; Killick, 2004; Pauketat and Alt, 2005; Wylie, 1992, 2000). With ongoing advances in methods for data collection and analysis, archaeologists endeavor to create and explain narratives of the past with increasing detail, accuracy, and insight. But regardless of the methods used or the relative emphasis on historical accounts or explanation, the reconstruction of the past still underlies all modern archaeology.

Taking an approach that utilizes multiple lines of convergent evidence from increasingly sophisticated analytical protocols (Killick, 2004; Wylie, 2000)

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has been successful in reconstructing the manufacturing processes and uses of a variety of ancient material culture, as well as physical aspects of resource processing and consumption. However, conceptual issues still can make such reconstructions problematic, especially for nearly extinct technologies such as chipped stone that fall beyond the everyday experience of archaeologists (Barton, 1991, 1997; Bleed, 2001). Moreover, when we attempt to extend reconstructions beyond resource use, and the production and physical use of material culture to those issues of individual and social dynamics across space and time—the issues that most interest most archaeologists and the larger public—we encounter increasingly insurmountable problems with the archaeological record.

A major tenet of the "new archaeology" of the mid-20th century (and one that was more fundamental to its original call for a revolution in the field than the "processual" approach that involved the attempt to make the field more scientific through the discovery of general laws of human behavior) was its exhortation to make people rather than artifacts the primary subject of archaeological inquiry (Binford, 1962). That is, archaeology should be a sort of ethnography of the past, a perspective that is largely implicit in much of the Anglo-American archaeological literature today. Yet much of the dynamics of society occur as interactions between individuals, as webs of meaning (Geertz, 1973) that leave no material traces. Even with participant observation that is a hallmark of anthropological methods, anthropologists have long wrestled with the difficulties of interpreting the meanings of behaviors or even the sense of identity in societies with very different cultural knowledge and histories (Abu-Lugbod, 1991; Geertz, 1973; Keesing, 1974; Taylor, 1971). For prehistoric societies, a goal of interpreting such interactions and their meanings "place archaeologists in the role of ethnographers of a lost 'ethnographic present,' struggling hopelessly to overcome the problems posed by the fact that the people they would like to talk to are long dead and most of the residues of their lives long decayed" (Shennan, 2002: 9).

The standard archaeological response to this dilemma has been to refer to the rich world of material culture. Indeed, the new archaeology introduced the idea that artifacts not only provide information about technological behaviors but can also serve as a proxy for ethnographic observation (Longacre, 1964). Certainly, material culture is deeply entwined with human social life and can even serve as an active agent of social reproduction (Hegmon, 1998; Newton, 1981; Pauketat and Alt, 2005). Although some of the social significance of material culture cannot be known without conversation with the users (Killick, 2004), the spatial arrangements of material objects can sometimes provide clues to the social contexts in which they were embedded. Unfortunately, the spatial organization of material culture when it was an active participant in human society is not usually preserved when it enters the archaeological record, most commonly as trash (Barton et al., 2002; Schiffer, 1983). Moreover, most of the material record originally produced by human social practices has long since been lost to natural and cultural formation processes. Of that small part that remains, the great majority is undiscovered or inaccessible, or cannot be recovered owing to time and money constraints. Excavations represent a very tiny window on a mostly missing record. Archaeologists do a truly amazing job at recovering and analyzing the data available from the archaeological record. However, they cannot analyze a record that they cannot recover or that no longer exits.

So how then can we reconstruct past human lives and societies in reasonably complete detail across space and time, so as to trace and explain the dynamics of human society when our informants cannot speak to us, when most of the objects they made and used are gone, while those that remain are jumbled into palimpsests of trash, and we have resources to recover a only tiny fraction of those? I fear the answer is that we cannot. Certainly, we can say that each and every artifact that we find was produced by a once living individual or a group of individuals working together, but this is an intellectually trivial insight. And when multiple lines of evidence converge, we can even infer with reasonable confidence the nature of a particular event that took place at a particular place and time. But beyond this, the archaeological record is absent, and our reconstructions are simply speculations—careful, statistically informed in some cases and imaginatively subjective in others, but reconstructions remain speculative narratives in all cases.

Perhaps others may be more confident in their ability to accurately imagine the past or perhaps they don't mind that their stories of the past are a sort of historical fiction. But these very real constraints of the archaeological record on our ability to reconstruct the past have concerned me increasingly over the course of my professional career. At the same time, I have become increasingly convinced that the human past is essential to understanding human society today and planning for our long-term future (Barton et al., 2004; Barton, Ullah, and Mitasova, 2010; Fisher, Hill, and Feinman, 2009; Redman and Kinzig, 2003; van der Leeuw, 2000; van der Leeuw and Redman, 2002). Fictional narratives will not be helpful in such an endeavor, no matter how compelling. The importance of the past to present and future makes it all the more imperative that we find new ways to make more effective use of the incomplete, discontinuous, and highly altered archaeological record in order to provide reliable insights into the long-term dynamics of human society and the interactions between the social and natural worlds. This has led me to explore alternative ways of collecting and analyzing archaeological data and ultimately to an evolving perspective on the practice of archaeology.

Over the last two decades a variety of new digital technologies, which I will gloss here under the phrase *computational modeling*, have become available that offer a new way to allow archaeology to move forward in producing valuable insights from the human past and that can be applied broadly to the understanding of human social dynamics in spite of the limitations of the archaeological record. I illustrate some of the potentials and limitations of computational modeling with examples from my research over the past decade. But although these new technologies may offer a way to create more systematic and transparent reconstructions of the past, these reconstructions are not necessarily any more accurate than traditional narratives and still cannot replace the lack of data that characterizes the archaeological record. What computational modeling does hold a promise to do, however, is provide archaeologists with the tools to better understand and explain the spatial-temporal dynamics of human societies, with important benefits to archaeology and to social science more broadly. Before reviewing how I have used models in archaeological research, I briefly review the ways in which models are widely used in archaeology today.

Models in Archaeology

A model is an abstract representation of real-world phenomena. Models are inherent in the way we make sense of our world in our everyday lives and are equally important in scientific practice. Models in science are commonly created to simplify very complex reality so that we can better identify and comprehend critical relationships among entities and key processes that drive the operation of real-world systems. Models are generally evaluated in science by their ability to account for a constrained set of relevant empirical observations. Especially since changing their focus from describing artifacts to describing and explaining human societies, models have become pervasive in archaeology. In the great majority of cases, these models take the form of narrative prose that may or may not be supported by statistics or graphs. Narratives are a format that we find intuitively easy to understand; they can help us to mentally envision humans of the past and the world these people inhabited. However, narratives are can be difficult to evaluate scientifically in a systematic and convincing manner, because they can employ inherently ambiguous natural language.

It is significant that archaeological models (and particularly narrative models) are usually constructed inductively from empirical data, rather than deduced from theory. In fact, the more empirical data that is used to create these inductive models, the more convincing they seem to be to most archaeologists and to many others who read their accounts. Such archaeological inference is found throughout the literature and by far dominates the process of model-building. As noted previously, when based on the convergence of multiple and distinct lines of evidence, such inference can provide robust knowledge about past physical events and the manufacture or use of artifacts (Wylie, 2000).

However, the inferential approach to model-building also creates models that are difficult to test in an effective and convincing way. An obvious issue is that the data used to create a model cannot also be used as an independent test of the model. This leaves much explanation in archaeology epistemologically equivalent to the interpretive approaches, or hermeneutics, of the humanities. As Taylor (1971) explains in his classic paper: "A successful interpretation is one which makes clear the meaning originally present in a confused, fragmentary, cloudy form. But how does one know that this interpretation is correct? Presumably because it makes sense of the original text: what is strange, mystifying, puzzling, and contradictory is no longer so, is accounted for." This is equivalent to saying that the measure of a good model is that it can sensibly account for the empirical data. Although this statement may seem perfectly reasonable to many archaeologists—and certainly to the general public—a difficulty of this approach is how we define "sensibly" and how we can compare two models that both account for available data in a way that is sensible to different adherents.

Such epistemological issues are exacerbated by problems of "equifinality" that arise when inferential models are generated from the limited archaeological record. In spite of the seeming vast quantity of artifacts (mostly broken pottery and chipped stone) that fill museums and repositories, the archaeological record is so sparse temporally and spatially, relative to the kinds of processes described in many narratives, that multiple, quite different models can be (and often are) constructed to account for the same data—as I illustrate below. An interpretive approach, inherent in inferential model-building, has no mechanism to evaluate which of alternative competing models is better—or even a way to systematically define what "better" means. This situation can lock archaeological explanation into what Taylor calls the "hermeneutical circle," in which the ultimate recourse for convincing others of the superiority of one inductive model over another is to assert the scholarly "authority" of the model author (see Clifford, 1983).

I do not mean to imply that induction or inference has no role in science. Careful analysis of large, rich data sets commonly offers important insights into dynamic processes and relationships. Moreover, induction can be important in generating provisional models—that is, hypotheses—although in most sciences, theory plays an equally or even more important role. It is significant that models are constructed in other scientific fields so as to predict data that have not yet been collected rather than to account for observations already made. And models are then evaluated on their ability to predict empirical phenomena (Dunnell, 1982; van der Leeuw, 2004). However, archaeology is seriously under-theorized, and, consequently, this kind of interplay between induction and testing is little practiced, in spite of it being part of the proscriptive literature for decades. It is also worth noting that the kind of robust archaeological inference based on triangulating multiple lines of evidence derived from different scientific disciplines is most successful when the evidence derives from fields with a robust tradition of hypothesis testing (for example, Wylie, 2000: 232–33).

These pragmatic issues inherent in inferential model-building may not be problematic to those who are content with an archaeology whose primary goal is the creation of plausible reconstructions about an unknowable past. However, if insights about the human past are to play a meaningful role in understanding human society today and inform policy decisions for the future, narrative fictions are an insufficient for such contributions, no matter how plausible. This suggests that archaeology needs alternatives to inferential narratives for creating and evaluating models about human social practice. Moreover, as discussed shortly, it also suggests that although reconstruction of past societies will remain an important activity of archaeologists, we can realistically aspire to more ambitious goals.

In the next sections I draw on examples from my research to illustrate the transition from an archaeology focused on inferring stories of the past to one that seeks to test transparent models of the dynamics of human societies.

Example 1: Long-Term Land-Use in Eastern Spain

The landscapes of Mediterranean Europe have been occupied and reoccupied by hunter-gatherers at least since the Middle Pleistocene, by subsistence farmers since the early Holocene, and by urban empire-builders for over three millennia. These inhabitants have strewn the surface with lithic debris, sherds of broken vessels, and fragments of building materials. This artifactual palimpsest has been plowed, eroded and redeposited, piled into terraces and other structures, and modified physically and chemically. Consequently, most Mediterranean archaeologists focus their research efforts on carefully excavating in those rare prehistoric towns, farmsteads, and caves that have somehow escaped the normal alterations of subsequent human activities.

Beginning over two decades ago, colleagues from the University of Valencia (Spain) and I began a project to systematically collect and analyze the palimpsest of archaeological data scattered across the landscapes of eastern Spain (Figure 7.1).[1] Using a patch-based survey methodology, we systematically recorded information across broad swaths of a series of upland valleys, rather than seeking to locate "sites." We augmented the intensive survey data with information from coring, geophysical prospection, and hand excavation (Barton et al., 1999; Barton et al., 2002; Barton et al., 2004; Bernabeu Aubán et al., 1989; Bernabeu Aubán et al., 1999; Bernabeu Aubán et al., 2000; Bernabeu Aubán et al., 2006; García Puchol, Barton, and Bernabeu Aubán, 2008). This work has involved innovative statistical and GIS-based analyses to "unmix" the altered palimpsests that constitute much of the archaeological record of the Mediterranean region. The result has been a more comprehensive, empirically grounded view of human land-use and its changes through time than is afforded by more normal site-based studies in this region.

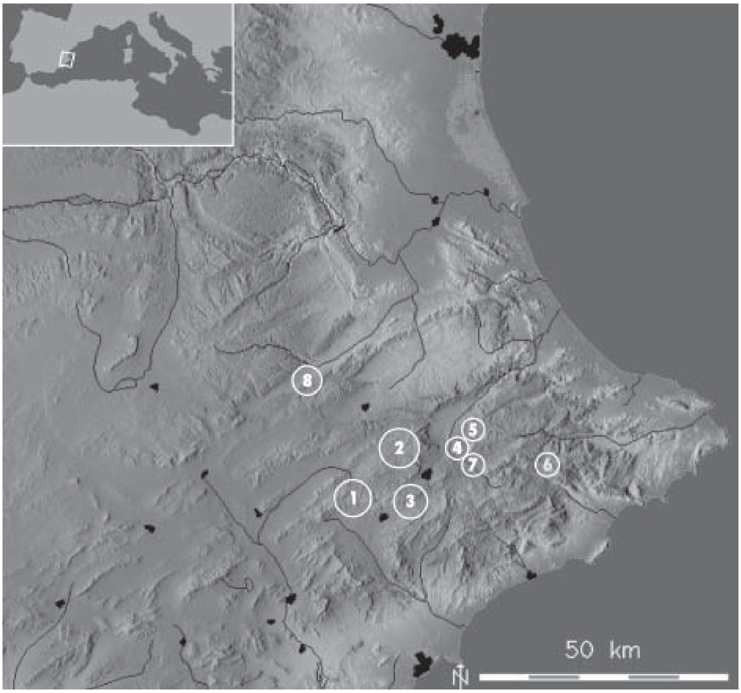

Figure 7.1 Locations of Alicante Prehistoric Ecology and Land-Use project in northern Alicante Province, Spain: (1) Polop Alto Valley, (2) Middle Serpis Valley, (3) Penaguila Valley, (4) Alcalá Valley, (5) Gallinera Valley, (6) Gorgos Valley, (7) upper Ceta Valley,(8) Canyoles Valley.

We recognized at the outset of this research that millennia of artifactual accumulation, interspersed with human and natural formation processes of varying severity, made it impossible to accurately reconstruct the settlement system of any particular social group at any particular time. Rather, we interpreted our results as models of cumulative socioecological landscapes produced by varying patterns of land-use and social organization (Barton et al., 1999; Barton et al., 2002). This approach allowed us to create a narrative of past human occupation of this region in terms of land-use intensity, clustering and dispersion, and persistence and to compare human action at regional scales in different valleys across time (Barton et al., 2004a; Barton et al., 2004b).

Models of changing spatial configurations of land-use intensity for the Polop Alto Valley for the past 100,000 years are shown in color Figure I.1. Our approach involves a systematic and replicable way to combine spatially and temporally dispersed archaeological data into comprehensive and comparable geospatial models of human land-use. This is more transparent methodologically and more empirically grounded than the more common subjective interpretations of land-use based on excavations of a few square meters from a few sites in a region. Nonetheless, our models of the social processes that generated the land-use patterns we observe are completely narrative and inferential. We do examine alternative lines of evidence for mobility strategies to bolster our inferences. However, even with a patch-based approach to collecting archaeological data across valleys, the available data remain very sparse, and using surface collections necessitates a coarse temporal resolution many orders of magnitude greater than the scale of real human generations (although the mismatch between archaeological chronological frameworks and the temporal scale of human action is not limited to surface collections). Hence, alternative narratives could be developed to fit the data we present, with no way to assess whether they constitute better reconstructions than ours. Our models are in no way predictive, in that they cannot account for human land-use in as yet unstudied locales; in fact, we generate different land-use models for each valley we study (Barton et al., 2004a, 2004b). This situation makes it impossible to test the accuracy of our inferential models and makes them of limited use for making decisions about future land-use beyond offering general insights about socioecological path dependence and the interaction of environment, society, and history.

More sophisticated, scientific data collection and computational analysis methods can lead to new insights about past societies. Moreover, the methodological transparency and replicability that come with applying such methods systematically are desirable. However, when they are used for inferential reconstructions, computational models still cannot create narratives of the past that can be demonstrated to be any more accurate than ones created subjectively. And, because they are created to account for known data, these inductively created models are unable to reliably forecast the outcomes of human social practices. These shortcomings are a significant reason that society has difficulty in making use of the "lessons of history," even though we have been admonished to do so since antiquity. If the lessons of history are simply interpretations of often debatable (and regularly debated) plausibility, how can we feel confident that we are even getting accurate lessons to apply? And if these lessons are simply reconstructions of particular past circumstances with no predictive power, how can we use them for decision making even if they are reasonably accurate?

Example 2: Technology and Ecology in Upper Pleistocene Europe

Studies of change over long timespans are a hallmark of archaeology and other historical sciences. In addition to narratives, change through time is often represented in a variety of graphical formats that can range from images of artifacts arranged in a proposed chronological order to graphs of radiocarbon samples with error ranges. Estimating the age of material culture is a task that an inferential approach often performs well. Careful age inference often involves assessing the degree of agreement between several very different kinds of information, including stratigraphy, seriation, and radiometric methods. Such archaeological dating is cited by Wylie (2000) as an example of using of multiples lines of evidence to make strong inferential arguments.

Change—or more often simple variation—across space is also of considerable importance in archaeological research. Since most archaeological practice takes place in the contexts of sites, variation in artifact densities, artifact types, features, or other material residues of human activities are very commonly represented across the space of sites. In addition to narratives, maps are the most common way in which variation across sites is represented. Variation is similarly represented at regional scales in the form of maps that usually show the distribution of sites occupied "contemporaneously" (for example,, Hill et al., 2004), but occasionally other kinds of data also are displayed in map form (for instance, Ebert, Camilli, and Berman, 1996; Kvamme, 2007; Weatley, 1995; Williams, Limp, and Briuer, 1990)

Because of the nature of the archaeological record and archaeological practice, there is a common tendency to model change through time as a sequence of discrete packets of time-temporal "phases"— for example—during which nothing (or nothing of importance) changes. Change takes place in the time between these packets (see Dunnell, 1982). Moreover, artifacts, features, and sites inferred to be included within the same time packet are considered to be contemporaneous and treated as if individual humans living within the same temporal phase potentially could have interacted. Sometimes such contemporaneity is reasonable, but often temporal phases can be over a century or even millennia in length—far beyond human generation spans. Spatial variation commonly has been treated as discrete, especially at a regional level represented by maps showing site distributions. However, the increasing use of GIS has provided archaeologists with tools to create models of the more continuous use of space that is probably closer to the way in which people used landscapes (for example,, Bell and Lock, 2000; Carey et al., 2006; Hill, 1998; Indruszewski and Barton, 2008; Kvamme, 2007; Llobera, 2001). An example of such continuous spatial models of prehistoric human land-use is discussed in the previous section and is shown in color Figure I.1.

In reality, human social practice changes simultaneously and more or less continuously across both temporal and spatial dimensions. Archaeologists have been rather less successful in representing such combined spatial-temporal change in forms other than narrative reconstructions that take the form of stories about past societies. Very often, such narratives present a story of past life during a time phase, then a story of life during a subsequent time phase, and yet another reconstructed past during the next phase. Sometimes processes internal or external to a society are invoked to account for differences between the reconstructed societies portrayed in each phase. When an attempt is made to model spatial-temporal change in a more formal or quantitative way, it usually takes the form of a series of graphs of change through time in material culture or a more inferential measure, such as political structure—with each graph representing a discrete geographic place—or a series of maps that show the spatial distribution of sites or other archaeological data—with each map representing a distinct temporal packet or phase. Although both of these kinds of representations can be seen in my own work (for example, Barton et al., 2004a, 2004b), neither does a particularly good job of representing continuous change in both space and time dimensions or interactions between spatial and temporal change.

Recently, several colleagues and I sought to characterize the spread of a particular hunting technology across Pleistocene Europe in the millennia leading up to the last glacial maximum (LGM). Careful reanalysis and calibration of several hundred radiocarbon dates for the first occurrence of shouldered points (*punta de muesca* or *pointe à cran*) suggested that these might indicate a radiation of this technology from eastern Europe as the climate became increasingly glacial. Using GIS methods, I created a computational model that combined spreading rates derived from a spatial analysis of the radiocarbon data with information about the rates at which humans on foot likely traversed terrain of varying ruggedness. An initial interpolation of the spatial-temporal distribution of shouldered points (color Figure I.2a) indicated that this technology spread from a single region in central Europe. I then used the location of the earliest date for the first appearance of shouldered points as a starting point and calculated an anisotropic cost surface map that estimated costs for a human to walk across variable terrain from that point to any other point in Europe as a way of weighting the spread with real-world values about the ease and likelihood of foot travel. Next I calculated a regression equation that used the cost surface values to estimate date of first occurrence for each known site with shouldered points. The regression gave a fairly good fit with $R^2 = 0.6$ and $p < 0.0001$. Finally, I used the regression equation and the cost surface map in a map algebra expression to estimate the first appearance of shouldered points in every $30' \times 30'$ grid cell of Europe (Tiffagom et al., 2007). The resulting map is a model of the combined spatial-temporal spread of shouldered points across glacial Europe (Figure I.2b).

This computational model can be transformed back into a narrative. These points probably represent the tips of compound weapons used for hunting large steppe ungulates. This technology, and presumably the hunting practices that utilized it, first appeared in central Europe around 27,000 years ago. From that time and place it spread north and then both east and west across the "mammoth steppe" in front of the advancing continental ice sheets. As the ice sheets reached their farthest southern extents and the environment of Europe became the most glacial of the last 100,000 years, this technology then spread south across the rest of Europe to the Mediterranean.

This quantitative, computational model of ecological change among Pleistocene hunters of Europe is considerably less complex than the land-use models of eastern Spain discussed in the previous section. However, it is a more robust model in a couple of important respects. It is predictive in that it predicts the time of arrival for shouldered point hunting technology in nearly 22 million grid cells across all of Europe, of which only 69 have radiocarbon estimates. This predictive ability also makes it testable in a way that the land-models were not. To test this model, it is necessary only to locate more Upper Pleistocene sites with shouldered points and secure radiocarbon dates. Those dates could then be compared with the dates predicted by the model, and its accuracy can be systematically evaluated. Finally, this model is sufficiently general that it potentially could be applied to other technologies or items of material culture in other regions of the world as a way to represent the spatial-temporal changes in their distributions. It should easily differentiate between the dispersal of a form of material culture from a single source or from multiple sources.

However, this model is largely a descriptive one. Although it incorporates real-world human movement parameters, it tells us nothing about social or ecological process that drove the spread of shouldered point technology. It was necessary to return to an inferential narrative story to imbue this computational model with such information. Moreover, the model is very closely tied to data from the very sparse archaeological record (that is, only 0.00032% of the $30' \times 30'$ grid cells have data). Not only could new sites and dates produce a new regression equation for predicting the remaining grid cells, but a single new site discovered with an earlier first-appearance date for shouldered points than that of Jarosov II in the Czech Republic (the starting point for the original cost surface) could completely alter the spatial-temporal pattern of the model by becoming a new starting point for the walking costs map.

Example 3: Resilience and Agriculture in the Southwestern United States

In the late 1990s I began a comparative project in the American Southwest to look at the socioecology of the shift from hunting and gathering to agricultural dependence in a region that bears considerable resemblance ecologically to the study area in eastern Spain discussed previously (Example 1) but that had experienced a different social history. My team carried out patch-based survey and limited subsurface testing in the vicinity of the middle Chevelon Creek drainage in north-central Arizona (Figure 7.2). Analyses of the survey data suggested important changes in the distribution of small farming settlements through time that we interpreted in a model of the reorganization agricultural ecology (Peeples, Barton, and Schmich, 2006).

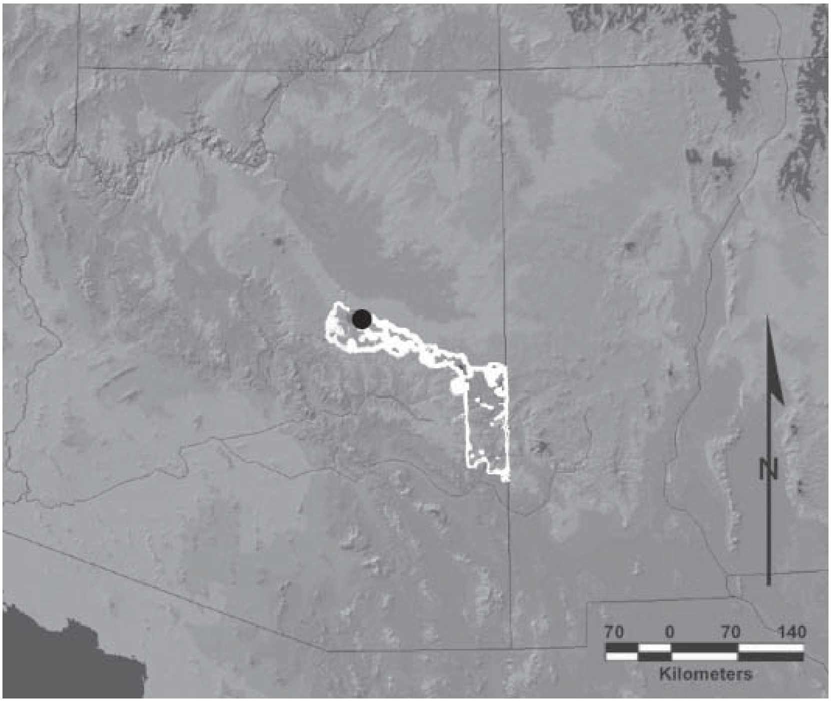

Figure 7.2 Location of Mogollon Region Small Sites projects (survey and testing) in the state of Arizona. Black dot is location of fieldwork, white outline marks boundary of Apache-Sitgreaves National Forests.

In this model we suggested that the earliest part-time agriculturalists in this region focused their subsistence activities on the dynamic environments of deeply incised canyons—like that of Chevelon Creek. Small gardens of maize, squash, and beans—planted on terraces along streams—became one of a diverse suite of resources utilized by ancient inhabitants. Although the canyons provided a rich array of food resources, no particular resource or particular locale was continuously dependable, owing to regular flooding that continually altered the narrow canyon bottoms. This discouraged permanent settlement or labor investment in any particular resource, including domestic plants, and kept population densities low. Such Late Archaic sites are relatively uncommon in this area and tend to be highly clustered near the canyons (color Figure I.3).

However, sometime before 1000 C.E., a new strain of maize was introduced into the region that could be grown on the uplands between the canyons. Dominated by pinyon pine and juniper woodlands, these uplands were a much more stable landscape, in which swidden cultivation of maize could produce predictable yields from year to year. These uplands also had a much lower biodiversity than the canyon lands, and woodland clearance for cultivation would have reduced the availability of the only abundant wild crop in this environment, pinyon nuts. Together, this predictability and low biodiversity encouraged increasing dependence on cultivated crops. However, upland landscapes also suffered from thin soils that developed very slowly in the rocky terrain. A few years of cultivation would have exhausted the productive capacity of a field, and the agricultural potential of the lands around a small farmstead could have been exhausted in a generation or less, forcing a family to abandon its farm and establish a new residence in uncleared woodland. The thin soils recovered too slowly to permit the abandoned land to be cultivated by others, and abandoned farms were never reoccupied. After a few generations of successful upland agriculture, all available land had lost its ability to be farmed successfully, and the region was permanently abandoned. An important empirical implication of this model is that the repeated process of swidden cultivation, abandoning an unproductive farmstead, and establishing a new farm would have created a cumulative archaeological landscape of regularly spaced prehistoric sites—a pattern that we observed in this region (color Figure I.4).

In our original publication, this model was largely narrative and supported by GIS-based maps and statistical analyses. We presented a traditional archaeological reconstruction of ancient land-use in the middle Chevelon Creek drainage, but we also we framed our model within the concepts of resilience theory (Gunderson and Holling, 2001; Redman, 2005; Redman and Kinzig, 2003) and suggested that it could offer more general insight into the socioecology of small-scale farming and the long-term consequences of human-environmental interactions. Although aspects of this model are potentially testable, the model's narrative format makes it difficult to test in any robust way. Untested, the model may serve as a useful cautionary tale, but its ability to contribute to land-use decisions for small-scale farming remains limited.

A few years ago, I carried out a test of one aspect of the model we developed for early agriculture in the middle Chevelon Creek region as an exercise in building computational models. I created an a computational model in Netlogo (Wilensky, 1999)—a platform for the creation of agent-based models (ABM)—to test whether land-use dynamics in which small-holders exhausted the fields around a farmstead and moved to another could produce a cumulative archaeological landscape of regularly spaced sites. I created a group of agents, representing small-holder farming households, and gave each agent a set of simple land-use rules. In brief, each agent seeks to farm the most productive land in the vicinity of its farmstead. The harvest from cultivation a plot of land returns an abstract "energy currency" to the household. If a household accumulates sufficient excess energy, it will produce a daughter household that will establish a new farm at some distance from its original home. If a plot becomes unproductive, a new plot of land is cleared and cultivated. If a household loses enough energy because of unproductive farming, it will abandon its farmstead and establish a new one in a more productive locale. Besides seeking to maximize farming returns, each household seeks to minimize farming costs (including clearing new land or traveling to a farm plot) and to minimize the cost of moving and establishing a new farm. The environment in which the household agents live and farm is a simple one, with soil that loses fertility (and consequently the amount of energy produced by a harvest) each time it is farmed and vegetation that starts as woodland (that must be cleared to be farmed) that regrows slowly when a plot is not cultivated.

When this portion of our narrative is translated into a computational model in this way, it does indeed produce a cumulative archaeological landscape of regularly spaced sites. The computational model also offers additional, useful insights into this aspect of small-scale agriculture. A few farming household agents will be successful at swidden farming in the ABM and even produce daughter household agents that will also be successful initially. Declining fertility and agricultural returns will force agents to move to new locations, however. Over time, with fewer and fewer areas of potentially productive land available, agents will have to move more frequently and will not accumulate enough surplus to produce daughter household agents. Ultimately, all farmsteads will be abandoned, leaving a regularly spaced pattern of sites in the virtual "archaeological record." Each site has a short occupation span, with more recent sites occupied for shorter spans than older sites, and there is little overlap in the occupation spans of many of the sites. The vegetation returns to woodland as more and more farmsteads are abandoned, and soils become permanently depleted across most of the region.

Other socioecological dynamics also can produce an evenly spaced spatial distribution of farmsteads. If soils can regain fertility when they are left fallow, household agents can continue to occupy a farmstead permanently if they control enough land to rotate their fields over the time needed for a plot of land to regain sufficient fertility before it must be cultivated again. Because daughter household agents must seek unoccupied land on which to establish a new farm, over time, the landscape will become populated by evenly spaced farmsteads around which agent households rotate fields. The vegetation becomes highly diverse with patches of woodland and fallowed plots in various stages of forest succession. While farmsteads are evenly dispersed on the landscape, they are not often abandoned, and the occupations of most farmsteads overlap each other temporally. If something else (social or environmental changes) leads to regional abandonment, the "archaeological record" will be one of regularly spaced sites, most of which would have a long occupation span and with considerable temporal overlap among the occupations of different sites.

Translating the narrative that we developed to account for the archaeological record along Chevelon Creek into a computational algorithm offers several important benefits. First, it allows us to test or validate the model—or at least a portion of the model in this case. I was able to show that the kinds of land-use practices we proposed indeed can produce the archaeological record that we observed empirically. As van der Leeuw observes (2004), ability to potentially falsify a computational or other formal model is one of the most powerful advantages of such an approach over inferential models, which cannot be evaluated in this way. Testing an independently derived model against empirical data is a rigorous way to differentiate better from worse models (that is, those that are better able to forecast real-world outcomes), rather than debating the "sense-making" merits of alternative inferential models. Second, it offers a way to investigate invisible past socioecological processes (van der Leeuw, 2004). Once a formal model like this one has been validated, it can be treated as a hypothesis about prehistoric land-use that can be tested in other locales. This provides a way to transparently evaluate the likelihood that particular socioecological processes did in fact take place in the past.

Finally, the computational model I developed is about small-scale farming, not about past societies. If we can show through validation against the archaeological record that such a model—or perhaps a more sophisticated version of such a model—can reliably forecast long-term outcomes of different land-use practices under different environmental conditions, it may be useful for land-use planning today. In fact, even the simple, abstract model I constructed in NetLogo offers an important insight in this regard. Under the environmental conditions that prevailed along Chevelon Creek, households had to regularly shift residences to make a living; and eventually they had to abandon the region entirely. But the computational model also shows that the very same kinds of land-use practices led to the prehistoric abandonment of middle Chevelon Creek also could produce long-term, sustainable agriculture under slightly different conditions, where thicker soils could regain their fertility through fallowing. The computational model is not about what happened in the past but about the dynamics of human socioecological systems. The Chevlon case helps to validate the general model and illustrates one possible outcome of a suite of land-use practices in one particular place and time. However, the model makes clear that this is not the only possible outcome, and in so doing it becomes a potentially valuable planning tool.

Example 4: Socioecological Dynamics in the Mediterranean

The last example is from the Mediterranean Landscape Dynamics (MedLand) project. Although this large-scale (six years) National Science Foundation supported project[2] involved numerous archaeologists and paleoecologists, and worked extensively with archaeological and paleoenvironmental data, it was not designed to learn about the past. Rather, from the outset, the goal of this project was to build a sophisticated modeling laboratory to carry out virtual experiments (sensu Bankes, Lempert, and Popper, 2002; van der Leeuw, 2004) on the long-term, recursive interactions between society, land-use, and environmental change. Rather than reconstruct past societies from archaeological data in this virtual environment, we use the rich archaeological record of the Mediterranean region to validate and parameterize the components of the MedLand Modeling Laboratory (MML).

Because it aims to simulate high-resolution, real-world landscape dynamics and land-use practices, the MML is a hybrid modeling environment with components that utilize different modeling approaches (Mayer and Sarjoughian, 2007, 2008, 2009; Mayer et al., 2006). These include GIS-based modeling of landscape surface processes such as hydrology, erosion/deposition, and vegetation succession; an ABM of farming households and their land-use practices; and regression-based paleoclimate and paleovegetation models (Figure 7.3). The details of the MML are published elsewhere (Barton, Ullah, and Bergin, 2010; Barton, Ullah, and Mitsova, 2010; Ullah and Bergin, 2012; Ullah, 2011), so I will offer only a brief synopsis here.

Agropastoral land-use can be modeled stochastically or in an agent-based modeling (ABM) platform. When modeled stochastically, farming and grazing patches are randomly distributed within catchments—calculated using GIS routines to account for terrain and suitability for farming and/or herding—around communities (Barton, Ullah, and Mitasova, 2010; Ullah, 2011). Alternatively, individual households can be simulated as virtual agents, organized into villages. Agents choose land to farm or graze on the basis of their need for farming/herding returns (calories that affect birth and death rate), the suitability of land for particular agricultural activities, and costs to use the land (including access on foot and vegetation clearance) (Barton, Ullah, and Bergin, 2010; Mayer and Sarjoughian, 2009; Mayer et al., 2006; Ullah and Bergin, 2012). Agents also can collect fuel wood, the need for which varies according to household size and activities. Whether modeled stochastically using GIS routines or by using ABM technology, household land-use can alter the vegetation cover and soil characteristics.

These anthropogenic changes to landscapes, in turn, affect the results of other surface processes on landscapes in terms of location and intensity of erosion and deposition. These are simulated in a surface process model that uses 3-dimensional algorithmic implementations of the unit stream power erosion/deposition (USPED) model—based on the well-known universal soil loss equation (USLE/RUSLE)—and the reach-average shear stress equation (Degani, Lewis, and Downing, 1979; Flannagan, Laflen, and Meyer, 2003; Haan, Barfield, and Hayes, 1994; Mitasova, Mitas, and Brown, 2001; Mitasova et al., 2004; Moore and Burch, 1986; Singh and Phadke, 2006; Tucker and Hancock, 2010; Warren et al., 2005; Wischmeier, Johnson, and Cross, 1971; Wischmeier and Smith, 1978). Climate and natural vegetation values also are input to the landscape module and can come from modern values or, for ancient settings,

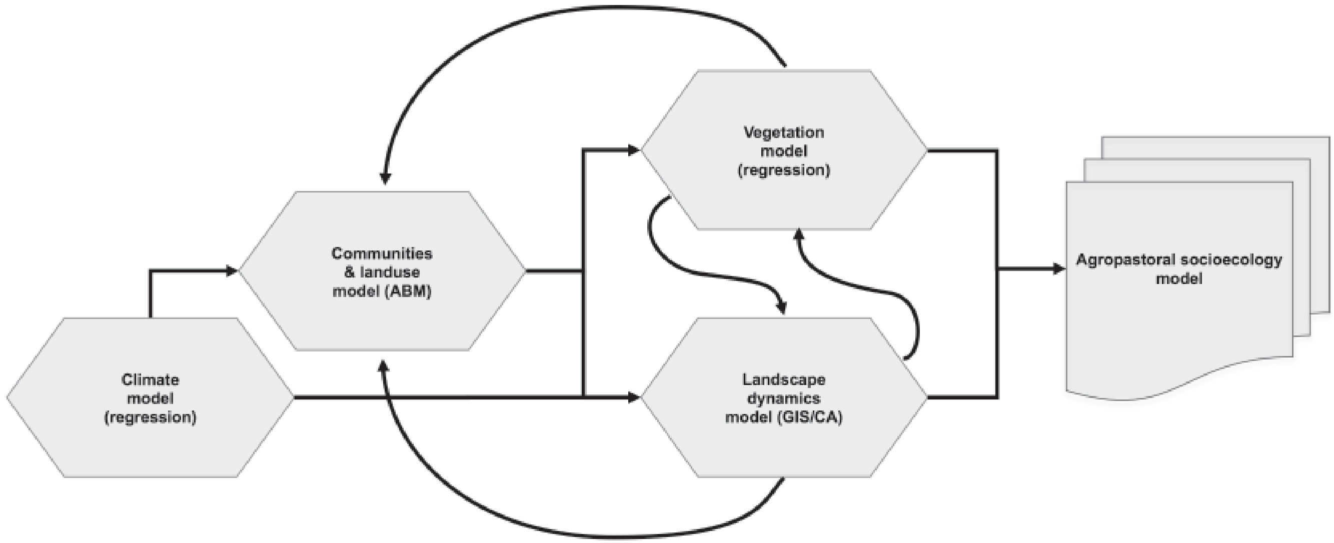

Figure 7.3 Schematic representation of components in MedLand Modeling Laboratory

from the results of paleovegetation and paleoclimatic modeling. The landscape simulation can change the terrain and soil depth, as well as allow vegetation to regrow and soils to regain fertility if a patch of land is not used. This provides feedback to land-use in the ABM when households make new decisions about which land to farm and graze.

Initial results of using the MML to study the dynamics of ancient land-use have been promising. In one set of modeling experiments, we parametrized the MML with values derived from Neolithic farming communities of northern Jordan and examined the consequences of varying land-use (intensive vs. shifting cereal cultivation, and ovicaprine grazing vs. no grazing) and community size on soil loss and vegetation over the course of two and ten generations, 40 and 200 years, respectively (Barton, Ullah, and Bergin,, 2010; Barton, Ullah, and Mitasova, 2010). Some of the modeling results confirm widely held expectations about such land-use: shifting cultivation can cause greater soil loss than repeated cultivation of a few plots (for example, with manuring); extensive ovicaprine grazing will cause more erosion than farming without associated grazing; larger communities with more people farming and grazing more land will have a greater impact on the landscape than smaller communities (color Figure I.5). Other results were less intuitively obvious because of the complex interactions between land-use and landscape dynamics. Notably, when community size is below some threshold, whose value is determined by local environmental conditions, the amount of soil loss can be substantially offset by soil accumulation (that is, by the redeposition of sediments eroded from other parts of a catchment), so that the economic effects of mixed agropastoral land-use can be negligible or even beneficial. However, if communities pass the threshold size, the consequences change qualitatively such that soil loss greatly exceeds soil accumulation within a land-use catchment. This imbalance continues over the long-term, with the potential for leaving a catchment unsuitable for farming. One mitigating strategy is, not surprisingly, to reduce community size through emigration or fissioning. Another less obvious solution discovered in these experiments is to increase the area devoted to grazing relative to cultivation, moving zones of soil loss into uncultivated uplands and providing more sediment for redeposition in the areas around farmed fields. Conservation measures, like terracing, also could be instituted but could require some degree of social reorganization to ensure the availability of sufficient labor for terrace construction and long-term maintenance. This kind of investment in landesque capital and intensification of land-use has often been accompanied by the growth of inequalities in social power and prestige.

As inferred independently from the archaeological record, Neolithic settlement and land-use generally follow patterns suggested by our modeling experiments (Kuijt and Goring-Morris, 2002; Legge and Harris, 1996; Martin, 1999; Quintero, Wilke, and Rollefson, 2004; Rollefson and Kohler-Rollefson, 1992; Rosen, 2008; Simmons, 2007; Twiss, 2007). In the earliest Prepottery Neolithic (PPN-A), most communities were very small and practiced mixed agropastoral subsistence strategies. These mixed farming/herding strategies continued into the PPN-B, as many communities grew in size, with some in apparently favorable localities having thousands of inhabitants. In the late Neolithic, however, the large towns were abandoned or greatly reduced in size, with most of the regional population again living in very small communities. Additionally, some groups may have begun to rely more on animal herding, marking the beginning of mobile pastoral economies. Finally, the late Neolithic record of Mesopotamia, at least, is interpreted to suggest increased social inequality along with investments in landesque capital. Note, however, that currently, we can only make comparisons between our model results and the *inferred* prehistoric record of southwestern Asia; we are not yet able to evaluate model results directly against empirical archaeological data.

A second experiment carried out in the MML involved studying the results of situating a small farming village in different topographic contexts within the Rio Penaguila and upper Rio Serpis Valleys of eastern Spain, the location of one of the earliest known farming communities in the Iberian Peninsula (Bernabeu Aubán et al., 2003; Bernabeu Aubán and Orozco Köhler, 2005). In four different experimental runs (Figure 7.4) a simulated village, populated by household agents, was set alternatively in an alluvial plain (for easy access to land for farming and grazing), in a canyon bottom (for seclusion), at the base

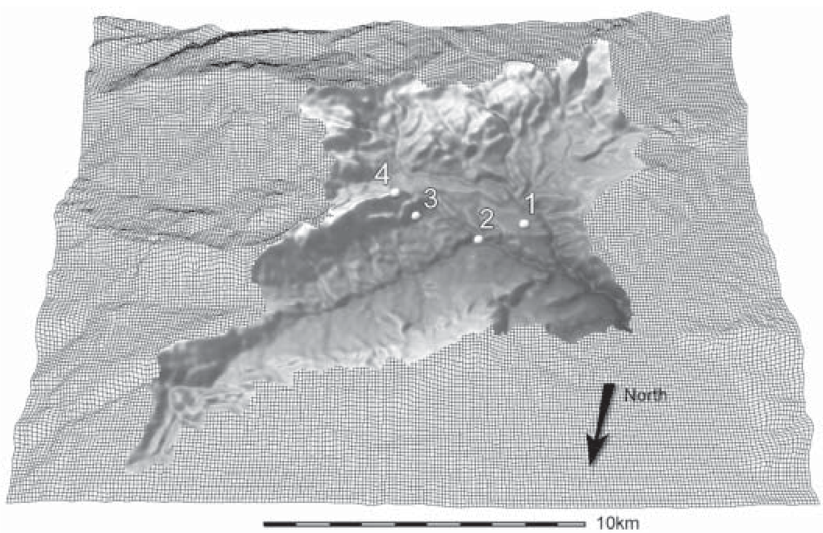

Figure 7.4 Four different locations for modeled village and its agropastoral catchment. Setting is in the Rio Penaguila and upper Rio Serpis valleys of northern Alicante Province, Spain (from Ullah and Bergin, 2012).

of a cliff (for defensibility), and on a topographic prominence (for maximum visibility). In each locale, all other initializing parameters besides geographic setting were kept the same for the village. The agents farmed and grazed the land around each site for 100 years, and resulting data were collected on population size, economy, vegetation cover, and erosion/deposition (color Figure I.6). When the village was located in the alluvial plain it was more successful initially than when placed in the other settings, as measured in terms of population growth and agricultural returns. However, this success also led to a recursive, self-amplifying growth cycle of increasing population, expanding cultivation and grazing, soil degradation and loss, and even more expansion of cultivation and grazing. When situated in the other locales, the same village grew more slowly and experienced more variable economic returns. However, the smaller and more stable population also had much less detrimental impact on the surrounding landscape (Ullah and Bergin, 2012). Archaeological sites are commonly found in a variety of topographic settings—including ones analogous to those in the MML experiment—and archaeologists regularly speculate on the reasons for settlement placement. But as far as I know, there has been no study to assess the ecological impact of prehistoric settlements in such different settings. This set of experiments, then, provides a set of hypotheses about the long-term ecological consequences of socially mediate site placement that could be tested against the archaeological record.

Unlike the other models presented, the MML is not designed to tell us about the past but is rather a much more generic modeling environment or laboratory where we can ask a wide variety of questions about human socioecological systems. As such, it can also be used to simulate land-use/landscape dynamics in prehistoric contexts. Also, unlike the other models presented, the MML is not designed to match empirical data. The other models were inherently valid in that they accounted for a set of empirical data. But as already noted, such inherent validation of inferential models—even computational ones—does not necessarily make them more accurate. The MML is very different conceptually in this regard. Because it is designed on the basis of our knowledge of human land-use practices and surface processes as we observe them today, the MML can create realistic scenarios that do not match the prehistoric record. For example, we have regularly run what we call control models for our experiments in which landscape simulations are run without a human presence—because the environment changes whether people are involved or not. This approach allows us to calibrate the results of experiments in which we *do* simulate human land-use to better measure net anthropogenic consequences of alternate suites of activities (Barton, Ullah, and Bergin, 2010; Barton, Ullah, and Mitasova, 2010). Results generated by the MML can be treated as hypotheses about human-environmental interaction. When these complex hypotheses are tested repeatedly and validated against situations for which we know the results (that is, from the archaeological record), it can give us increasing confidence that the models are accurately simulating relevant processes and can forecast the likely real-world results.

Discussion

The past dozen years of exploring ways to embed computational model-building into archaeology has led me to a changing perspective on archaeological practice. While the work we are now doing with the MML involves a variety of activities that traditionally would be considered archaeology, our goal is not to collect empirical data of the archaeological record in order to reconstruct past societies. Rather, we are using the archaeological record to verify and to improve our models of human socioecological dynamics. The goal of this research is to gain a better understanding of the operation of human society and to use that understanding to create formal or computational models that can more reliably forecast outcomes of human decisions and social practice—in the past, present, or future.

As noted, the archaeological record is one of shreds and patches (to paraphrase Hamlet) and in many cases is inadequate to reconstruct the past at the level of detail needed to create reliably accurate models of ancient social process. However, it can be very useful as a dataset against which we can test the long-term and large-scale results of computational models created from ethnographic knowledge of the small and intimate practices of human actors. It is this potential to forecast large-scale, long-term consequences of day-to-day decision making that can make an archaeology refocused in this way increasingly valuable to social science and to society more generally.

For the most part, social science has largely remained an observational science since its inception. Much like natural philosophy and natural history of the 18th and 19th centuries, social scientists collect data on human social behavior "in the wild" and inductively create narrative, statistical, or formal models to account for observed behaviors. The practical, and in recent decades ethical, restrictions on carrying out controlled social experiments has precluded the testing of most social science models, retarded the development of comprehensive social theory, and severely limited the ability of social sciences to produce reliable forecasts about the consequences of social practice—even when models are highly formal and quantified (Buchanan, 2009; *The Economist*, 2009; Farmer and Foley, 2009). Hence, social science has been saddled with the unwarranted label of being a soft science (Diamond 1987). Very recent microscale social experiments, scaled up through formal and quantitative modeling, are beginning to revolutionize our perception of social dynamics (Bowles and Gintis, 2003; Fehr and Simon Gächter, 2000; Henrich et al., 2006; Janssen et al., 2010). However, we still cannot carry out experiments at the scale of real-world social groups that could involve hundreds to millions of individuals, or experiments to study effects over the course of decades to millennia. For such studies, computational modeling experiments, verified against the archaeological and historic records can play a vital role—especially since the coarse-grained nature of the archaeological record tends to emphasize processes occurring at larger spatial scales and long temporal scales, while processes happening in more familiar human time and space frames are often blurred, mixed, or impossible to distinguish (Shennan, 2002: 9–21; van der Leeuw, 2004).

Science is not simply the creation and use of technology, but some technologies can be transformational in science. The telescope transformed astronomy, the microscope transformed biology, and particle accelerators transformed physics. Social sciences have largely made little use of technologies—and in some cases have even appeared antitechnological. Modern archaeology is similarly a largely low-tech field. It is true that there are a few archaeologists who study bone isotopic chemistry, or use magnetometry or other geophysical methods in the field, but most data-collection and analysis methods have changed little in over a century. Surface data are collected in pedestrian walkovers; excavations are carried out by shovel and trowel or patishe and goofa; artifact classes are intuited and exemplars counted; analyses are statistically simple and largely can be done with a spreadsheet (or even by hand with a little more time). Computers are used most widely and intensively to write narratives. Traditional methods may suffice very well for some tasks, but there has been little impetus for technological development within archaeology. Rather, archaeologists are more often the (frequently reluctant) consumers of technologies developed by other fields. Astronomers and physicists, in contrast, well understand the importance of enabling technologies such as the Hubble space telescope and Large Hadron Collider and work to develop these technologies as they do other aspects of their science.

Computational model is a potentially transformative technology for the social sciences in general and archaeology in particular (Bankes, 2002; Cioffi-Revilla, 2009). It offers a new way to couple the rich and varied database of the archaeological record with field observations of societies today, microscale social experiments, and the complex dynamics of large-scale socioecological systems (Kohler and van der Leeuw, 2007; van der Leeuw, 2004). And although such modeling may give us a different window on ancient societies, its greater value lies in its potential to integrate the record of the past with a new science of social dynamics—a science we need to help us to face the challenges of the 21st century. To fully benefit from the potential of this technology, archaeology also will need to transform itself. Because the power of modeling lies in its potential to connect data, theory, and explanation in powerful ways and to carry out computational experiments in social process and dynamics, it must be used by archaeologists acting as social scientists; it cannot be relegated to a "black-box" type of specialist analysis such as radiocarbon dating. Currently, few social scientists, and even fewer archaeologists, use computational modeling or are more than vaguely aware of its existence. It will be necessary for archaeologists to intellectually retool—requiring investments of time and resources—and to establish new academic programs that teach computational or algorithmic thinking to the next generation of archaeologists, along with new methods in combination with the still important domain knowledge of the archaeological record. Likewise, archaeologists need to become actively involved with the development of technology such as computational modeling for social science. We cannot afford to leave this to others who are not trained in the social sciences. With a rich and unique database that is critical for building robust models of long-term social change, archaeologists can play a fundamental role in the development of an advanced and socially valued science of human society.

Notes

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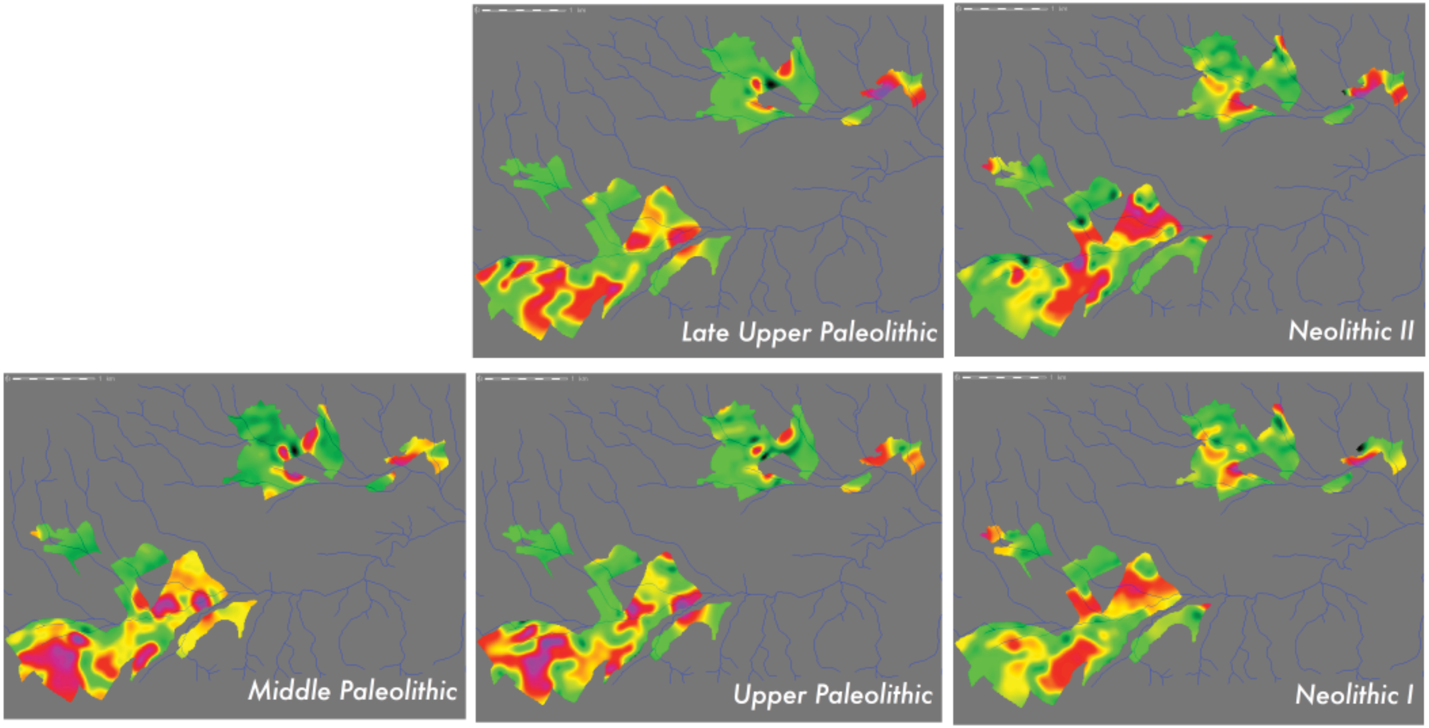

Figure I.1 Settlement Intensity Index for time periods from the Middle Paleolithic through Neolithic II-B in the Polop Alto Valley. High values represent more intensive settlement (see Barton et al., 1999; Barton et al., 2002; Barton et al., 2004b for calculation of settlement intensity index).

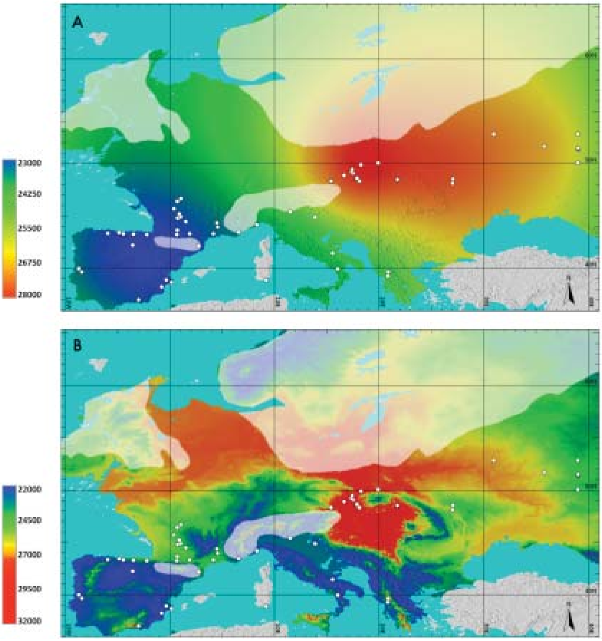

Figure I.2 Spatial-temporal distribution for the dissemination of shouldered point hunting technology in western Eurasia during the Late Pleistocene: (A) Interpolation of the spatial-temporal distribution of the first occurrence of shouldered at a series of Upper Paleolithic archaeological sites (indicated by circles); (B) Map of spatial-temporal temporal spread of shouldered points combining interpolation and anisotropic cost surface of walking costs.

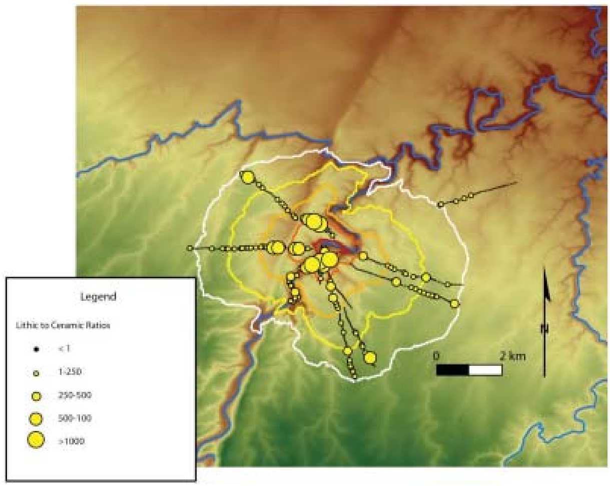

Figure I.3 Density of lithics in survey patches along transects extending outward from Chevelon Crossing, Middle Chevelon Creek, Apache-Sitgreaves National Forests, Arizona (from Peeples, Barton, and Schmich, 2006).

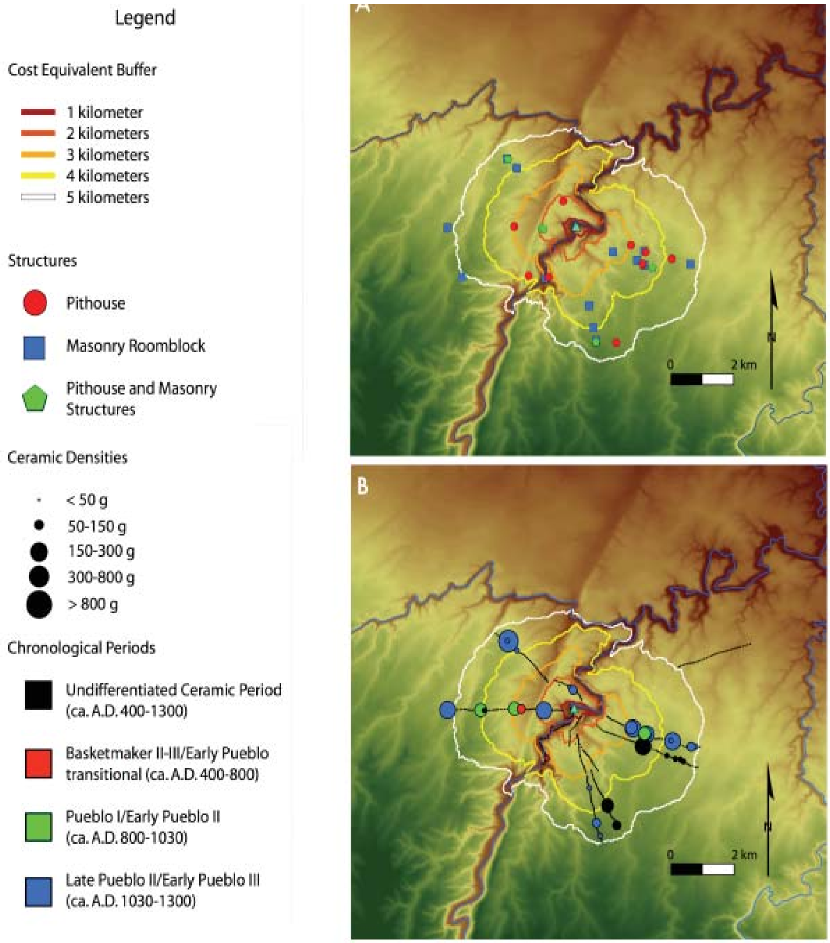

Figure I.4 Locations of structures (A) and densities of ceramics (B) and in survey patches along transects extending outward from Chevelon Crossing, Middle Chevelon Creek, Apache-Sitgreaves National Forests, Arizona (from Peeples, Barton, and Schmich, 2006).

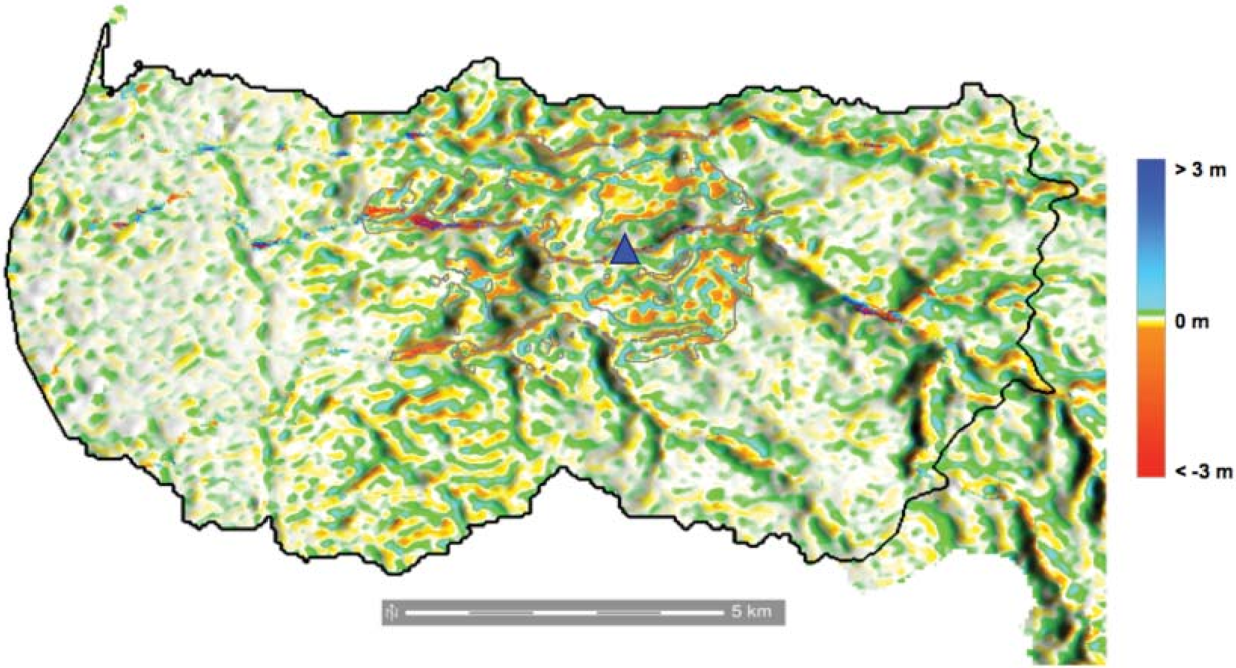

Figure I.5 Cumulative erosion and deposition around a Neolithic village after two generations (40 years) of shifting cultivation and ovicaprine grazing. Black line indicates outer limits of grazing catchment, gray line indicates outer limit of shifting cultivation catchment. Village indicated by blue triangle (from Barton, Ullah, and Bergin, 2010).

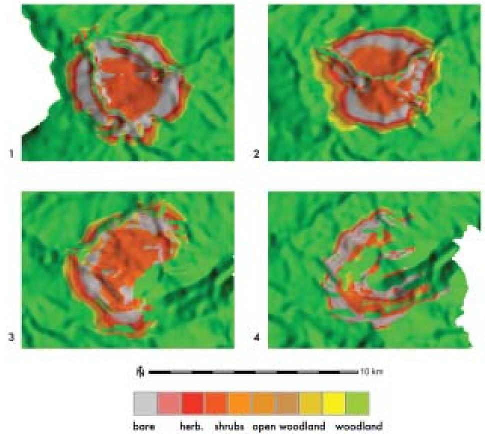

Figure I.6 Maps of anthropogenically altered land-cover around each of the four village locations after 100 years of shifting cultivation and ovicaprine grazing. Numbers refer to locations of village in Figure 7.9 (from Ullah and Bergin, 2012).