LANDUSE AND LANDSCAPE SOCIOECOLOGY
IN THE MEDITERRANEAN BASIN:
A NATURAL LABORATORY FOR THE STUDY OF THE
LONG-TERM INTERACTION OF HUMAN AND NATURAL SYSTEMS

INTERNATIONAL, INTERDISCIPLINARY RESEARCH
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**Project Description and Significance:** The longest and best-studied record of the ways in which human activities have transformed the world is found in the Mediterranean Basin, encompassing both the earliest known agricultural landuse and the earliest civilizations to become dependent on these human-managed socioecosystems. Decades of intensive archaeological and paleoecological study, has amassed rich and diverse data about human-environmental interaction in this region. We use this body of information in a new and exciting way as the basis for a modeling laboratory to investigate the long-term dynamics of human landuse and landscapes.

All of modern society is based ultimately on an agropastoral subsistence economy. Such dependence on domestic plants and animals first appeared in the Mediterranean basin in the early Holocene, and represented a dramatic reorganization of human ecology. It also involved increasingly intensive efforts by farming peoples to control environmental factors favorable to the life cycle of domesticates, with a consequent cascade of complexly interlinked effects on regional landscapes and human society. The ongoing impacts of agropastoral landuse on natural landscapes, and their recursive social effects is a critical global issue. However, landscape evolution takes place over the course of decades, centuries, and even millennia. Even the loss of a landscape’s ability to support a people and their subsistence economy is often the result of longer term changes that are much more visible at the resolution of the prehistoric record. Only by studying this long-term record can we truly begin to appreciate the long-term consequences of past and present landuse decisions on earth’s landscapes and society, and use this understanding to make more informed decisions today.

While such agropastoral impacts have been a growing focus of Mediterranean research, it has not been possible previously to systematically and quantitatively study relevant processes at the regional scales and long time spans over which they operated. Recent advances in geospatial modeling and agent simulation now make this a feasible endeavor. Our project combines these technologies in a new integrative study to use the prehistoric Mediterranean as a natural laboratory for investigating the long-term outcomes of alternate landuse practices in variable social and ecological settings. We use this laboratory to investigate three interrelated themes that are critical to understanding the long-term dynamics of Mediterranean socioecosystems: 1) **the effects on biodiversity of growth in agropastoral systems**; 2) **the changing impacts of landuse intensification and diversification on landscapes, their resilience, and vulnerability to degregation**; and 3) **the long-term sustainability of human maintained socioecosystems in varying environmental and social contexts**. We bring together three teams of multidisciplinary researchers who have each spent over a decade investigating long-term human ecology and landscape change in the Mediterranean and using GIS and related technology to model landuse-landscape dynamics of this region, and additional experts in geospatial and agent modeling. A GIS platform dynamically integrates and links geospatial modeling of geomorphic and vegetation change with agent modeling of human landuse. The rich prehistoric/geologic/paleoecological record of this region serves to tune and validate this modeling laboratory to approximate the actual outcomes of agropastoral landuse. By focusing our study in two ecologically diverse regions, at opposite ends of the Mediterranean Basin (eastern Spain and the southern Levant in Jordan), we encompass much of the social and natural variability of the entire region and give our study broader applicability beyond our study areas.

**Broader Impacts:** We expect our work to generate significant new knowledge about long-term consequences of alternative landuse practices that can help communities make more responsible and effective decisions about landuse today. We also have designed this project to have broader benefits beyond our research questions. Concrete products, including compiled archaeological and paleoenvironmental datasets and landuse-landscape modeling routines will be disseminated via the internet, conferences, and publications for use by researchers addressing other questions. Our work is tightly integrated with an active educational program for undergraduate and graduate students especially geared towards hands on training in the research process, and collaborative transdisciplinary work. Finally, we have developed a K-12 outreach partnership with the Arizona Geographic Alliance, with a special focus on minority outreach to poor and underserved schools. We will work with administrators and teachers to co-develop and disseminate curricula that enables science learning within the context of core requirements of the No Child Left Behind legislation.
INTRODUCTION

Early in the interglacial period we call the Holocene, the human species embarked on a dramatic reorganization of its relationships with the physical and natural environment. We took on the role of managers of simplified 'socioecosystems', controlling the reproductive cycles of a limited number of plants and animals (i.e., domesticates). The complex co-evolution of domesticates and domesticators [1, 2] in these agropastoral systems initiated cycles of increasingly large-scale landscape transformations that directly and indirectly resulted from human attempts to improve the productivity of these systems [3]. Both humans and the world we live in have been changed irrevocably as a result. The global ramifications of this change in human socioecology are still being felt today as humans are continually required to intensify their input (in time, energy, and information management) into maintaining and increasing the consumable output of the systems we manage. Importantly, these effects have spread far beyond the immediate surroundings of human settlement to transform what we often think of as the 'natural' world [4, 5].

The causes and processes by which humans came to control their subsistence base has long been one of the fundamental issues of prehistory [6-10]. Because this ecological transition began in the distant past and took place over the course of millennia, it can only be studied by means of interdisciplinary archaeological and paleoenvironmental research. Furthermore, while some of the more immediate ecological effects of agropastoral economies can be monitored today, many landuse-induced landscape changes occur at timespans that far exceed a human lifetime. It is clear from our own prior work on long-term human-environmental interaction, that landuse not only can alter the biophysical characteristics of landscapes, but also can alter the vulnerability of landscapes to degradation from future landuse and, in turn, change the sustainability of subsequent landuse practices on those landscapes. Because these human-managed socioecosystems occupy the majority of the earth’s habitable surface, systematic study of their long-term consequences is crucial not only to biodiversity in general, but also to human survival and the quality of life experienced throughout the world [3, 5, 11-13].

In spite of the growing recognition of the importance of long-term studies of landuse-landscape interaction [14], it has only recently become feasible to integrate the rich and diverse paleoecological and archaeological data sets, accumulated over the course of decades of research, for effective modeling of the socioecological dynamics of of agropastoral systems. Recent developments in geospatial and agent modeling offer the means to do this at the regional geographic and temporal scales at which landscape evolution occurs. We propose to use these new technologies to utilize the long prehistoric socioecological record of human-environmental interaction in the Mediterranean Basin as a laboratory to investigate the complexly recursive relationships between landuse and the biophysical components of landscapes at regional scales. We focus especially on the growth and effects of early agriculture on biophysical diversity, the subsequent effects of the intensification and diversification of agropastoral systems with the growth of civilization, and the long-term sustainability of such systems.

RESULTS OF PRIOR WORK

The Mediterranean Basin is uniquely suited for long-term studies of socioecosystem dynamics. It has a coherent ecological definition, incorporating diverse but interrelated environmental settings, and a long human history that encompasses the transformation from ecosystem participant to ecosystem modifier and, eventually, to socioecosystem manager. This region witnessed the earliest known agropastoral economies and their attendant effects on the biological and physical landscape, and the world's earliest development of social complexity and urbanism. Recognizing the potential that the Mediterranean Basin holds for understanding the complex, changing nature of human-environmental relationships and their impacts, members of our research team (table 1) integrate three interdisciplinary studies of these issues initiated in this region over a decade ago.

Clark and Schuldenrein began NSF-supported work in the late 1980’s on the ecology of late Pleistocene hunter-gatherers in relation to the changing alluvial landscapes of the Wadi al-Hasa (a major tributary of the Jordan River valley in western Jordan) [15-18]. Human settlement and landuse was structured by late Pleistocene landscapes whose character was primarily determined by climate and topography. In the mid-1990’s, they were joined by al-Nahar whose work centered on the end-Pleistocene hunter-
gatherers, and Hill who extended the Hasa study into the Holocene. Hill used geospatial modeling to analyze the interconnected dynamics of prehistoric agropastoral landuse, human settlement locations, erosion, and soil loss from the beginning of farming to 19th century Ottoman rule, focusing on how human landuse altered landscapes and, in turn, subsequent landuse [19, 20]. For example, he linked the first agricultural use of the Hasa, over 6000 years ago, to an erosional episode that permanently changed the valley’s productive potential for agriculture—and all subsequent landuse patterns. However, it is also clear from Hill’s work that the vulnerability of the Hasa landscape to erosion and its overall resilience in the face of differing intensities of agropastoral landuse varied dramatically across space and over time. Less than 20 km from where the ancient floodplain of the Hasa was lost to erosion, similar forms of landuse have been sustained for 6000 years.

In the 1990’s, Falconer and Fall began collaborating (supported in part by NSF grants SBR-9600995 [21] and SBR-9904536 [22]) on the impacts of agricultural intensification, and the collapse and rebirth of civilization on landscapes of the southern Levant [23-32]. Their work at Bronze Age towns of Tel Abu en-Ni’aj, Tel el-Hayyat, and Zahrat adh-Dhra documented the importance of rural communities on the evolution of the region’s anthropogenic landscapes. GIS-based simulations of the emergence of urbanism and polities [33, 34] built on their research show the social and economic resilience of these agrarian villages across periods of urban growth, and collapse, and provide a framework for larger-scale modeling of the effects of social complexity on Mediterranean landscapes.

Table 1: research team

<table>
<thead>
<tr>
<th>Principal Investigators</th>
<th>Expertise</th>
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<tbody>
<tr>
<td>Lead: Michael Barton</td>
<td>Geoarchaeology, geospatial modeling</td>
</tr>
<tr>
<td>Ramon Arrowsmith</td>
<td>Geology/geomorphology, remote sensing</td>
</tr>
<tr>
<td>Steven Falconer</td>
<td>Archaeology</td>
</tr>
<tr>
<td>Patricia Fall</td>
<td>Paleocology, paleobotany,</td>
</tr>
<tr>
<td>Hessa Sarjoughian</td>
<td>Agent modeling, computer science</td>
</tr>
<tr>
<td>Senior Personnel</td>
<td>Expertise</td>
</tr>
<tr>
<td>Ernestina Badal</td>
<td>Paleocology, paleobotany</td>
</tr>
<tr>
<td>Joan Bernabeu</td>
<td>Archaeology, GIS</td>
</tr>
<tr>
<td>Reid Bryson</td>
<td>Climatic modeling, climatology</td>
</tr>
<tr>
<td>José Carrión</td>
<td>Paleocology, paleobotany</td>
</tr>
<tr>
<td>Geoffrey Clark</td>
<td>Archaeology, statistics</td>
</tr>
<tr>
<td>Brett Hill</td>
<td>Geospatial modeling, geoarchaeology</td>
</tr>
<tr>
<td>Helena Mitasova</td>
<td>Geospatial modeling</td>
</tr>
<tr>
<td>Maysoon Al Nahar</td>
<td>Archaeology</td>
</tr>
<tr>
<td>Neus La Roca</td>
<td>Geology/geomorphology</td>
</tr>
<tr>
<td>Charles Redman</td>
<td>Urban ecology, archaeology</td>
</tr>
<tr>
<td>Joseph Schudelenrein</td>
<td>Geology/geomorphology</td>
</tr>
<tr>
<td>Elizabeth Wentz</td>
<td>GIS modeling, spatial statistics</td>
</tr>
</tbody>
</table>

At the same time, Barton, Bernabeu, Badal, and La Roca began NSF funded work (BNS-9115209 [35], SBR-0075292 [36]) in a series of valleys of eastern Spain, at the opposite end of the Mediterranean Basin, using geospatial modeling to trace the dynamics of human settlement and its ecological consequences from the late Pleistocene to the beginnings of Bronze Age civilization [37-43]. They showed that human landuse and its impacts on landscapes varied significantly across surprisingly short distances, indicating that vulnerability to land degradation and resilience of biophysical systems cannot be treated as uniform characteristics of landscapes, even at relatively small scales. For example, in the Polop Alto valley the use of domestic plants and animals had little effect on human landuse patterns or on valley landscape for some two millennia. However, in the Penaguila valley, less than 20 km away, humans rapidly came to depend on agriculture that led to massive erosion similar to that seen in the Hasa, altering the potential of this landscape to sustain ‘natural’ plant communities and different agrarian systems.

The project proposed here synergistically integrates these three teams and builds on their prior research to study the ecological consequences of the evolution of agro-ecosystems in the Mediterranean Basin (ca. 10,000 to 3,000 years ago). Our team includes several additional researchers whose expertise assures robust analytic, modeling and outreach capabilities. Sarjoughian joins the team to direct the development of agent-based simulations of human landuse decisions. His research focuses on agent-based simulation [44-46], collaborative modeling and distributed simulation methods (e.g., recent NSF grant EIA-9975050 [47] that created a workbench for large-scale, multi-faceted modeling in a distributed computing environment). He is a developer of the DEVJAVA simulation and [48-51] collaborative modeling environment, and co-founder of the Arizona Center for Integrative Modeling and Simulation <www.acims.arizona.edu/>. Arrowsmith has parallel interests in Quaternary geology, geomorphology,
and neo-tectonics. His work in combining field studies with multispectral remote imagery and digital topography to map Quaternary landforms is a key factor in this project [52, 53]. Recent NSF-funded research includes a study of landscape context and the impacts of urban expansion for the Central Arizona/Phoenix Long Term Ecological Research site, and two geoinformatics-related initiatives to build geospatial tools and data systems for enhanced problem solving across the geosciences (EAR-0112960 and EAR-0225543 [54, 55]). Arrowsmith will direct the integration of remote sensing and geomorphic field data into digital models of prehistoric landscapes. Wentz specializes in spatio-temporal modeling, data interpolation, and analytical capabilities of GIS platforms, for investigating human-environmental interactions [56-58]. As a member of the modeling group, Wentz will oversee the interpolation of ancient landscapes from discontiguous paleoecological and archaeological data, and the statistical evaluation of landuse-landscape models. Redman’s archaeological work in the Mediterranean spans the first farming communities to urban civilization. He is also a leader in using prehistory to understand the long-term ecological impacts of civilization [5, 59]. As director of the ASU Center for Environmental Studies, and the Central Arizona-Phoenix LTER, Redman has developed comprehensive programs to bring the results of research on this issue to the lay public, K-12, and university levels, with special emphasis on diversity of student populations (e.g., <caplter.asu.edu/explorers/>). Redman will contribute his expertise on human-environmental impact in the Mediterranean and oversee the broader dissemination of project results to include K-12 and informal science education. Finally, two additional groups will lend expertise to key parts of the project. Helena Mitasova and the Surfaces Processes Group (Marine, Earth, & Atmospheric Sciences, NCSU <skagit.meas.ncsu.edu/~helena/index.html>) will assist with the developing of our geospatial modeling environment. Mitasova is an expert in modeling geomorphic processes at landscape scales, and one of the developers of GRASS GIS and modeling package [60-63]. The Archaeoclimatology Laboratory (U. Wisonsin <ccr.aos.wisc.edu/bryson/archaeoclim.html>), headed by Reid Bryson, will provide paleoclimatic data. Over the past decade this lab has developed a high-resolution model especially useful for providing critical Holocene paleoclimatic parameters for archaeological locales [64-67].

THE MEDITERRANEAN AS A NATURAL LABORATORY FOR LONG-TERM SOCIOECOLOGY

The evolution of complex interactions between humans and their environmental context can be explored in numerous dimensions. Our study centers on three interrelated themes that are critical to understanding the long-term dynamics of Mediterranean socioecosystems: the effects of growth in agropastoral economies on biodiversity, subsequent landuse intensification and diversification and its impacts on landscape vulnerability and resilience, and the sustainability of human maintained socioecosystems. These themes, discussed below, echo critical issues in understanding the coupling of human and natural systems today. We briefly present here an overview of the setting for our project and discuss the conceptual basis for using Mediterranean prehistory as a natural laboratory for investigating these themes.

Ecological and Cultural Setting

Geographically, this project is anchored in the prehistoric southern Levant and central Mediterranean Spain (Fig. 1). These study areas encompass a wide range of environmental and social diversity, allowing us to examine the significance of critical socioecological variables (such as climate, vegetation, topography, soils, subsistence economy, population size and distribution, and organizational complexity of societies) on the dynamics of
landuse-landscape interrelationships. Due in part to our joint prior research, these two areas rank among the most intensively studied regions of the prehistoric Mediterranean and have produced some of the richest, most complete data on early agriculture and its effects at regional scales. Elevations vary from sea level at the coast, to 1000-1500m in the highest parts of inland mountain ranges, with the Jordan Rift below sea level (~400m at the Dead Sea). In the western study region, precipitation ranges from 450mm along the southern coast to over 800mm in the interior uplands. In the eastern region, precipitation is more variable, reaching a maximum of 650mm in upland areas, and dropping to <60mm in the Sinai, Negev, and the Eastern Desert of Jordan.

All of the western and probably much of the eastern study region was wooded at the beginning of the Holocene, with evergreen oak-pistachio woodland at lower elevations and conifer forest in mountainous areas; mixed deciduous, oak-dominated forests were present at intermediate elevations in the western area [6, 68-70]. Arid shrub or steppic communities were present south of the Spanish study area, in Almeria [71, 72], semi-arid (Irans-Turanian) steppe occupied the eastern and southern margins of the southern Levant, and desert communities flourished in the Negev and Sinai. Today, valley bottoms are intensively farmed, often with irrigation at lower elevations, and hillslpotes are terraced. Traditionally, cereals (wheat and barley) were grown in valley fields, arboriculture (especially olives, almonds, and fruit trees) occupied many upland terraces, and arid steppe and desert areas served as pasture for ovicaprine herds.

**Table 2: prehistory summary for study areas**

<table>
<thead>
<tr>
<th>Period</th>
<th>Southern Levant</th>
<th>Mediterranean Spain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neolithic</td>
<td>(8000-4300 BC) Beginnings of agropastoral economies, villages with &gt;1000 people. Long-term settlement. [73-87]</td>
<td>(5500-2400 BC) Mixed foraging/farming with shifting settlements, &amp; fully agropastoral settlements with large-scale earthworks [6, 38, 39, 40, 42, 43, 88-89]</td>
</tr>
<tr>
<td>Chalcolithic</td>
<td>(4300-3500 BC) Agriculture with landscape modification (e.g., terraces &amp; checkdams) &amp; nomadic pastoralism. Rise of social complexity [94-103]</td>
<td>(2400-2200 BC) Extensive upland farming &amp; herding; plow agriculture. Large villages. [68, 90]</td>
</tr>
<tr>
<td>Early–Middle Bronze Age</td>
<td>(3500-1500 BC) Intensive agriculture with large scale terracing, arboriculture, &amp; limited irrigation; urbanism and state formation, high population densities [26, 104-106]</td>
<td>(2200-1200 BC) Agriculture with landscape modification (terracing). Simple settlement hierarchies. [107, 108]</td>
</tr>
</tbody>
</table>

Because of their historical importance, the cultural and environmental legacies of Mediterranean societies have been studied especially intensely. Here and in Table 2 we provide a brief outline of the culture history, noting some of the more significant dimensions of variability relevant to this project. Hunter-gatherers occupied both regions at the beginning of the Holocene. Agriculture began to spread in the eastern study region shortly thereafter, but *Neolithic* societies did not appear in the western region for over two millennia. In the Levant, agriculturalists lived in settlements (sometimes quite large) that persisted in favorable locales for centuries. In Spain, domesticates sometimes were incorporated into hunter-gatherer subsistence systems; in other cases, early farming was practiced in smaller settlements than seen in the Levant, though with a potential for large-scale landscape modification indicated by substantial earthworks. By the end of the Levantine Neolithic, *Chalcolithic* groups exhibited the beginnings of social complexity—including differentiation in settlement sizes, socioeconomic roles, landuse patterns, and differences in wealth and political power characteristic of ‘civilization’—and evidence of direct alteration of the landscape (including terracing and simple forms of water control) to increase agricultural productivity. This trend intensified in the urban societies of the Levantine *Bronze Age*. In the western study region, there is less differentiation of settlements or of landuse, and more limited landscape modification. Over the course of the Neolithic through Bronze Age, the southern Levant experienced repeated cycles of population growth and aggregation interspersed with episodes of social collapse, dispersal, and local abandonment [20, 109]. Such cycles are not apparent in the archaeological record of central Mediterranean Spain.

Within each larger region, our study will focus on a subset of locales where recent studies have produced abundant, high-resolution archaeological and paleoenvironmental datasets on prehistoric settlement, subsistence economy, and ecology. For example, research over the past two decades in part of one of these
study areas—the Wadi Hasa—has recorded over 1600 archaeological sites, of which more than 250 date to the time interval of this project. (Table 4 details the rich datasets available from both areas.) These intensively studied locales will form the basis of a natural laboratory for quantitative modeling of long-term human-environmental interaction. In the eastern region, our study will focus on two intersecting transects (Fig. 1): the Jordan Rift, encompassing the most fertile agricultural lands of the Southern Levant; and the Wadi Hasa from the Transjordanian Plateau to its mouth at the Dead Sea. This sample area encompasses the major environmental variability between the wetter north and the arid south, and between the lowland Jordan Rift and the rising elevations to the east along the Wadi Hasa. In the western study region, we will focus on three interconnected valleys—the lower elevation Serpis, and the higher Penaguila, and Polop—each of which evidence different socioecological trajectories for the transition to agropastoral economies and the beginnings of social complexity [42, 43]. Quantitative models developed for each study area will be situated within their larger geographic and ecological contexts using region-wide data analyzed collectively and according to physiographic zones (e.g., Mediterranean coastal plain, Jordan Rift and Spanish upland valleys, Transjordanian plateau). Recent advances in geospatial and coupled agent modeling enable us to integrate these rich and varied data sets and use the diversity of the two study areas—in terms of socioecological structure and dynamics; climate, topography, and vegetation; and locations at opposite ends of the Mediterranean basin—as a natural laboratory for investigating the outcomes of alternative trajectories of landuse change in different social and environmental contexts. Anchoring our research in these two areas will keep our modeling to a manageable spatial scale with current technology, but encompass sufficient variation to permit us to generalize beyond our study areas to the Mediterranean more broadly. This represents an exciting new way to use knowledge from the long human past to address critical issues today.

Conceptual Issues for the Prehistoric Record

For investigations of modern ecosystems, quantitative models can be based on direct measurements of a biophysical parameters and relationships, and evaluated against observations of real-world processes. Long-term outcomes of ecological models (e.g., the effects of global warming) cannot be tested against observations, however, because the relevant real-world outcomes have yet to occur. Studying past ecosystems poses a different set of challenges. While it is impossible to directly measure processes (e.g., stream flow) in extinct ecosystems, the archaeological, geological, and paleoecological record does reveal the outcomes of such processes (e.g., prehistoric agricultural terraces or imbricated channel gravel deposits). Our goal in using the past to investigate the dynamics of landuse-landscape relationships, is to understand processes, not to predict outcomes. This means we evaluate the accuracy of our models by how well their outcomes match the known outcomes observed in the prehistoric record. While we can never be certain that models accurately represent past real-world phenomena, this gives us a way to differentiate among better, worse, and erroneous models and more closely approximate the processes we seek to understand. This approach to modeling prehistoric processes has been used successfully by Kohler and colleagues to investigate the spread of prehistoric farmers across southwest Colorado [110-113].

A related issue in using the prehistoric record as a laboratory for studying ecological processes is the need to use proxy data for measuring significant parameters of past socioecosystems. This is a widely accepted extension to the uniformitarian principles that are the foundation of the historical natural sciences [4, 114: 30]. For example, while we cannot perform a vegetation census for an ancient landscape, we can use knowledge about relative pollen productivity, transport agents and distance, and preservation under various depositional contexts—gained from the study of modern plant communities—to relate the relative proportions of ancient pollen taxa extracted from a sediment core (i.e., proxy data) to the composition of a prehistoric plant community [115]. We seek to contribute to an understanding of socioecological dynamics, not to develop new interpretive methods for archaeology and historical geosciences. Hence, as indicated below, we will employ widely accepted, standard proxy data and interpretive methods for reconstructing biophysical and cultural features of ancient landscapes [e.g. 115, 116, 117-121].
Conceptual Issues for Landscape and Landuse Modeling

A fundamental component of this project is the development of quantitative models to study the dynamics of long-term interaction of humans and their environment. When linked with archaeological and paleoenvironmental data, this modeling environment will serve as a laboratory for investigating the socioecology of Mediterranean agropastoralism. As simplified, symbolic representations of complex real-world phenomena, models can take many forms. Modeling is especially important for understanding the development of agriculture, agricultural intensification, and its impacts on ‘pristine’ landscapes (i.e., never affected by agropastoralism) because these processes took place in the distant past and permanently transformed the earth. Currently, models of past landscapes and landuse commonly appear as narratives [13, 122-124]. While these remain valuable, we will develop explicitly quantitative models to better understand the variables affecting the reciprocal relationships between landuse and landscapes. Quantitative models also come in many forms, from simple linear causal models to multivariate agent-based simulations. As indicated by our previous research, landuse-landscape interaction varies significantly across both space and time and is best represented by modeling environments that explicitly account for such dimensionality. Additionally, agropastoral landuse results from human decisions based on information about the landscape and human perception of this information structured by the socioecological context.

For these reasons, we will employ geospatial process modeling to quantitatively represent the dynamics of physical and biological features of landscapes, and agent modeling to characterize the dynamics of human landuse decisions and their outcomes. We will use a geographic information systems (GIS) platform to integrate the disparate data required for modeling, and provide an environment for coupling geospatial and agent modeling.

**Modeling of Physical and Biological Processes:** Geospatial modeling of physical and biological processes [62, 125-127] involves the solution of governing equations that describe the behaviors of these systems in space and time. We propose to employ spatially distributed models that simulate landscape evolution as a result of geomorphic processes—including water-flow induced soil erosion, sediment transport and deposition on hillslopes, and valley and floodplain processes—with a focus on the impact of spatial and temporal variability in landcover. Depending on scale and level of detail, modeling of physical and biological phenomena can be complex, involving multiple equations and empirical parameters. Because such parameters are hard to obtain in sufficient detail from historical data alone we will focus on the modeling of fundamental relations between the land cover, climatic conditions and topography using generalizations of existing models that will allow us to adequately capture the modeled processes. Our geospatial models will be based on principles and concepts used in state of the art landscape evolution models such as the Channel-Hillslope Integrated Landscape Development (CHILD) model [127] <www.geog.ox.ac.uk/~gtucker/child/>, the SIBERIA catchment evolution model [128, 129] <www.eng.newcastle.edu.au/~cegrw/GRWpages/siberiahp.html> and the SIMulation of Water Erosion (SIMWE) model [60, 61] <skagit.meas.ncsu.edu/~helena/index.html>.

**Agent-Based Modeling of Human Settlement and Landuse Decisions:** Agent modeling is an exciting approach to studying human activities and their impact on landscape, and a variety of approaches exist to represent human activities at individuals or societal levels. Agents may be specified using a variety of high-level rules and constraints which determine how they may consume/produce resources over a period of time [44, 130-135]. The behavior of these agents represent both internal and external interactions and thus model how they influence or are influenced by their surroundings. While agents may also include cognition, belief, and capacity for reasoning (e.g., they can develop plans and deal with unforeseen situations), this class of agents, is not necessary for the representing of the socio-ecological dynamics we are concerned with here. Instead, agents with basic capabilities to model socio-economic organizations and progression across a variety of landscapes and climate conditions with passage of time will be sufficient. In an important sense, such modeling mimics evolutionary processes, and has been applied to social change in archaeological contexts [110, 111, 113]. These characteristics make agent-based methods a potentially powerful way to model the evolution and spread of Mediterranean socioecosystems.

Extant software toolkits, such as DEVSJAVA (Sarjoughian and the ACIMS), SWARM (Santa Fe Institute [136]), and Magical (Mark Lake, University of Reading [137, 138]) can be used with GIS systems
such as GRASS, while environments such as DEVSJAVA offer an important theoretical foundation for characterizing key interactions among landuse, vegetation and terrain (see Figures 2&3). For example, XeriScape [49, 139] is a Sugarscape-style [140] artificial society tool based on Discrete Event formalism in the DEVSJAVA environment [45]. XeriScape provides an efficient, flexible, and extensible simulation environment that can serve as a basis for agent modeling like that proposed here. Using an agent-modeling approach with well-defined modeling constructs and properties, allows us to study human decision-making processes, and can support multi-resolution models, exchange of data geospatial modeling, and scaling up and down the continuum of temporal resolution while maintaining model effectiveness in a systematic and scalable fashion [133].

**GIS Platform for Integrating Data and Coupling Geospatial and Agent Models:** A geographic information system (GIS) platform will serve to organize the data and outcomes of geospatial and agent modeling, and also to thereby link both modeling environments by allowing the output of one to serve and input to the other. Organizationally, a GIS platform can integrate disparate data collected at different spatial scales, and to integrate it into a common reference framework. To simplify the challenge of modeling complex landuse-landscape dynamics over long time periods, we focus on three sets of critical phenomena: surface terrain and landforms, vegetation communities that occupied those landforms, and the settlements around which human landuse practices were centered—representing some of the most accessible forms of information about past socioecosystems and the best developed geospatial algorithms for landscape modeling. Climatic parameters are equally relevant, and will be provided by the Archaeoclimatology Laboratory of the University of Wisconsin (see below). Because these three sets of phenomena involve different proxy data and analytical approaches, and because each set will require input from multiple GIS ‘layers’ for modeling (e.g., elevation, slope, aspect, erosion vulnerability for terrain), we conceive of them as polymorphous or ‘poly-layers’ in the GIS platform (Fig. 2).

A GIS platform allows us not only to superimpose these poly-layers, like overlays on a map, but more importantly to vertically integrate them, using “map algebra” [141, 142] and more sophisticated geospatial algorithms, to produce a dynamic, composite model of past landscapes and landuse. For example, values from a human landuse poly-layer, representing a predominance of ovicaprine grazing on a particular patch of the landscape, can serve as input to a vegetation community poly-layer as an edaphic factor favoring the presence of shrubs and ‘pasture weeds’ over woodland taxa in a vegetation modeling algorithm. Values from the corresponding location in the vegetation poly-layer can then serve as input to a geospatial algorithm for surface geomorphology in a terrain poly-layer, as vegetation cover affecting the potential speed and quantity of overland water flow from precipitation for entrainment and transport of sediment in the corresponding terrain locale. While this may seem exceedingly complex from a computational standpoint, it is in fact standard operation for a GIS.

Furthermore, raster GIS represents these landscape poly-layers as n-dimensional cellular space—e.g., a grid of equal-sized cells having x and y spatial coordinates, plus information such as erosion potential, vegetation composition, and grazing intensity [142-144]. Values of the multiple dimensions of this cellular space can serve as input to geospatial process modeling, and modeling output can alter the values (and hence the represented landscape) in any cell. Agent simulations of human land-use, also operating in this cellular space, can use the multiple values from each cell (including output from geospatial modeling) as resources or information for decision algorithms that determine the landuse behavior and

**Figure 2: multidimensional geospatial data**
replication potential of agents. Agent behavior, in turn, can equally alter parameters of each landscape cell (e.g., by changing the vegetation cover through land clearance or erosion potential through cultivation).

The major challenge in building the sorts of models described here will be in conceptualizing socio-ecological processes in terms of governing equations in geospatial models and decision algorithms in agent models, not in primary development of software platforms sufficient for the carrying out this work. Using well-defined conceptualizations, existing suitable software tools will be adapted, extended, and integrated to construct a dynamic modeling environment. This will give us a digital laboratory, based on the paleoecological and archaeological record, for studying the processes responsible for the biophysical changes in prehistoric Holocene landscapes of the southern Levant and Mediterranean Spain. The data and software for building this environment will reside on a collaborative database/development server maintained in the ASU Department of Anthropology (see budget and facilities sections).

**A Modeling Environment for the Laboratory of the Past**

**Model Design Overview:** In order to address research questions about the long-term dynamics of scale and diversity, intensification and resilience, and long-term sustainability of Mediterranean agropastoral systems, we need to build three parallel and linked models: a Reference Landscape Chronosequence, a Potential Landscape Model, and an Agropastoral Socioecology Model. The Reference Landscape Chronosequence is a temporal sequence of static landscape models (i.e., terrain, vegetation, and human landuse) developed from archaeological and paleoenvironmental data. Together, they represent the landscape as it actually was at particular times in the past. The more closely the outcomes of the Agropastoral Socioecology Model (i.e., terrain configuration, vegetation cover, distribution of human settlements and landuse) correspond to the conditions of this reference model at appropriate time intervals, the more likely it approximates long-term processes that actually took place in each study region. The Potential Landscape Model dynamically represents terrain and vegetation communities through time in both study regions without the effects of human agropastoral landuse. This serves as a baseline to help evaluate the effects of the development, dispersal, and intensification of agripastoral systems on Mediterranean landscapes. The last of these three models is a quantitative representation of long-term dynamics of human interaction with the natural environment in the context of the development of Mediterranean agropastoral systems.
Reference Landscape Chronosequence: We start with a description of this model because it is essential for defining the initial states of both the Potential Landscape and Agropastoral Socioecology Models, and illustrates the role of archaeological and paleoenvironmental data in model development and evaluation. In brief, we will create a sequence of landscapes, using data from the prehistoric record, that represent each study area as it was at various intervals from 8,000-1,500 BC: paleoterrains will be modeled from remnant landforms, such as alluvial terraces and channel fills; paleovegetation cover will be modeled from prehistoric micro- (i.e., pollen) and macro- (i.e. seeds and preserved plant parts) botanical data; and human settlement will be modeled from the distribution of archaeological materials. In basic concept, this is very similar to the kinds of narrative models that have been developed in the past to portray human-environmental interaction [122]. However, we will do this quantitatively in a GIS environment because the results of this work will be used by the other two, dynamic models. The design of the reference chronosequence, and its relationship to the other models is shown schematically in Figure 3.

First, a terrain poly-layer will be created as chronological sequence of digital elevation models (DEM’s) to represent past terrains. We will start with a modern DEM of each area. These are available at a 25x25m cell-size for eastern Spain and 30x30m cell-size for the southern Levant. However, we will create higher resolution (10x10m) DEM’s from paired SPOT satellite images (using standard Orthomax routines in ERDAS Imagine software) to permit higher precision geospatial modeling of erosion and deposition. Remnants of ancient Holocene landforms—such as alluvial terraces, alluvial fans, and channel fills—will be identified using extant geological data, combined with analysis of multispectral of satellite imagery and groundproofing during new geomorphological surveys (see below). Information derived from these remnant landforms will be used to modify modern DEM’s to create models of the terrain at different past intervals. For example, Hill and Schuldenrein documented a series of alluvial terraces in the Wadi al-Hasa that are remnants of the valley floodplain at different times in the past [17-19]. It is a straightforward GIS procedure to ‘fill’ (a standard, map algebra operation) the valley to the level of each terrace (taking into account its sloping geometry in the upstream direction) to create a map of the ancient floodplain for each terrace set. Analogous interpolation techniques [126, 142] will be used to digitally trace ancient streams from channel fills and expose ancient surfaces now buried under alluvial fans. A simple example of such procedures is shown for one of the Spanish study areas in Figure 4.

The paleoterrains modeled here will be used by the other two dynamic models in two ways. First, the earliest Holocene (i.e., pre-agropastoral) terrains of each region serve as initial states for each of the other two models. That is, they begin with the terrains prior to the effects of agropastoral landuse, and subsequently dynamically model Holocene landscapes with and without the effects of such landuse. Second, as discussed below, terrains dynamically created by the Agropastoral Socioecology Model need to approximate actual past terrains of the Reference Landscape Chronosequence if they are accurately representing past processes. In this sense, the terrains of this reference chronosequence help to validate the dynamic model that is a major component of our study. Finally, the terrains of the Reference Landscape Chronosequence provide critical topographic edaphic parameters for modeling the reference vegetation poly-layer

Long pollen cores, shorter pollen sequences from archaeological sites and other localities, and macrobotanical assemblages from archaeological and other localities (e.g., Hyrax middens) will provide the data for assembling a poly-layer of vegetation cover for the reference chronosequence in both study regions (Table 4). Following methods developed by Spikins [145] and Schmich & Barton [146, 147], we will combine Boolean operations to identify landscape cells in the terrain poly-layer that meet edaphic re-
requirements for major Mediterranean plant taxa [144: 171-176, 148, 149] with regional and local scale paleobotanical data to distribute vegetation across landscape cells in a manner that best matches these data. For example, matorral/maqui shrub communities and evergreen oak woodland potentially can occupy the same hillslopes. We will use paleobotanical data to estimate which community is most likely in the landscape cells of different parts of our study regions [69, 70, 146, 147]. Given the resolution of paleoenvironmental data sources, we will create vegetation models at the level of community associations rather than the distribution of individual taxa. However, this is sufficient for addressing issues of long-term ecological change in the context of this project.

Finally, a reference chronosequence of human settlement will be generated from known archaeological data within each study region. Given that the terrain has changed significantly over the past 10 millennia in some areas, but especially in alluvial landscapes conducive to both early agriculture and erosion, it is highly likely that remaining archaeological sites underrepresent actual prehistoric settlement in some areas. Hence, known archaeological sites (i.e., extant remnants of past settlement systems) will be used to identify the terrain and vegetation characteristics conducive to past human settlements of varying sizes as well as probability estimates that a settlement of a particular type will occupy a landscape cell. A combination of Boolean and stochastic algorithms will be used to ‘populate’ the remainder of each reference terrain (e.g., prehistoric floodplains modeled from alluvial terraces) with prehistoric settlements, following well-established methodologies of GIS-based archaeological settlement modeling [150-153]. To give an oversimplified example, for an alluvial terrace with a density of 1 medium village and 3 family farms per 10 sq. km. of landsurface with a slope of <5°, this same density will be applied to the level parts of the modeled floodplain for which the terrace is a remnant landform. Again, this kind of settlement model will serve well to address the issues of long-term landuse posed here. Our goal is to understand long-term outcomes of human landuse, not locate particular archaeological sites.

**Potential Landscape Model:** The potential landscape model dynamically represents Mediterranean landscapes and their evolution in the absence of agropastoral landuse. Landscape change in the model is driven ultimately by Holocene climatic dynamics, affecting primarily the distribution of vegetation communities, but also terrain morphology through both colluvial and fluvial processes. Within the Holocene of both areas, tectonism and sea level change contributed much less to landscape change than the other processes we model here [19, 154]. They are included in the CHILD and SIBERIA models, however, and can be included in our work as appropriate, using extant data for both regions.

The early Holocene terrain and vegetation of the Reference Landscape Chronosquence will constitute the initial state of this model. Climatic parameters, topography, and landcover will subsequently serve as input into a geospatial process model to simulate landscape dynamics. We will not develop our own climatic model, but will use a macrophysical climate model developed by Bryson and colleagues of the Archaeoclimatology Laboratory (Univ. of Wisconsin, <http://ccr.aos.wisc.edu/bryson/archaeoclim.html>), who will serve as consultants to this project. Over the past decade this team has developed a high-resolution model especially useful for providing critical Holocene climatic parameters (e.g., monthly and annual temperature extremes and means, and precipitation accumulation and intensity) for archaeological locales [64-67]. Very recently, this model has been coupled with GIS to produce georeferenced climate data. In a test case, climatic parameters critical for dryland farming and ovicaprine grazing were modeled across Mesopotamia from 10,000-3,000 BC [155]. This georeferenced Holocene climate model agrees very well with regional proxy climate data derived from pollen cores, sediments, and lakebed geochemistry.

Again following Spikins’ methods [145], algorithms that combine climatic (e.g., temperature and precipitation) and topographic (e.g., elevation, slope, aspect) parameters will be used to determine the most likely vegetation association to occupy each landscape cell, draping vegetation cover across the initial terrain. Landcover and climate will serve as input to a geospatial model of geomorphology using algorithms that alter the elevations values in landscape cells through addition (i.e., sediment deposition) or subtraction (i.e., erosion). Table 3 illustrates the computation of net erosion and deposition due to overland water flow developed by Mitas and Mitasova [60, 156]. Implementing this model in a GIS platform, the coefficients are landscape layers combined through map algebra to calculate a new terrain layer in which each cell...
holds a value for $ED(r)$. $ED(r)$ cell values in this resultant layer are added to or subtracted from cell elevations of the original DEM to simulate deposition or erosion respectively. Colorful examples of such process models in action can be seen at the modeling web sites mentioned previously [157-159].

Table 3: USPED algorithm

<table>
<thead>
<tr>
<th>$ED(r)$</th>
<th>$K_i$</th>
<th>$\left[ \begin{array}{c} \text{grad} h(r) \end{array} \right] s(r) \sin b(r) - h(r) [k_p(r) + k_t(r)]$</th>
</tr>
</thead>
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$ED(r)$ is net erosion/deposition, $K_i$ is a sediment transport coefficient dependent on vegetation cover and soil characteristics, $s(r)$ and $b(r)$ are slope vectors, $h(r)$ is the runoff from upslope, & $k_p(r)$ and $k_t(r)$ are local terrain curvature measures.

The results of such geospatial process modeling will create the terrain of the next step of the model. Algorithms for vegetation cover and geomorphic dynamics will be recalculated, and the process repeated iteratively for each subsequent step. Because the intent is to model the landscape without agropastoral landuse, the Reference Landscape Chronosequence will not be useful for validating subsequent vegetation or terrain in subsequent steps generated by the Potential Landscape Model. Spikins’ methods allow for the inclusion of ecological succession factors to more accurately model the rate and nature of changes in vegetation communities within cells. The number of steps used to model 6500 years of landscape change is limited ultimately by the resolution of the climate model. Although the Wisconsin climate model can theoretically generate parameters at monthly resolution, we will initially use the output from 50-year steps for model development—for example using temperature and precipitation averaged over 50-year intervals for vegetation or run-off accumulated over 50 years for terrain (internally, such averaging may require smaller, intermediate time-steps for some parameters, of course [127]). This resolution equals or exceeds that of the prehistoric record (i.e., reference chronosequence) used to anchor and validate the agropastoral landuse model. More importantly, it permits us to focus on the long-term dynamics of human-environmental interaction rather than the day-to-day and annual dynamics that are better seen in studies of modern systems. The dynamic nature of this model is not altered by the temporal resolution, however. (It is irrelevant whether there are 130 50-year steps or 130 1-minute steps). It is dynamic in that each step is quantitatively a function of the state of the preceding step (i.e., vegetation cover and terrain) and an equally dynamic outside factor (climate), and in turn determines the state of the succeeding step. This significantly differs operationally from the Reference Landscape Chronosequence, which is a series of static ‘snapshots’ of past landscapes that are not dynamically linked with one another.

The result will be a long-term dynamic model of non-agropastoral landscapes in each study area. As such, it is useful for comparison with the Reference Landscape Chronosequence to assess the extent to which anthropogenically modified landscapes may have varied from non-anthropogenic ones. However, to understand the processes by which agropastoral landuse transformed Mediterranean ecosystems, a more sophisticated model is required. To build this, the basic design used in the Potential Landscape Model will be followed in the model of agropastoral socioecology, described in detail below, with the addition of anthropogenic landscape alteration simulated by agent modeling of human landuse, and validation of the model against actual past conditions (represented in the Reference Landscape Chronosequence).

Agropastoral Socioecology Model: This model serves as the primary tool of our laboratory for understanding agricultural dispersal, intensification, its effects, and sustainability. It begins with the same early Holocene paleoterrain and vegetation as the Potential Landscape Model, includes the same input from the Wisconsin climate model, and uses the same geospatial algorithms to link and model the dynamics of topography and vegetation through time. But it differs from the Potential Landscape Model in two important respects. First, it includes algorithms for modeling human landuse decisions and their effects on vegetation cover and terrain surface. As explained above, agent modeling better simulates these decision processes than does normal geospatial modeling based on physical governing equations. Nevertheless, human landuse took place in the same spatio-temporal context as the biophysical processes represented by geospatial modeling. Human landuse modeling and its linkage to geospatial modeling are described in more detail below. Second, the Potential Landuse Model represents the probable Mediterranean landscapes that would have obtained in the absence of human agropastoral landuse. Because this was not the actual course followed by Mediterranean ecosystems, however, it is not possible to truly validate the Potential Landscape Model beyond ensuring that the landscapes it produces reasonably match what might be generally expected of Mediterranean biophysical systems based on modern data. However, close comparison with
extant Mediterranean landscapes, even so-called natural preserves, is problematic as there is likely no place in this region that has not been affected in a significant way by humans at some time in the past 10,000 years [3]. On the other hand, the objective of the Agropastoral Socioecology Model is to represent the actual ecological dynamics of this region. Hence, it will be validated against the prehistoric record from each study region—represented here by the Reference Landscape Chronosequence—and modeling parameters will be adjusted to improve the fit between the model and the known outcomes of human-environmental interaction (see below). In this way, we will combine the rich prehistoric record of this region and new digital technologies to create a laboratory to investigate socioecological processes.

As shown in Figure 3, the agent modeling routine of the inclusive Agropastoral Socioecology Model will obtain inputs from the georeferenced biophysical data (derived from geospatial modeling) managed in the GIS platform, and as a result of landuse behavior, alter biophysical characteristics of terrain and vegetation. In reality, of course, landuse decisions are made by individuals over timeframes of days or hours, and generally within the course of the annual seasonal/agricultural cycle. As with the Potential Landscape Model, we will utilize a coarser temporal and organization scale, more appropriate to the prehistoric record and our research questions, for modeling long-term processes across 6,500 years. Organizationally, agents will represent communities rather than the individuals and the combined landuse decisions of community members. This approach is reasonable for at least two reasons. Ecologically, the impact of agropastoral systems can be regarded as an ecological footprint surrounding a community, its size and impact proportional to the population in the community and their cumulative resource use [160]. This makes sense here from the perspective of our goals of investigating human-environmental relationships at regional scales over long time periods. Second, most prehistoric farming communities (and many in the modern world) were comprised of a limited number of (often related) individuals. Much agricultural work, especially in preindustrial settings, requires cooperative involvement of numerous individuals. As a result, while individuals may still attempt to maximize their personal returns, this often involves considerable cooperation and corporate decision-making at the community level. We also will treat landuse decisions and their impacts cumulatively over a modeling step interval of 50 years. Again, this is reasonable because of our focus on long-term change. However, it also falls within the lifespans of many individuals who reach maturity—even in prehistoric societies—and hence landuse information processing and decisions over 50 years are well within the span of accurate social memory of communities [161].

Landuse Decision Model Overview: We will use prior work on agent modeling of prehistoric agricultural communities as a guide in developing our agent modeling environment (e.g., [49, 111, 137-140, 162]). In broad outlines, an agent community will occupy one or more cells on a landscape, its size proportionate to community size and, consequently, productive capacity and potential for landscape modification. It will collect information about biophysical conditions in neighboring cells—for example cells representing the distance over which people normally walk to fields, perform work, and return in a day. Based on information such as landcover (e.g., forest, matorral, cultivated, fallow), topography (e.g., slope, aspect, sediment/soil cover), and expected climate (e.g., current temperature and precipitation values), a community agent will allocate different landuse activities to the neighborhood cells (e.g., do nothing, graze x number of animals, cultivate plants, fallow a previously cultivated field). An agent’s costs for landuse activities will include both agropastoral labor and travel to and from fields or pastures. The agent’s objectives initially will be simply to maximize agricultural returns for the community in the next cycle (but see below). Storage in such societies was limited and will only be maintainable for one 50-year model cycle. Successful communities will either maintain themselves or grow. If they grow beyond a specified size, they will fission (i.e., replicate) and establish a daughter community at some distance from the parent community. Unsuccessful communities can shrink or disappear. Agropastoral landuse will produce subsistence resources that will determine the success of the community. However, it will also alter the biophysical characteristics of the landscape. For example, soil cultivation itself directly increases the potential for erosion on slopes. Both cultivation and gazing can reduce the vegetation cover, increasing erosion potential, while fallowing can increase vegetation cover. Land clearance can replace woodland with fields; when fallow, these can begin to return to woodland, but may never reach this stage due to renewed cultivation, grazing, or loss of soil cover. These factors will be added to the vegetation cover algorithm for
cells that have been cleared, cultivated, and or grazed. Also a ‘declining fertility’ function will be added to cultivated fields, increasingly favoring fallowing for a cultivated cell over time, and vegetation cover in grazed cells will change and decline over time. These changes in landscape characteristics will influence landuse choices and their landscape effects in the next model step.

**Validation:** Initial values will be derived from ethnohistoric studies of Mediterranean small-scale farming [154]. However, there are many factors whose values can be varied with effects on landscapes that range from minimal to significant, with consequent effects on future landuse and communities success. Systematically adjusting these factors, we will ‘tune’ the model to approximate real prehistoric landscape and settlement characteristics of the Reference Landscape Chronosequence. The fact that data in the reference chronosequence from different types of prehistoric datasets are not necessarily synchronized chronologically or spatially (e.g., dates of particular remnant landforms may not exactly correspond with vegetation data from a pollen core, or the dates of a set of prehistoric settlements) provides a wider dispersion of verification points for our model in space and time. Because the output data from both agropastoral and reference models will be managed within the same GIS platform we will be able to quantitatively compare model outputs through spatial covariance measures of terrain characteristics, vegetation communities, and settlement location for each time interval with relevant data in the Reference Landscape Chronosequence (see analogous procedures in [20, 111, 154]). This will allow us to identify areas of spatial and temporal convergence and divergence between the dynamic model and prehistoric reference data, and better adjust the former as needed.

### A LABORATORY FOR ADDRESSING MAJOR RESEARCH THEMES

**Theme One: Effects of Agricultural Dispersal and Settlement Growth on Landscape Diversity**

| Research Questions: | How does landscape diversity vary with spatial scale in Mediterranean ecosystems? How do diversity-scale relationships change with the scale of human landuse? |
| Laboratory Tests: | Model agropastoral landuse growth and landscape change for Neolithic Levant and Spain. Calculate spatial diversity measures for landforms and vegetation. Compare zones around settlements with those away from settlements. Track changes in diversity measures across space and time through the Neolithic of both regions (see Table 2). Compare with contemporaneous spatial diversity indices for Potential Landscape Model. |

This theme centers on issues of spatial scale in coupled human and natural systems, particularly the linkages between measures of biophysical diversity at different scales, and variation in the extent of agropastoral landuse. Diversity is a function of the scale at which it is measured, from the few square meters under the canopy of a single tree to the taxa and their web of interrelationships within the entire Mediterranean biome. A common perception that human perturbation of ‘natural’ ecosystems always reduces biodiversity ignores issues of scale. While the diversity of a tilled field may be less than that of an untilled plot, overall biodiversity may actually increase in an agricultural zone at larger scales if one considers the remnant suite of pre-agricultural flora and fauna, introduced domestic plants and animals and their commensals, and a landscape that includes tilled, fallow, uncleared, and pasture patches.

During the Holocene, agropastoral landuse created a patchwork mosaic of distinct micro-habitats in Mediterranean landscapes, and made landscapes more dynamic with hillslope erosion and gullying due to forest clearance and grazing on the one hand, and soil and water conservation projects on the other. These linkages between landuse and landscape diversity were iterative and dynamic, influencing landuse decisions that, in turn, increased, decreased, or redistributed landscape diversity. Such changes in the distribution of ecological diversity may, in fact, have favored agropastoral economies over alternative means of improving returns (i.e., making hunting and gathering more efficient) in early Holocene subsistence economies.

Understanding why agriculture spread so rapidly and globally at the expense of economic systems that had been enormously successful for hundreds of millennia remains one of the fundamental questions of human prehistory [1, 8]. Previously, it has not been possible to address the long-term effects of the spread of agropastoral systems on biophysical diversity, regardless of the abundance of archaeological and palaeoenvironmental data at any particular site. Even interdisciplinary regional studies that have been able to
provide a glimpse of the complexity of long-term human-environmental interaction [13, 123, 124] have lacked the basis to systematically assess the effects of agropastoral landuse on biophysical diversity. This can only be done by quantitatively integrating data from multiple locales into a comprehensive modeling environment.

To quantify topographic diversity within our modeling laboratory, we will reclassify cells of digital landscapes in terms of terrain parameter indexes (e.g., slope, aspect, elevation, profile curvature, and morphometric features such as peaks, ridges, channels, etc.). Cells of vegetation poly-layer incorporate information about the vegetation community occupying each cell. We will then measure diversity in such indices of biophysical landscape characteristics within moving windows of varying sizes to assess changes in diversity/scale relationships. We will do this for each modeled landscape throughout the Neolithic of each area, and compare areas around human settlements with landscapes away from human settlements. We will also compare diversity/scale relationships measured from landscapes of the Agropastoral Socioecology Model with those of contemporaneous landscapes of the Potential Landscape Model.

Alternate hypotheses about the effects of human agropastoral landuse on ‘pristine’ Mediterranean landscapes that we will evaluate include: 1) agropastoral settlements are biodiversity ‘sinks’, much lower than the surrounding area; 2) although individual fields may have low diversity, the combined ecological footprint of early agropastoral settlements are diversity ‘peaks’ relative to the surrounding area; 3) diversity varies in some way (e.g., from low to high to intermediate) at varying distances from settlements. An important related question is to what distance do agropastoral impacts on the landscape extend beyond the area actually cultivated and grazed, if any? And over what kinds of time scales? That is, does the impact of agropastoral landuse spread in some regular fashion proportional to the growth of settlements or are there more complex effects that can cause such landuse to lead to cascading non-linear changes in surrounding ecosystems? Answers to these questions are relevant to understanding how agropastoral economies came to replace successful hunting and gathering economies—even though they appear to have no clear initial benefit in terms of providing subsistence, reducing labor for subsistence (quite the contrary in fact), or even buffering subsistence risk more than social networks. They are also relevant to better understanding the broader spatial impacts of cultivation and grazing on modern landscapes. For example, many world “hot spots” of high ecological diversity are surrounded by or interspersed with small-scale village farming. What can we expect to see in these areas in 50, 100, or 500 years?

In this respect, we will also evaluate the impacts of agropastoral landuse on biophysical diversity over long time spans. It has been suggested that: 1) initial impacts are high, but decrease as the landscape re-adjusts to a new anthropogenic equilibrium [122], 2) impacts can be variable and limited to the life of an agricultural settlement [163], or 3) impacts are long term and essentially permanent [83, 84]. It is not unlikely that all such alternatives are possible and conditioned in part by climate/landscape features as much as human landuse. By modeling agropastoral-landscape interaction over millennial time scales at opposite ends of the Mediterranean and across diverse environmental conditions in each region, we should gain a better understanding of these processes. Finally, in comparing the landscapes of the Agropastoral Socioecology Model with those of the (essentially climate driven) Potential Landscape Model, we should be able to gain a clearer picture of some of the complex kinds of interactions (including amplifying and dampening) between anthropogenic and climatic landscape change [164].

**Theme Two: Landuse Intensification and Diversification, Landscape Stability, and Resilience**

**Research Questions:** How does intensification of agropastoral landuse and associated diversification affect landscape stability and resilience?

**Laboratory Tests:** Add algorithms for agropastoral intensification, and add production for exchange/markets to primary subsistence goals in agent modeling environment. Model landuse change and effects on landscapes from late Neolithic through Chalcolithic and Bronze Age in Levant and Spain. Calculate and compare measures of biophysical diversity and landscape change as in Theme One.

This theme deals with the effects of landuse intensification and diversification on Mediterranean socioecosystems. Landuse intensification refers to increased labor (or other) investment for increasing the productivity of agropastoral systems. Examples include manuring and other kinds of fertilization, expansion of lands cultivated through animal drawn plows or terracing slopes, and control of water through...
check dams and irrigation. Landuse diversification refers to both to an increasing array of domestic plants and animals managed and, more importantly, to increased use of agricultural produce for exchange and markets rather than direct subsistence only. Examples include cultivation of olives for oil and raising sheep for secondary products like milk (for cheese) and wool. Intensification and diversification often co-evolve because production for exchange and markets assumes production of surplus in excess of subsistence needs, in turn requiring higher productivity from agropastoral systems. Such intensification and diversification are almost always associated with the rise of craft specialists, social differentiation, and the potential for differential accumulation of wealth and power among individuals [5]. Recently, intensification and diversification have also been linked with attempts to raise or simply maintain productivity in the face of landscape degradation from prior landuse [165]. Finally, very recent research in our study areas is suggesting that the earliest agriculture may have been practiced primarily in easily tillable Holocene floodplain alluvium, but that these areas also have a high risk of erosion and soil loss when cleared of floodplain woodland, tilled, and grazed [42, 154]. In the face of the loss of the most productive lands, as a result of prior agropastoral landuse, only those early agricultural societies that dramatically altered their agropastoral socioecology, through intensified agropastoral practices and diversified domestic products, were able to maintain socioeconomic integrity—alike to ecological adaptive cycles described by Holling [59, 166].

Direct effects of these processes are the spatial growth of highly anthropogenic landscapes and increased vegetation diversity (and possibly terrain diversity also) within these landscapes. Intensification especially, by more actively transforming larger areas of vegetation and terrain, increases the potential for much greater geomorphic activity (e.g. increasing erosion/deposition rates) and significant, widespread vegetation changes. These are often viewed as landscape ‘degradation’ [13, 167]. However, it is unclear whether such degradation is continuous and cumulative over time, as agropastoral societies grow and spread, whether it occurs primarily when human labor maintaining anthropogenic landscapes ceases due to political or economic reasons, or whether a period of rapid landscape change is followed by long periods of dynamic equilibrium [3, 122, 123, 167, 168]. Similarly, the resilience of Mediterranean landscapes over variable spatial and temporal scales in the face of intensive anthropogenic agropastoralism remains the subject of considerable debate [19, 20, 154]. While these issues have been conceptualized at appropriate regional scales it has so far been very difficult to track actual processes and their effects [169] because of the lack of a regional-scale modeling laboratory such as we propose here.

We will use our modeling environment to address these issues related to changing landuse practices and their long-term spatial and temporal effects on landscapes and human behavior. To focus on intensification and diversification, slight changes will be made to the agent modeling environment. In both study regions (and across much of the Mediterranean), landuse intensification took the form of terracing slopes, building checkdams across small watercourses, and expanding areas cultivated and/or grazed. We will modify the landuse options of the agent modeling environment to add terracing and checkdams to the suite of landuse behaviors (with consequent effects on algorithms for geospatial processes). We will also alter the goals to add production for exchange or markets to the initial goal of production for subsistence only, with additional possible returns in storable wealth that can add to a community agent’s growth potential. This, of course has the potential to alter decisions about the allocation of labor and landuse by agent communities. Again, we will verify the model by iteratively tuning it to match conditions of the Reference Landscape Chronosequence for the periods from the end of the Neolithic through the early Bronze age in both regions.

We will calculate measures of biophysical diversity and change at varying spatial scales through time, as described for Theme One and do similar kinds of comparisons through time, between the two geographic regions, and between the Agropastoral Socioecology Model and Potential Landscape Model. We will pay special attention to the extent to which zones of intensive agropastoral landuse diverge from equivalent areas in the Potential Landscape Models and the extent to which they converge (or do not converge) in locales where settlements have been abandoned (i.e., unsuccessful agents) to evaluate potential landscape resilience. We will also look for evidence (or its lack) of areas of dynamic stability of anthropogenic landscapes and the potential for rapid degradation when human labor input is removed. Finally, we
will compare the effects of more intensive and diversified agropastoral systems modeled for the Chalcolithic and Bronze Age of each region and those of earlier Neolithic systems.

**Theme Three: Sustainability of Human-Maintained Socioecosystems**

<table>
<thead>
<tr>
<th><strong>Research Questions:</strong></th>
<th>How is socioecological sustainability distributed across time and space? How does sustainability vary with environment and landuse practices?</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Laboratory Tests:</strong></td>
<td>Calculate settlement and landuse persistence measures through time (entire Holocene sequence). Compare with measures of biophysical parameters (Themes 1 &amp; 2). Undertake modeling ‘experiments’ to assess effects of alternative landuse practices on sustainability.</td>
</tr>
</tbody>
</table>

Long-term sustainability of landuse practices is an issue that has multiple facets. In the sense that agropastoral systems began to spread 10,000 years ago and form the basis for nearly all human subsistence today, these systems are sustainable at a global scale for millennia. Sustainability at more local scales is of more critical importance to making informed landuse decisions and is the focus of our research here. However, even such local sustainability is a function of temporal and spatial scale. For example, the Jordanian Neolithic site of ‘Ain Ghazal is an often mentioned example of large scale landscape degradation by Neolithic communities and the unsustainability of such practices—leading ultimately to the permanent abandonment of the once flourishing town [75, 83-85]. However, it is arguable that towns such as ‘Ain Ghazal had impacts that extended only a few kilometers around the settlement [154]. More importantly, ‘Ain Ghazal was only abandoned after many centuries as one of the largest and most successful population centers of the prehistoric Levant—with a history far longer than most human settlements today. Was ‘Ain Ghazal successful and was its socioecology sustainable? The answer depends on spatial and temporal scale. Within our study areas there is extreme variation in the temporal extent and continuity of human settlement and agropastoral landuse. The Neolithic hamlet of Niuet, in the comparatively lush Serpis valley in eastern Spain was occupied for a few generations at most, while the famous town of Jericho, situated in an apparently much less hospitable landscape in the Jordan valley is still occupied after nearly 10,000 years.

A long-term perspective on sustainability is important in the face of current debates over the ecological future of humanity. This involves better understanding social and natural factors that favor sustainable socioecosystems in varying environmental contexts and across varying temporal spans. Because agropastoral subsistence economy forms the underpinnings of civilization today, agropastoral landuse is of fundamental concern in any discussion of sustainability. The Mediterranean is an ideal locale to investigate long-term sustainability because of the continuous presence of agropastoral systems for most of the Holocene, and the modeling laboratory we propose here is well suited for addressing many issues related to sustainability in this region.

To identify and begin to quantify sustainable systems, we will build on methods developed by Hill and Barton for measuring temporal persistence of human settlement across landscapes [20, 38, 42, 43, 154]. This will allow us to recognize different ‘degrees’ of sustainability. We will subsequently compare spatial and temporal variation in sustainability with measures of biophysical variability at varying spatial and temporal scales, as described for research themes one and two above. Because the nature and factors influencing long-term sustainability are poorly understood, this will necessarily be a more inductive part of our overall research program. However, our modeling environment also permits us to undertake hypothesis testing of a sort not previously possible.

Having tuned the modeling environment to approximate real outcomes of long-term Mediterranean socioecosystems during research for Themes One and Two, we can begin to conduct ‘experiments’ of ‘what if’ scenarios in the region and assess their results in the modeling environment. For example, we can adjust our community agents to have the goal of maximizing agropastoral returns 2-3 steps ahead (i.e., 100-150 years into the future) rather than the next step to simulate long-term planning. It is widely felt that longer term planning is a key to sustainability. However, the complexity of social and natural interactions [110, 170], especially when combined with the potential for even more complex interactions with climate variability over longer time-spans [14] could obviate the supposed benefits of such planning. Such experiments can give us an understanding of the nature of sustainability not available from any other source.
They are not speculative exercises, but a way to explore some of the long-term consequences of alternative landuse decisions at variable spatial and temporal scales, especially with respect to the potential of diverse landscapes to sustain human populations. This kind of information can be valuable to modern land-use policy and planning, and can only be acquired through studies of the long-term human past.

**DATA SOURCES FOR MODEL BUILDING**

An advantage of the Mediterranean as a natural laboratory for studying the long-term interactions of human and natural systems is that an abundant body of rich and of archaeological and paleoecological data already exists for this region [e.g. 23, 24, 33, 34]. This is especially the case for the two study areas we have selected for the focus of our research. A comprehensive (though not exhaustive) list of extant datasets to be used in developing the Reference Landscape Chronosequence is shown in Table 4. Many datasets from the two study regions are already in digital formats that can be integrated into a common GIS data management platform. These will be parsed into standardized formats and rescaled as needed using modern database tools and GIS.

**Table 4: data sources for reference chronosequence**

<table>
<thead>
<tr>
<th>Research Type</th>
<th>Data Type</th>
<th>Example sources</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Archaeology: Southern Levant</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Digital archives (in GIS or GIS ready)</td>
<td>Site locations, sizes, structure/function, dates</td>
<td>Israel, W. of Jordan R.</td>
</tr>
<tr>
<td>Excavation**</td>
<td>Site structure/function, size, dates, economic data (plant &amp; animal remains)</td>
<td>Jordan Rift</td>
</tr>
<tr>
<td><strong>Paleoecology: Southern Levant</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pollen cores</td>
<td>Pollen spectra (composite vegetation history), microcharcoal (fire history), dates</td>
<td>Jordan Rift</td>
</tr>
<tr>
<td>Macrobotanical studies**</td>
<td>Seeds, charcoal, other plant remains</td>
<td>Jordan Rift</td>
</tr>
<tr>
<td><strong>Archaeology: central Mediterranean Spain</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>National &amp; local archives*</td>
<td>Site locations, sizes, structure/function, dates</td>
<td>Comunidad de Valencia, Consulta Jaciments Arqueològics online database Serpis drainage system, Alcoi Museum, [6, 88-91, 223-226]</td>
</tr>
<tr>
<td>Survey (in GIS)</td>
<td>Site location, sizes, structure/function, dates, surface collections of archaeological material</td>
<td>N. Alicante Province</td>
</tr>
<tr>
<td>Excavation – caves &amp; rock-shelters**</td>
<td>Long temporal sequences with artifact collections, plant &amp; animal remains, pollen, sedimentological data, dates</td>
<td>Serpis drainage system</td>
</tr>
<tr>
<td>Excavation (in GIS or GIS ready)</td>
<td>Site structure/function, sizes, dates, economic data (plant &amp; animal remains)</td>
<td>Middle Serpis, Penaguila, &amp; Polop valleys</td>
</tr>
<tr>
<td><strong>Paleoecology: central Mediterranean Spain</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pollen cores</td>
<td>Pollen spectra, microcharcoal</td>
<td>Comunidad de Valencia, unpublished data at U. Valencia and U. Murcia [239]</td>
</tr>
<tr>
<td>Sediment column**</td>
<td>Pollen spectra, microcharcoal, magnetic susceptibility, sediment/soil characteristics dates</td>
<td>Albufera de Gaianes, Barton 2000 fieldwork Caves &amp; rockshelters in N. Alicante Province [149, 240-242]</td>
</tr>
<tr>
<td>Macrobotanical studies**</td>
<td>Seeds, charcoal, other plant remains</td>
<td>N. Alicante Province</td>
</tr>
<tr>
<td>Geomorphic survey***</td>
<td>Landforms, dates, soil characteristics</td>
<td>N. Alicante Province</td>
</tr>
</tbody>
</table>

*Most sites in digital format (e.g., in online archives) and GIS ready; others may need manual data entry.

**Most data are published sources that need manual entry, though a few data sets are in digital format.

***Many sources include geologic maps that can be digitized into GIS format; some Hasa geologic data in GIS format.

Some data remain in hard copy format (paper maps, recording forms, field notes) and will need to be manually digitized and relevant attribute information entered into associated databases. While no new archaeological excavations or surveys are needed to complete this project, it may be necessary to reexamine...
original archaeological materials and collect new samples for radiometric dating (AMS 14C or luminescence dating) from older research projects to more precisely date agropastoral settlements and improve the accuracy of the Reference Landscape Chronosequence. This work will be carried out by our foreign collaborators (Bernabeu and Al Nahar) in both study regions, in coordination with US team members (Barton, Falconer, Clark, Hill).

**Geomorphic Survey:** Geologic studies have been carried out in both study regions. However, in some areas these have not been of sufficiently fine resolution (due to different field objectives) to identify and date the full range of Holocene remnant landforms needed to construct the paleoterrains of the Reference Landscape Chronosequence. To better identify and map these geomorphic features, Arrowsmith will combine extant geological data, with multiband satellite imagery (LandSat TM, Terra ASTER, and SPOT) and high resolution DEM’s created from paired SPOT imagery. These preliminary, fine-scale maps of remnant Holocene land surfaces (e.g., terraces and alluvial fans) and associated erosional features (e.g., wadi/barranco channels and truncated soils) will be ground-truthed, augmented, and dated during geomorphic field survey undertaken in both study areas. La Roca will direct a survey in the Serpis/Polop/Penaguila valley system, and Schuldenrein will direct a parallel survey in the northern end of the Jordan Rift transect and the lower reaches of the Wadi al-Hasa. The ultimate objective of this work is a digital geologic base map of dated remnant Holocene land surfaces for each study area, to be used for reference chronosequence terrains.

**Paleobotanical Study:** Numerous paleobotanical datasets exist for both study areas. However, in several cases, these have not been analyzed sufficiently for the purposes of this project. Badal will analyze plant charcoal and seeds that have been collected from a set of archaeological and non-archaeological contexts in eastern Spain for information on local vegetation; they will also provide more direct evidence of human farming practices. Fall and students will complete similar paleobotanical studies for the southern Levant, including completing analysis of the Holocene section of a 30m long sediment core previously extracted from the Dead Sea in 2000, in the southern part of the eastern study area. Carrión will extract and analyze the Holocene section of a new pollen core from the Laguna de Villena, Spain—in the basin immediately north of the Serpis/Polop corridor—to provide data on upland vegetation and hillslope erosion to complement extant regional-scale paleobotanical and geomorphic information. Although there are numerous short pollen sequences from this region and long cores from lower elevation locales, there are no long, complete sequences from an upland locality here. This former lake basin is the best upland locale in the western study region for obtaining a late Quaternary sediment sequence.

**Project Significance**

This project will provide ground-breaking opportunities to examine at regional scales the long-term processes that led to the evolution of human maintained socioecosystems, producing a significant body of new knowledge for understanding the long-term impacts of landuse decisions. The kinds of questions that can be addressed and their importance to issues critical to modern agropastoral landuse have been discussed in detail in the context of the major research themes above. We also expect it to produce broad benefits to scholars beyond those directly involved with this research. However, because of the important ramifications for understanding the integrative relationships between society and the natural environment generated by this project, it is essential that it be disseminated beyond the academic world. The most effective way to embed the knowledge we generate in the larger community is by making education an active element in the research process. We explicitly endeavor to do this at all levels.

In addition to knowledge generation, direct products of this work will include regional-level archaeological and paleoenvironmental datasets in standardized formats, and a vertically integrated, geospatial and agent modeling environment for landscape and landuse study. The datasets will be useful to Mediterranean scholars pursuing other questions and researchers can use the modeling environment to investigate landscape-landuse interaction in other regions and times. Both will be made widely available through a project web site, created with the assistance of the ASU GIS Laboratory and hosted by ASU. Integration of such large-scale models across multiple layers, model types, behavior, and degrees of spatio/temporal
resolution is now recognized as an important challenge in modeling. Our work will be a significant contribution to complex ecological modeling as well as to understanding socioecological dynamics. We will submit our modeling tools—as modules for widely available GIS packages from GRASS and/or ESRI, and agent-based modeling packages in environments such as DEVSJAVA, RePast, or SWARM—to international archives such as that of the International Society for Ecological Modeling <eco.wiz.uni-kassel.de/ecobas.html>. Final project results will also be presented in a symposium, held in conjunction with a national professional meeting, and subsequently published in a book-length volume. Individual project members and collaborative teams will publish more specific papers in international journals.

**Education Plan**

Our program for integrating research with education is multifaceted with a strong effort identified for outreach to students traditionally underrepresented in the sciences. At the university level, we will offer hands-on training for graduates and undergraduates, sponsor MA, MS, and PhD research programs, and enhance classes. Graduate RA’s will be offered in parsing and analysis of archaeological and environmental datasets, geospatial and agent modeling, creating web-based GIS, and education and outreach. We will provide additional research and training support annually for four graduate students (3 month stipend and travel funds) to work with researchers at other institutions collaborating in this project, and similar support for two undergraduates (1 semester stipend) to participate in the research process. Project PI’s also will seek R.E.U. funding for outstanding undergraduates. Finally, this project will be integrated into relevant courses taught by ASU PI’s (e.g., Human Impacts, Spatial Technology, Paleoecology, Geoarchaeology, Modeling, Simulation) that serve over 300 students annually.

Our study of the dynamic interface between humans and the environment has the potential for engendering an excitement for science and fostering a better awareness of the geography of the human past. While direct student involvement in research is especially productive at the university level, energizing teachers is the most effective way to convey our knowledge at the **K-12 levels**. Today, any K-12 science outreach must address the challenge of No Child Left Behind (NCLB) legislation. Because of the emphasis it places on testing in core Math, Reading and Writing subjects, teachers across the country are being told to avoid or substantially reduce science teaching until test scores go up [245, 246]. This is especially true in low-income and minority schools. Our overarching goal here is to develop a sustainable outreach program that meets the K-12 needs, especially of underserved (minority, poverty, rural) schools, while explicitly articulating with NCLB legislation. We will utilize the Arizona Geographic Alliance’s model <alliance.la.asu.edu/geoliteracy/intro/GeoLitPresent.html> of grassroots involvement through the development of lesson packages that teach socioecology content and also help prepare students for the required Math/Reading/Writing tests. Charles Redman will oversee this task, aided by a staff-level education/outreach coordinator and an ASU-funded graduate assistant, and supported by the Arizona Geographic Alliance and ASU Center for Environmental Studies.

To be successful, our K-12 outreach will include the following elements. We will work with administrators and teachers, especially in poorly served (minority, low-income, rural, Native American) schools, partnering with the Arizona Geographic Alliance which has a decade-long track record of working with master teachers and administrators in these settings. PI’s will be involved in training teachers in human and natural ecology—through the integrated lens of standards in science, reading, writing and math. The latest NCES report emphasizes the importance of integration in science training, noting that "Eighth-grade students enrolled in a life science course had lower scores than their peers enrolled in earth science, integrated science, physical science, or general science." [247]. We will emphasize a ‘grassroots approach’ of supporting teachers (financially and through training) to write lessons that teach biocomplexity content, but whose internal lessons assessment instruments also teach to the NCLB tested areas of Math, Reading and Writing. Integration with literature and math is not only sound pedagogy [248], but critical to self-perpetuation of the outreach. Our goal is the development of a ‘EcoLiteracy/EcoMath’ set of lessons by the very teachers who serve in minority and low-income settings. These teacher authors will then be supported to train teachers in their schools and districts on this EcoLiteracy/EcoMath lesson package. Throughout this program, we will work to ensure that our piloting and assessment instruments meet the
"What Works Clearinghouse" (WWC) standards <http://www.w-w-c.org/standards.html> of the U.S. Dept of Education and maintain administrative support for teachers involved in the EcoLiteracy/EcoMath package. Our ultimate vision is to have a set of NCLB and WWC articulated biocomplexity lessons available on CD, and a core of teachers committed to their integration in underserved classrooms.

**PROJECT ORGANIZATION AND MANAGEMENT PLAN**

**Coordination and Management**

As indicated in the prior research section, most PI’s have led interdisciplinary teams and have multiple areas of expertise. Hence, the project will be organized in several partly overlapping teams (Table 5) to provide maximal opportunities for cross-regional and cross-disciplinary collaboration. A PI will serve as coordinator for each of the teams (Table 5). Barton will oversee the project as a whole and coordinate regular meetings among team members for planning and exchanging information (quarterly for the first year and semi-annually thereafter for all ASU members, with additional meetings as needed for specific teams). We will be in regular contact with U.S. and foreign collaborators by email and will hold an internet video conference yearly. Funding is budgeted to enable senior personnel from the participating institutions to actively collaborate in diverse contexts.

**Table 5: project management**

<table>
<thead>
<tr>
<th>Task</th>
<th>Personnel*</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Data collection</strong></td>
<td></td>
</tr>
<tr>
<td>Geological data</td>
<td>La Roca (Spain); Schuldenrein (Jordan); Arrowsmith (imagery)</td>
</tr>
<tr>
<td>Botanical data</td>
<td>Badal &amp; Carrion (Spain); Fall (Jordan)</td>
</tr>
<tr>
<td>Archaeological data</td>
<td>Bernabeu &amp; Barton (Spain); Al Nahar, Falconer, Clark (Jordan)</td>
</tr>
<tr>
<td><strong>Data parsing &amp; management</strong></td>
<td></td>
</tr>
<tr>
<td>Landscape data</td>
<td>Arrowsmith, Schuldenrein, La Roca, RA</td>
</tr>
<tr>
<td>Botanical data</td>
<td>Fall, Badal, Carrion, RA</td>
</tr>
<tr>
<td>Archaeological data</td>
<td>Hill, Barton, Falconer, Savage**, RA</td>
</tr>
<tr>
<td><strong>Modeling</strong></td>
<td></td>
</tr>
<tr>
<td>Geospatial Agent</td>
<td>Barton, Hill, Mitasova, Wentz, 3-4 RAs</td>
</tr>
<tr>
<td>Climate</td>
<td>Sarjoughian, 1-2 RAs</td>
</tr>
<tr>
<td><strong>Outreach</strong></td>
<td>Redman, Fall, staff, 1-2 RAs</td>
</tr>
</tbody>
</table>

*Task coordinator bolded where relevant; ** Consultant (see project description)

While some data collection and aspects of model development will take place at other institutions, ASU will serve as the central facility for data integration, management, analysis and quantitative modeling. At ASU, these activities will involve collaboration between the departments of Anthropology, Geography, Geology, Computer & Engineering Science, the Arizona Center for Integrative Modeling & Simulation, ASU Information Technology, and the ASU Center for Environmental Studies. The ASU Department of Anthropology and ASU GIS Laboratory will serve as the primary facilities for data management and analysis (see facilities section). Additional details on senior personnel qualifications and project roles are provided in Table 1, the discussion of prior work, and Budget Justification section.

**Project Scheduling**

The total length of the project is four years. We will begin the project with a 3-day workshop for all senior project personnel to: 1) establish standards for data collection, management, and storage (i.e., database content specifications); 2) discuss the organization of the GIS platform and constituents of the poly-layers; and 3) prioritize criteria of the algorithms for the geospatial and agent modeling. Barton and Redman, assisted by CES staff, will coordinate this workshop. Data collection will take place in Years 1-2. Database and GIS development will begin in Year 1 with the GIS/DBMS structure to be completed by the beginning of Year 2 so that geospatial data can be input. Development of geospatial and agent models will begin in Year 2 and continue through the remainder of the project. The conference to present and review results will take place in the year following the completion of the project (see also budget and justification).
Bibliography


70. Badal, E., J. Bernabeu, and J.L. Vernet, Vegetation changes and human action from the Neolithic to the Bronze Age (7000-4000 B.P.) in Alicante, Spain, based on charcoal analysis. *Vegetation History and Archaeobotany*, 1994. 3: 155-166.


