HUMAN BEHAVIORAL ECOLOGY AND CLIMATE CHANGE during the Transition to Agriculture in Valencia, Eastern Spain

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Using the behavioral ecological model of ideal free distribution (IFD), McClure, Jochim, and Barton (2006) identified the tight linkage between agricultural subsistence strategies, herd management, and long-term dynamics of human land use. Missing from their discussion, however, was placing these changes into a broader environmental context. The IFD provides a useful heuristic device to illustrate cost-benefit decisions within a spatial context. This paper compares the previous interpretations of land use during the Neolithic with climatic data from the Holocene. Two main arid periods have been identified during the early and middle Holocene that correspond chronologically to Neolithic cultural horizons. Climate models recently generated for the area further suggest shifts in precipitation cycles may have exacerbated the impacts of broader climatic fluctuations on agricultural production.

THE NEOLITHIC IN THE ALCOI BASIN AND THE IDEAL FREE DISTRIBUTION MODEL

THE TRANSITION TO AGRICULTURE IN THE ALCOI BASIN, NORTHERN ALICANTE PROVINCE (Autonomous Region of Valencia; Figure 1), is marked by the appearance of domesticated plants and animals along with a suite of pottery types in the fourth millennium BC. Intensive archaeological survey and excavations in caves, rockshelters, and at the open-air village site of Mas d'Is have provided detailed information on Early Neolithic land use, settlement patterns, and economic activities. Scattered farming communities were located on fertile riverine headwater areas during the Neolithic I (ca. 5,600–4,500 cal BC; Table 1). Subsistence was focused on domestic animals and plants, although farmers continued to harvest wild foods to a lesser degree. Of the domestic animals, sheep and goat were the primary livestock, and archaeological evidence suggests that farmers used the landscape in an extensive manner, including travel to upland

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valleys for summer pasture (e.g., Geddes 1980, 1983; McClure et al. 2006; Pérez 1999). Large-scale ditches at the village of Mas d'Is and elsewhere (Bernabeu and Orozco 2005; Bernabeu et al. 2003), cave deposits with high quantities of decorated pottery, bone carvings and other "ritual" items (Bernabeu et al. 2006, Martí et al. 2001), and abstract rock art grouped in "sanctuaries" (Bernabeu 2002; Fairén 2007; Martí and Juan-Cabanilles 2002) have been interpreted as evidence for fairly complex group dynamics and the presence of a social power structure in the Early Neolithic (Bernabeu et al. 2006).

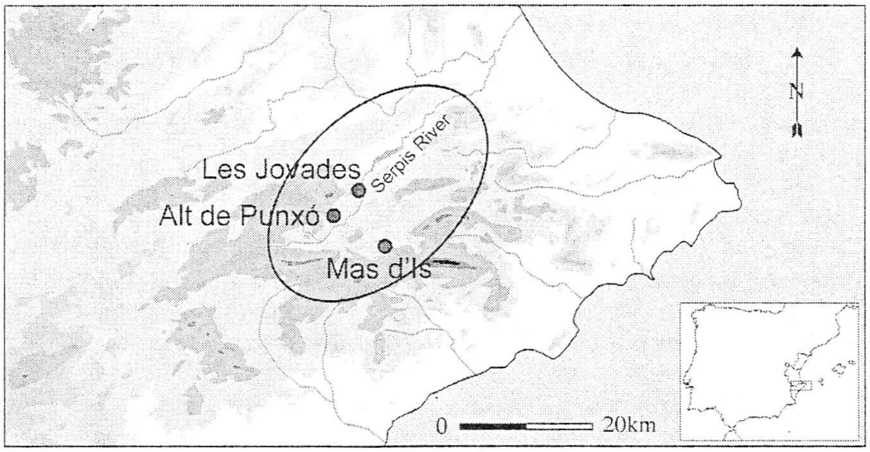

Figure 1. Location of sites mentioned in the text.

Current archaeological evidence suggests that this power structure changed dramatically at the beginning of the fifth millennium cal BC (Bernabeu et al. 2006). Many previously occupied caves and rockshelters were abandoned, and the earthworks at Mas d'Is began to infill naturally (Bernabeu et al. 2006; Molina et al. 2003, 2006). Few open-air sites dating to this period are known, but monumental earthworks are documented for the mid to late fifth millennium at Alt del Punxó (García et al. 2007). Farmers continued living in small, dispersed villages on fertile soils, but little information on internal group dynamics is available until the beginning of the fourth millennium cal BC.

By 3,500 cal BC, increased numbers of agricultural villages located on a greater diversity of soils document a demographic expansion. Agricultural activities were intensified by the use of the plow (Bernabeu 1995), and a greater emphasis was placed on pig and cattle rearing (McClure et al. 2006; Pérez 1999). Collective burials with numerous grave goods in caves and rockshelters parallel the development of megalithic tomb burial in other parts of the Iberian Peninsula and have been interpreted as evidence for emergent social hierarchies with links to complex societies of southern Spain (Bernabeu et al. 2001; Pascual 1987, 1990). Tighter economic links to regions farther afield are documented by the long-distance exchange of polished stone axes, ivory, amber, and other materials (Bernabeu 1995; Orozco 2000; Pascual 1987).

The Ideal Free Distribution

The ideal free distribution (IFD) is an ecological model, widely used in non-human population ecology, that seeks to represent habitat selection choices within an evolutionary framework whereby individuals attempt to maximize fitness (Fretwell and Lucas 1970). This model has been employed in studies on a variety of animal species, including humans (Abrahams and Healey 1990; Fretwell and Lucas 1970; Whitehead and Hope 1991). Recently the ideal free distribution has been employed to characterize and predict human behavioral ecology in archaeological contexts (Kennett et al. 2006, in press; McClure et al. 2006, Shennan 2007). The model also represents individuals' changing habitat choices in response to environmental change—including anthropogenic change. This makes it a valuable tool for exploring how individuals use and distribute themselves across a landscape under a variety of social and environmental conditions. Furthermore, the model provides a useful heuristic device to address cost-benefit decisions that people make on a regular basis in the absence of perfect knowledge and in the presence of underlying cultural and perceptual biases.

For the IFD, habitats are defined as biophysical regions in which a species is able to live, and landscapes are divided into habitats of different sizes and configurations (Fretwell and Lucas 1970:18). Individuals select a habitat based on its suitability; both (population) density-dependent and independent factors help determine a habitat's suitability. The relative suitability of habitats in a landscape provides the context for the distribution of individuals among habitats (Fretwell and Lucas 1970:19). This is akin to Brown's (1969) concept of the buffer effect: at low population densities, individuals tend to live predominantly in the more suitable habitats, whereas at higher population densities, a larger fraction will be found in poorer habitats (see also Sutherland 1996:7).

A habitat's basic suitability is initially defined when population density is close to zero (Figure 2). However, the suitability of the habitat changes as an increasing number of individuals exploit it. Declines in suitability may result from interference or competition from other individuals or longer-term resource depletion. Interference results when the presence of others restricts access to resources, thereby lowering the habitat suitability (Sutherland 1996:7). For example, interference can be due to increases in fighting or theft. In contrast, depletion is characterized by the removal or reduction of resources caused by immediate consumption or degradation of the environment.

The IFD assumes that individuals are making the best habitat choice available to them. As a result, the model predicts that individuals will distribute themselves first in the best resource location. As suitability of that habitat declines to the level of the next-highest-ranked habitat, individuals will move so their relative densities equalize the suitabilities of the two habitats. As populations continue to increase, densities within each habitat will rise, suitability will decline, and more habitats will be occupied.

Allee's Principle, a variation of the basic IFD model, recognizes that populations may also *increase* a habitat's suitability (Figure 3). The principle suggests that low population densities may increase returns to scale, and habitat suitability (H1) initially rises with increasing population size up to some maximum, or secondary suitability (Allee et al. 1949). Once that maximum threshold is reached, habitat suitability begins to decline. Human examples of this are agricultural investments such as irrigation systems or field terraces that require certain population densities to create and maintain, and result in higher agricultural yields (Kennett et al. 2006; McClure et al. 2006).

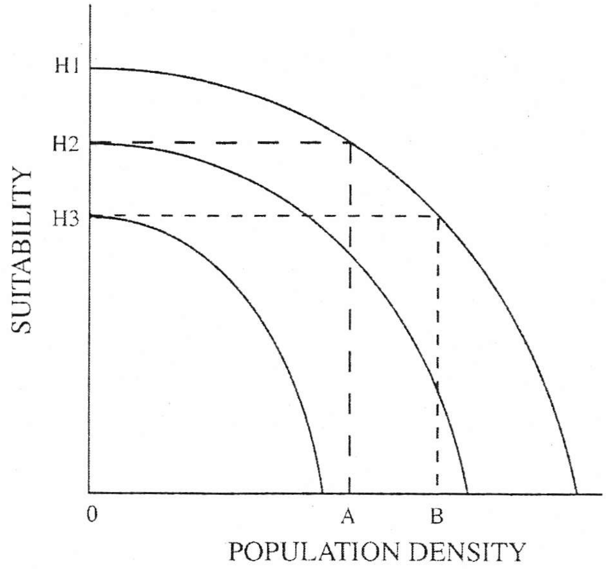

Figure 2. Ideal free distribution (after Fretwell and Lucas 1970:24; Sutherland 1996:5).

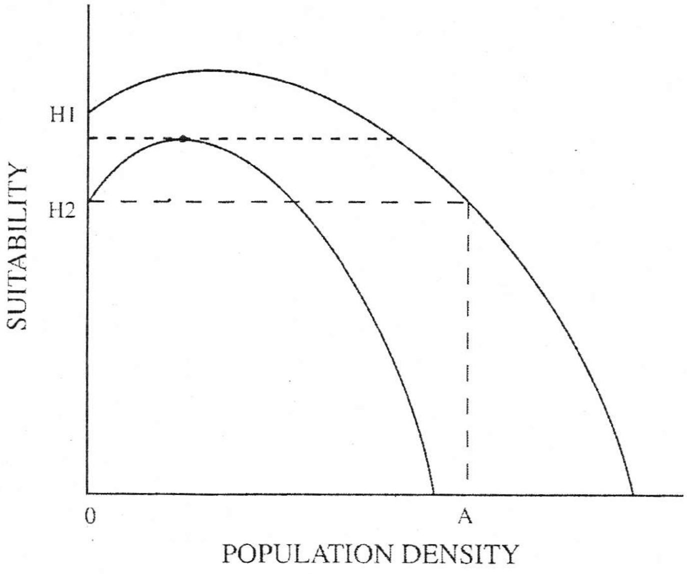

Figure 3. Allee's principle (after Fretwell and Lucas 1970:25; Sutherland 1996:11).

As the suitability of H1 declines, it eventually will equal the basic suitability of the next-highest-ranked habitat (H2), and individuals will distribute themselves equally in both habitats. One interesting aspect of Allee's Principle is that the suitability of H2 can increase with population growth, while H1 continues to decrease. Since the secondary suitability of H2 is higher than that in H1, individuals are expected to move from H1 to H2 until the suitability equalizes. This is important because the model illustrates how even a very small change in population density may result in a very large change in the distribution of a population within a landscape (Fretwell and Lucas 1970).

IFD and the Neolithic in the Alcoi Basin

Neolithic settlement and subsistence patterns were characterized using the IFD (McClure et al. 2006). The model provides a framework for understanding shifts in settlement practices that have been recognized in the Neolithic, and it identifies factors and processes that may have influenced habitat selection and population distributions. Eastern Spain has a long history of human occupation prior to the Neolithic, and the spread of farming was a complex process that likely involved several phases of migrating farmers and changing economic behaviors on the part of indigenous peoples. Despite some arguments to the contrary (e.g., Cruz and Vicent 2007; see McClure et al. 2008 for discussion), current archaeological evidence from faunal, floral, and ceramic assemblages indicate several independent phases of Neolithic spread into the western Mediterranean (Bernabeu et al. 2008; Guilaine et al. 2007; Manen 2000, 2002; Manen and Guilaine 2007; Zeder 2008). Agriculture appears rapidly in Mediterranean Spain, whereas demographic and socioeconomic data on indigenous hunter-gatherers is difficult to ascertain. As a result, the IFD model is particularly appropriate since the appearance of farming is a significant socioeconomic change and the farmers occupied an empty niche, even if low-density foragers were still present.

Previously we focused our discussion on animal management strategies, since livestock management involves landscape use and modification to make it economically viable. We argued that this spatial component of animal management is an important factor in estimating a habitat's suitability. Since Neolithic domestic animals of eastern Spain differ in meat yields, potential to provide secondary products, lifespans, and survival needs, they may be more or less suited to other economic pursuits. We examined the potential returns and costs of Neolithic animal husbandry in eastern Spain and their implications for habitat choices using the IFD.

We argued that the Neolithic I agricultural strategy is best described as a dispersed settlement focusing on the most productive patches for hoe agriculture. Individuals farmed these patches intensively and moved to another, equally high-ranking patch when fertility declined. They were accompanied by relatively small numbers of domestic animals, particularly sheep and goats, which were favored for their low management costs. The animals complemented the plant management strategy by allowing farmers to harvest resources in low-ranking patches such as abandoned fields and upland areas by converting inedible vegetation into meat.

The network of these productive patches for hoe agriculture was part of one habitat (Figure 4, H1).

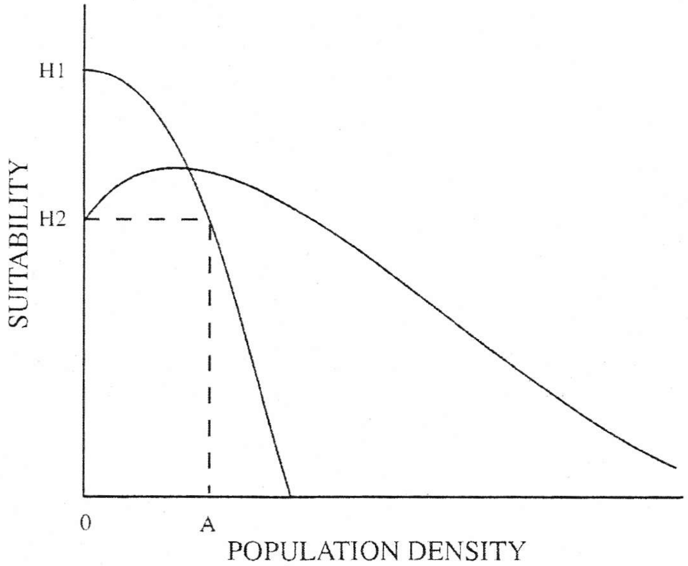

Figure 4. Adapted ideal free distribution and Allee's Principle models for the Neolithic in Valencia, Spain.

Habitat 1 (H1) represents settlement during the Neolithic I, habitat 2 (H2) represents Neolithic II settlement patterns (after McClure et al. 2006:213).

Although initially successful, the long-term consequence of this strategy was increased vulnerability to erosion during the winter rainy season owing to intensive cropping and pasturing, exacerbated by increasing human populations (another consequence of the initial success of this land-use strategy). Deforestation and greater sediment transport is evidenced by botanical and pollen records by the end of Neolithic I (Badal 1990; Badal et al. 1994; Bernabeu and Badal 1990; Dupré 1988; Fumanal 1986; Fumanal and Dupré 1986). High-ranking patches in H1 became scarcer, and habitat suitability declined (Figure 4). Notably, this reduction of basic suitability was not simply population-dependent; rather, human land-use permanently lowered the ability of this habitat to support subsequent farming activities, triggering shifts in population distribution and density (McClure et al. 2006).

During Neolithic II, farmers began exploiting another habitat that included patches in the valley margins (Figure 4, H2), especially along major waterways, representing a new socioecological niche (Barton et al. 2004a, 2004b; McClure et al. 2006). Extensive woodland clearance and use of ox-drawn plows made these patches more accessible and increased their suitability. This is presented graphically in Figure 4 as the Allee effect for H2. Numerous sites with storage pits (e.g., Les Jovades) indicate sizable sedentary populations, and evidence from cave sites shows an increased use of caves for sheep and goat corrals during Neolithic II (Badal 1999; Bernabeu 1993, 1995; Bernabeu and Pascual 1998; Bernabeu et al. 2006; Pascual 1989). Corral construction suggests that larger herds were kept in the caves for longer periods of time, and farmers were using areas farther from villages for pasture. In addition, corrals could house livestock while farmers hunted and gathered in upland areas. We have argued that the suitability of this new habitat rose with labor investment, improved technology, and shifts in domestic animal management from a focus on meat production to meat and milk production strategies, including more emphasis on cattle and pigs. The reasons for shifts in animal management strategies involved issues of labor allocation, scheduling, and the long-term viability of households (McClure et al. 2006).

The IFD model demonstrates that changes in population density did not have to be large to result in shifts in land use and socioeconomic niches. Decreases in suitability and a small increase in population density in the Neolithic I habitat (valley floors, H1) prompted initial settlement of the second-ranked habitat (valley margins, H2). Technological innovations such as the ox-drawn plow and ecological modification through deforestation increased the secondary suitability of this habitat. This increase in suitability may have attracted population and settlement away from the riverine margins fairly rapidly. However, what this earlier work failed to consider were climatic shifts during the Holocene and their potential ramifications for habitat suitability and selection. In the following, we summarize available climatic data and discuss the implications for the IFD model of Neolithic land use. We include preliminary data from climate modeling to strengthen the predictions and conclude with a discussion of factors relevant for Neolithic land use that continue to be tested in the archaeological record.

HOLOCENE CLIMATE CHANGE IN EASTERN SPAIN

Climate fluctuations during the Holocene are documented in a variety of paleoenvironmental records from eastern Spain (e.g., Badal 1990, 1999; Badal et al. 1994; Carrión et al. 1999, 2000; Dupré 1988; Fumanal 1986; Fumanal and Dupreé 1986; Jalut et al. 2000; see also Gil-Romera et al. 2009). Palynological studies of lake and marsh deposits and pollen and charcoal evidence from caves and rockshelters chronicle climatic and anthropogenic shifts in vegetation and erosion during the Holocene. Jalut et al.'s (2000) study of Holocene climatic changes along the western Mediterranean coast used modern data to identify threshold values for climatic conditions. These results were compared with data from marine and continental pollen sequences, lake-level fluctuations, and alpine glacier chronologies (Roetlisberger 1986, cited in Wigley and Kelly 1990; Magny 1999). This comparison yielded six arid phases during the Holocene that are interpreted as regional responses to more global climatic changes, two occurring during the early and middle Holocene between 6,400–4,600 cal BC and 3,300–2,200 cal BC (Table 1, Figure 5). Complementing these proxy paleoenvironmental data are new, high-resolution archaeoclimate models (Figures 6 and 7) developed for the Mediterranean Landscape Dynamics Project (Bryson and DeWall 2007; Miller et al. 2008).

Table 1
Neolithic Chronology in Valencia showing characteristic ceramic types (after Bernabeu et al. 2002:174).

Period	Phase	Characteristic Ceramic Type
Neolithic I ca. 5,600–4,500 cal BC	NIa ca. 5,600–5,300 cal BC	Cardial ceramics dominate assemblages
	NIb ca. 5,300–4,900 cal BC	Incised and impressed ceramics (non-Cardial) dominate assemblages
	NIc ca. 4,900–4,500 cal BC	Combed ceramics. Incised and relief decorations constitute < 5% of assemblages
Neolithic II ca. 4,500–2,800 cal BC	NIIa	Carved (*esgrafiada*) ceramics
	NIIb	Undecorated ceramics. Emergence of open forms (plates, platters)
Bell Beaker Horizon (Horizonte Campaniforme Transicional) after 2,800 cal BC	HCT	Bell Beaker Ware. Copper metallurgy

Continuing from the Last Glacial, pine dominated tree species during the Preboreal (8,150–6,650 cal BC) and eastern Spain was cool and dry with periods of warm and wet conditions that permitted the rapid accumulation of colluvium in the valley floors (Fumanal 1995). Archaeoclimatic modeling further indicates that the Pleistocene-Holocene transition was marked by rapid and extreme fluctuations in precipitation in this region, followed by a long period of more stable but lower precipitation, beginning about 6,400 cal BC (Figure 6). This corresponds with paleoenvironmental proxy data for the arid phase at 6,400–5,600 cal BC, which documents low lake levels and a decrease in arboreal pollen ratios regionally near the end of this period (Figure 5). Conditions were warmer and drier than they had been (Dupré 1988:118). Pollen records indicate a regeneration of vegetation, with herbaceous plants diminishing in importance and variety while oak and *Tilia* (linden) became more abundant (Fumanal 1995) and lake levels receded (Dupré 1988; Gil-Romera et al. 2009). Jalut et al. (2000:281) point out that it is contemporaneous with other events in the monsoon domains of West Asia and North Africa (Gasse and Van Campo 1994) and in the southern margin of the Sahara (Lézine and Cazsanova 1989). Charcoal data from Alicante document the expansion of deciduous oaks (*Quercus ilex/coccifera*) and other thermophilous taxa between 6,000 and 4,000 BC (Badal et al. 1994:164). Culturally this period corresponds with the late Mesolithic and Neolithic I.

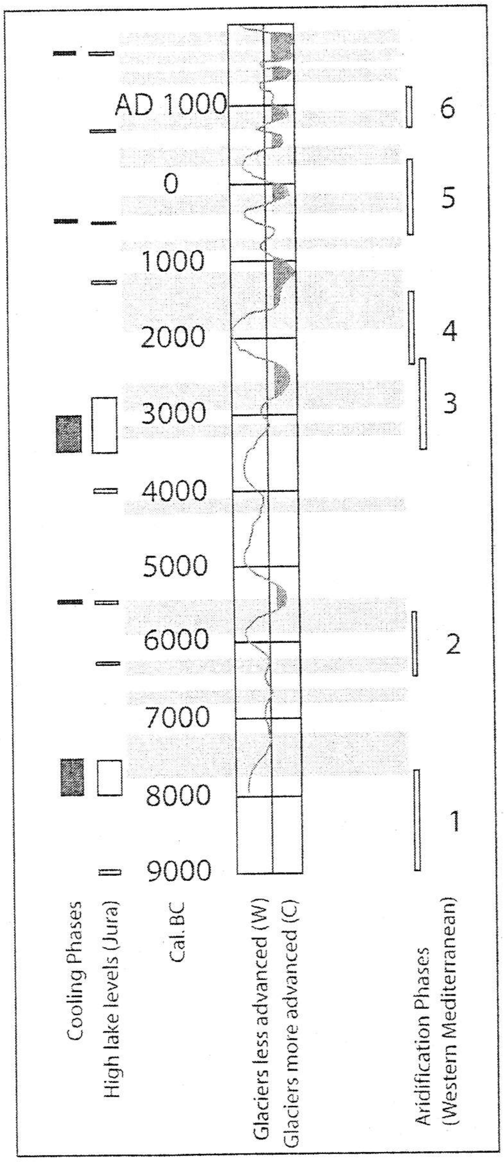

Figure 5. Climate chronology (after Jalut et al. 2000:281).

Global alpine glacier advance and retreat chronology (Roetlisberger 1986 in Wigley and Kelly 1990; W: Warm; C: Cold, marked by screening). Holocene cooling phases and high lake levels in Jura (Magny 1999), and Mediterranean aridification phases (Jalut et al. 2000).

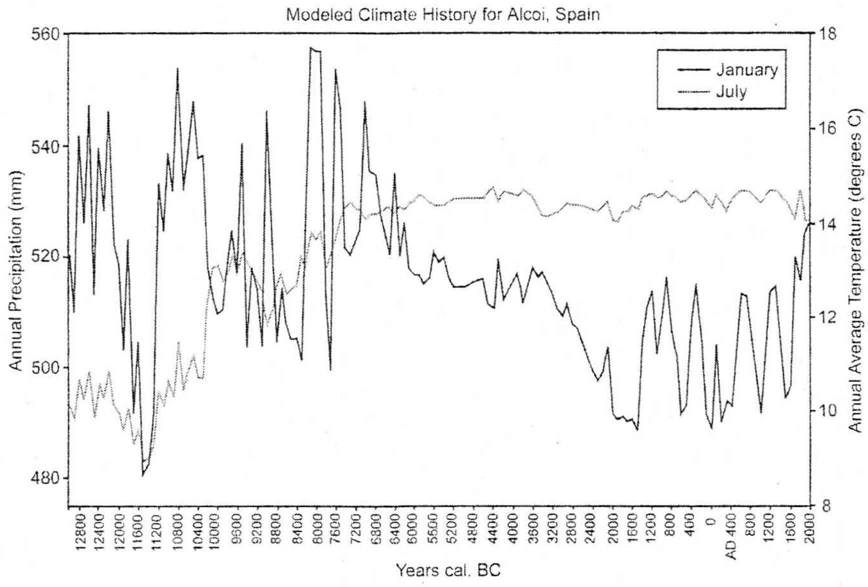

Figure 6. Temperature and precipitation model for the Terminal Pleistocene through the Holocene in the Alcoi Basin, Alicante, Spain.

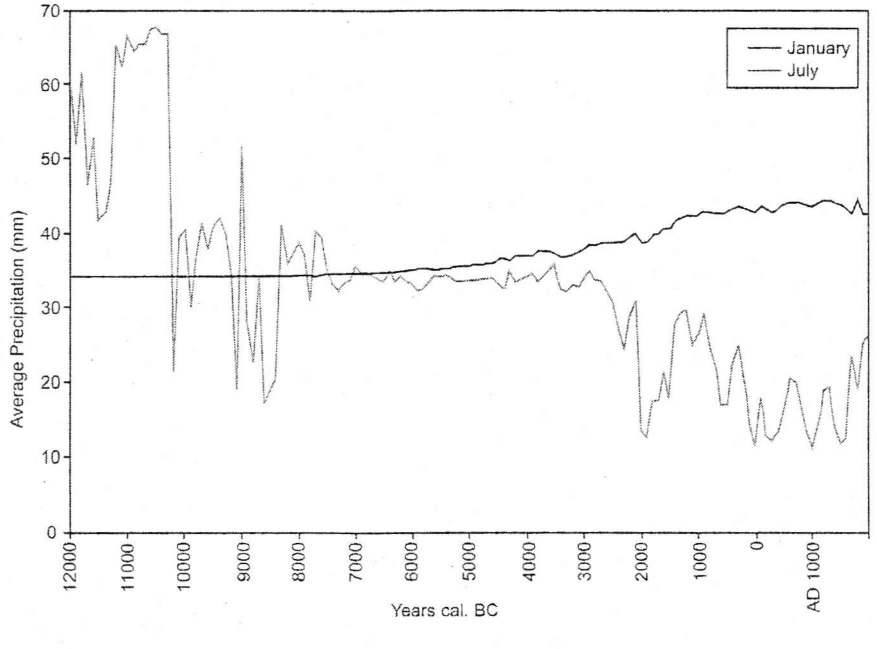

Figure 7. Model of January and July precipitation for the Terminal Pleistocene through the Holocene in the Alcoi Basin, Alicante, Spain.

Sedimentological studies indicate increased erosion due to human activity and marked periodic precipitation cycles between 5,450 and 4,000 cal BC (Fumanal 1986, 1995). A second, more intensive arid phase (3,300–1,600 cal BC) appears in the modeling results (Figures 6 and 7) and is further documented in paleoclimate proxy data (Figure 5) by an increase in xerophytic thermophilous taxa, a decline of temperate deciduous forest, and a trend toward a greater seasonal precipitation variation with an increase in the frequency of dry summers (Jalut et al. 2000:282). According to Badal et al. (1994:164), this phase includes an increase of evergreen oak and boxwood (*Buxus sempervirens*) in the supramediterranean or upper mesomediterranean climatic zones, and human impacts on vegetation communities is evident at this time. However, Jalut et al. (2000:282) argue that changes in vegetation cannot be explained by increases in anthropogenic burnings (see also discussion in Gil-Romera et al. 2009). Pollen records show decreases in relative percentages of charcoal particles, and a drying event is visible in archaeological charcoal profiles in eastern Spain as well (Badal et al. 1994; Terral and Mengual 1999). Furthermore, the climatic change recorded in eastern Spain is correlated with global climatic changes that are independent of human impact (e.g., West Asia, North Africa, and northern Mesopotamia; see Fontugne et al. 1994; Petit-Maire and Guo 1996; Weiss et al. 1993), and it is supported by lake-level changes during this period (Harrison and Digerfeldt 1991; Harrison et al. 1991).

DISCUSSION

The addition of climatic data to the IFD model interpretations leads to a number of observations. The earliest farming settlements were established during a wet/cold phase in the region, following a pattern identified by Gronenborn (2003) for other parts of western Europe. However, local climates ameliorated and most of the Neolithic I is marked by warmer and wetter conditions, lasting until the mid fourth millennium BC. Figure 7 represents a model of January and July precipitation, illustrating the possible fluctuations within the annual cycle. The Pleistocene/Holocene boundary is marked by rapid and extreme fluctuations that were likely stressful for plant and animal communities, including hunter-gatherers. However, the model suggests that precipitation stabilized in the early Holocene. Though drier overall than the late Pleistocene, this period was marked by considerably higher summer precipitation than today. This climatic stability may have favored early farmers who could reliably anticipate agricultural returns. Since farming population densities were relatively low, arable land may have been fairly easy to access, especially during the summer. In addition, greater rainfall in the warm season may have considerably increased crops and other ground cover, helping to stabilize the landscape against erosion.

By 3,000 cal BC this pattern changed to an arid phase contemporaneous with the onset of the Neolithic IIb. According to the climatic model, the increasing aridity beginning ca. 3,000 cal BC was primarily a function of the loss of summer precipitation, while winter precipitation increased. During this time, the Alcoi Basin switched to a winter-dominated Mediterranean climate regime and a period of much greater variability in precipitation. Fluctuations such as these would have had major effects on the suitability of potential farmland, including increased risk of harvest loss and erosion, creating the now-typical Mediterranean summer "drought" followed by higher winter precipitation. As a result, farmers may not have been able to accurately predict future agricultural yields, making stored surplus much more important. Increased vulnerability to erosion created by Neolithic I farming strategies did not have serious consequences during the climatic regime of the early Holocene, but it may have resulted in rapid and serious loss of productive farmland with the onset of higher temperatures and Mediterranean-type precipitation patterns after 3000 BC. Furthermore, as Gil-Romera et al. (2009) illustrate, the development of Mediterranean plant communities is contingent on past vegetation, climate, and human activities as well as current conditions. The combination of climate change and historical contingencies probably greatly accentuated the differences in potential returns for farmers in slightly different places, increasing the suitability of some areas, reducing the suitability of others, and making yet other areas more suitable for different kinds of agropastoral activities. We propose that processes of habitat decline were already occurring during the Neolithic I, but that the arid phase likely exacerbated the situation.

Elsewhere we have suggested that shifts in animal management strategies to greater numbers of cattle and pigs may have been related to shifts in strategies related to long-term viability of households (McClure et al. 2006:215). Goats and sheep reproduce relatively quickly, are more adept at surviving arid phases than cows and pigs, and tend to require less upfront investment in time and labor (e.g., stabling, pasturing, food and water requirements; see McClure et al. 2006). However, archaeological data from the Alcoi Basin indicate a shift in animal management practices during the Neolithic II to include more cows and pigs, precisely when increased aridity and seasonality in precipitation are documented. We originally discussed issues of herd management and household wealth in regard to identified shifts in herd assemblages (McClure et al. 2006), following Mace (1990, 1993a, 1993b) and Mace and Houston (1989). Those authors modeled and documented changes in optimal ratios of domestic animals given various socioeconomic and risk factors. Their model predicts herd compositions to maximize long-term viability within the context of household wealth (Mace and Houston 1989) and suggests high-yielding but high-investment species can function as a form of wealth storage. According to their study in sub-Saharan Africa, the optimal ratio of camels to goats for long-term household viability is dependent on total household wealth and a function of exchange potential (i.e., how many goats is a camel worth?).

We had suggested that the increase in high-yield but higher-risk cattle relative to sheep and goats in the Neolithic II may be indicative of greater household wealth than in Neolithic I (McClure et al. 2006:215). Given exacerbated declines in habitat suitability owing to shifts in climate and, perhaps more significantly, in precipitation, herd composition during the Neolithic II perhaps deserves closer attention. As argued above, new precipitation regimes may have rendered farmers more susceptible to agricultural loss and created a greater reliance on risk minimization strategies such as storage and exchange, particularly if differences in potential returns for farmers were accentuated in slightly different places. A new mosaic of productive and reliable farmland may have emerged that created increasing differences in household wealth. If this were the case, one would expect (following Mace and Houston 1989) that farming families managed animal herds accordingly, "storing" part of their wealth in higher-yielding but higher-risk cattle relative to goats only when other household economic factors allowed.

We have presented a heuristic application of the IFD to Neolithic developments in the Alcoi Basin of Alicante. Ideally, spatial modeling of paleohabitats and settlement would be the logical next step; however, explicit vegetation information is currently not available, and only proxy data from pollen and macrobotanical remains, coupled with climate modeling, can be used. It is our hope that future research will test these more explicit hypotheses generated with help from IFD to better illuminate the nature of Holocene adaptations by farmers in this region.

NOTE

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