Climate change, uncertainty and prehistoric hunter–gatherer mobility
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ABSTRACT

The onset of Little Ice Age conditions in California’s Sierra Nevada mountains resulted in increased temporal and spatial variability, and hence uncertainty regarding the distribution and production of resources targeted by its inhabitants, the Western Mono. The Mono responded with a risk-averse strategy composed of lowland winter population aggregation supported by logistical forays and seasonal residential dispersals to the high country, both ways of averaging variance in environmental productivity. These patterns were reconstructed using surface archaeology, GIS, and two straightforward spatial statistics, nearest-neighbor and variance-to-mean ratios, that combined provide a robust, objective picture of population aggregation and dispersal and the scale of these phenomena in different environments and seasons. These diverse strategies conform to expectations regarding the best ways for hunter–gatherers to cope with uncertainty, particularly in mountain environments. Despite this, the residentially mobile aspect of the pattern is rare in mountains and probably the result of historical connections between the Mono and Great Basin groups employing similar behaviors. Ultimately, this research suggests that climate change and environmental variability condition risk-averse, satisfying economic behaviors focused more on security than optimization, implying that pronounced environmental variability runs counter to economic intensification and its association with the evolution of more complex societies.

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Introduction

Mobility is arguably the principal concern of archaeologists focusing on hunter–gatherers (Kelly, 1992, 1998). How foragers moved about and exploited prehistoric landscapes is cited as key to understanding, among other things, prehistoric subsistence (Moore, 1998), trade (Yellin et al., 1996), sociocultural complexity (Keeley, 1988; Price and Brown, 1985), and even gender roles, power relationships, and evolutionary trajectories (Hawkes et al., 1989; McGuire and Hildebrandt, 2005; Surovell, 2000). But the problem for archaeologists is that movement is a transitory, abstract phenomenon rarely leaving direct material evidence (Close, 2000:49). So reconstructing prehistoric mobility is really a middle-range problem (e.g., Binford, 1977) subsuming the secondary challenges of identifying relevant archaeological proxies for movement and elucidating meaningful patterns within and between these proxies.

This study incorporates expectations derived from ecological theory and two relatively straightforward statistical techniques that together provide a clear picture of the adaptive nature of late prehistoric mobility in California’s Sierra Nevada. It operates on the perspective that though movement, especially pedestrian hunter–gatherer movement, usually leaves no trace, stopping does, with evidence of stops between moves determined by the distribution of bedrock processing features. The statistical methods it employs, the nearest-neighbor statistic and variance-to-mean ratios, measure dispersal and scale of dispersal, respectively, of stopping places in different ecological zones in different seasons. Combined, these provide a robust, objective picture of how and why people used late Holocene Sierran landscapes using techniques whose logic should be clear to anyone with a basic understanding of descriptive statistics. More importantly, the study identifies how population size, resource characteristics and climatic variability condition hunter–gatherer mobility. Ultimately this research describes a case where different forms of mobility were used to cope with pronounced environmental uncertainty resulting from late Holocene climate change, the implications of which show how hunter–gatherer economic behaviors evolve to cope with spatial and temporal variability in the distribution of mountain resources and, more importantly, uncertainty resulting from climate change and climatic variability.

Conceptualizing mobility

At its most fundamental level, mobility is way of bringing consumers to resources and is perhaps the simplest way of averaging temporal and spatial variations in resource productivity (Halstead and O’Shea, 1989:3; Woodburn, 1980). From a basic ecological perspective, mobility is critical to understanding how people manage
relationships between populations and resources and how they cope with uncertainty with regard to where and when resources become available (Kelly, 1992). Binford (1980), of course, codified thinking along these lines in the forager–collector model, correlating residential and logistical mobility with specific environments, defined by effective temperature. Derivations of this model (e.g., Ames, 2002; Kelly, 1985; Prentiss and Chatters, 2003) typically equate residential mobility with smaller groups living in aseasonal, homogenous environments where resources are patchy in neither time nor space, such as the tropics, or where resources are particularly dispersed. In contrast, logistical mobility is modeled as affiliated with larger populations living in seasonal climates, where resources are patchy in time and/or space. Patchiness requires intensified settlement and subsistence behaviors like logistical moves and the division of labor to provision larger groups. Actual behaviors, of course, rarely meet precise definitions of either form of mobility, often taking on aspects of the multiple behavioral options available in the logistical–residential continuum (e.g., Krist, 2001). The behavioral and semantic distinction between logistical and residential mobility, however, continues to be a useful heuristic device (e.g., Fitzhugh and Habu, 2002).

Beyond basic ecological context, many attempts to understand why and when hunter–gatherers choose one form of mobility over another employ cost–benefit models to ascertain when it is more efficient to transport resources back to a central place residence (i.e., be logistically mobile) and when it is more efficient to move residential location (i.e., be residentially mobile) to reduce logistical travel and resource transport costs (Kelly, 1990, 1998). These models predict optimal foraging radii around central places, beyond which it is more efficient to move camp rather than spend more time traveling and transporting resources in a logistical round. The most simple of these models predicts that the maximum size of this radius (in the Great Basin, 37–812 km) is determined by the point at which the caloric cost of transporting resources equals the caloric content of the resources being transported (Jones and Madsen, 1989). This ultimately means the type and quality of resources (or the habitat containing these resources) determines, to a large extent, the size of foraging radii and the distance at which it becomes more efficient to move residence (e.g., Grove, 2009). More complex models argue that it is more efficient to logistically transport unprocessed resources in small foraging radii (typically between 1.5 and 3.6 km for tree nuts like acorn and piñon) and to field process resources in much larger radii (as much as an absolutely large 1065 km for tree nuts) because field processing removes low-yield bulk and increases load utility (Bettinger et al., 1997; Barlow and Metcalfe, 1996). The implications of this type of modeling are that logistical procurement is usually quite cost effective to residential procurement and is only more efficient when resources are abundant enough and foraging radii small enough to reduce combined foraging and travel costs (Bettinger et al., 1997:897), or when population pressure reduces residential procurement return rates (Zeanah, 2000:12–13). But residential moves can also be costly and are only more efficient than logistical procurement when diet breadth is narrow, or broader-spectrum, lower yield resources like nuts and seeds are abundant enough to yield return rates above those of logistical procurement (Zeanah, 2002:242). Ultimately, this perspective argues that people should opt for residential over logistical procurement when transport costs exceed the one-way travel threshold (i.e., the foraging radius) of key resources, determined mainly by its caloric yield relative to weight.

But hunter–gatherers also face variability, or rather nonnormative resource return rates (Winterhalder, 1980). Variations in environmental productivity result in uncertainty for hunter–gatherers deciding whether or not to move: a group or individual leaving one place risks that the costs of moving will not be offset by the benefits of accessing a new resource patch (Winterhalder and Leslie, 2002). Environmental variability thus forces foraging decision makers to manage risk by coping with the probabilities of different outcomes that may result from their move (Low, 1990). In this light, though residential mobility can solve the immediate problem of temporal and/or spatial resource depressions when return rates are relatively high, it also entails coping with the risk of moving, elements exacerbated when environmental variability is also high (Goland, 1991). Because risks associated with moving increase under more variable environmental conditions, extreme environmental variability could conceivably favor increased sedentism supported by logistical forays. Alternatively, random search strategies and larger catchments have been found to generate optimal solutions to finding diffuse or randomly distributed resources, especially when information on resource distributions and abundance is poor or absent (Armsworth and Roughgarden, 2003; Brantingham, 2006). This suggests a corresponding pattern of high residential mobility may be the best way of coping with unpredictable circumstances. Finally, Goland (1991:110) argues that unpredictable circumstances require “flexible strategies,” implying that incorporating logistical and residential mobility types may be the best way of coping with extreme environmental variability.

The archaeology of hunter–gatherers in mountain environments sheds additional light on these problems. Almost without exception, mountain environments are seen as highly seasonal and marginal in terms of resource productivity (Aldenderfer 2006; but see Walsh, 2005; Walsh et al., 2006). Hunter–gatherer adaptations to these conditions consequently tend to focus on male-dominated logistical hunting, a pattern seen in North America’s Rocky Mountains (Bender and Wright, 1988; Wright et al., 1980), Sierra Nevada (McGuire et al., 2007; Stevens, 2005), and Great Basin (Bettinger, 1991; Thomas, 1982); in the Andes (Aldenderfer, 1998, 1999; Rick, 1980); and on the Tibetan and Ethiopian Plateaus (Aldenderfer, 2006). Only in rare circumstances do hunter–gatherers build residential structures indicating some form of residential mobility (e.g., Thomas, 1982), a phenomenon that appears to be conditioned by population pressure, at least in the Great Basin (Bettinger, 1991; Zeanah, 2000). Aldenderfer (2006) explains these patterns by arguing that because mountain environments are marginal, seasonal, patchy, and uncertain with regard to resource productivity, people should be risk-averse, choosing to employ little residential mobility and support themselves with logistical forays in small catchments. Ultimately risk-aversion under these conditions is akin to economic satisficing, ensuring minimum targeted requirements for subsistence rather than maximizing return relative to labor, this conditioned mainly by the high costs of gathering sufficient information upon which to make optimal decisions (Bordley and LiCalzi, 2000; Simon, 1957). In other words, risk-aversion is a way of hedging one’s bets that at least one behavior (or mobility option) will solve the problem of meeting subsistence targets when good information regarding probable decision outcomes are hard to come by, a situation exacerbated by increased environmental variability.

Ethnographic and paleoenvironmental setting

The focus of this study is the late Holocene in California’s southwestern Sierra Nevada, a 4000 m high mountain range along the eastern edge of California and an area occupied in late prehistoric and ethnographic times by a group known as the Western Mono (Fig. 1). Mono populations were small (usually no more than 39 people to a group) and widely dispersed, with families and kin occupying small, politically autonomous hamlets along or near the San Joaquin, Kings, and Kaweah rivers (Kroeber, 1925). Hamlets...
tended to cluster around springs, streams and flats along canyon margins immediately below winter snowline (Gayton, 1948; Gayton, n.d.; Gifford, 1932; Gifford, n.d.). Subsistence was based mainly on deer (*Odocoileus hemionus*), salmon (*Oncorhynchus* sp.) and especially acorn. Acorn, particularly black oak (*Quercus kelloggii*) acorn was a portion of nearly every meal and is still a form of Mono identity (Lee, 1998; McCarthy, 1993). Evidence of acorn processing is ubiquitous in the area, with outcrops of granite bedrock often pocked with bedrock mortars (BRM) used to reduce acorn into flour, especially in hamlet locations (Aginsky, 1943; Driver, 1937; Gifford, 1971; Hindes, 1962). Hamlets were supported in large part by dried, but otherwise unprocessed acorn cached in 5 km radii centered on settlement areas (Morgan, 2008).

Like most hunter–gatherers living in mountain environments, the Mono exploited a patchy resource base (Aldenderfer, 2006). Mountain resources are generally patchier than in adjoining valleys and other physiographic provinces because of the effect orographic precipitation has on biotic zone distribution and composition. Put simply, there tends to be much more precipitation at altitude, with growing seasons constrained by temperature and snowpack at high altitudes. This situation results in the compositionally and elevationally discrete biotic zones found in mountains, each compressed into relatively small horizontal spaces (Holdridge, 1967; Leemans et al., 1996). To illustrate this, on the west slope of southern Sierra Nevada, Küchler (1977) maps seven distinct biotic zones across a 40 linear km, NE–SW transect between 1000 and 4000 m elevation (Table 1). To the southwest, in the adjoining San Joaquin Valley, he maps only two (Valley oak savanna and San Joaquin saltbush) over the same transect orientation and distance. This indicates, at least for this region, that mountain environments are on the order of 3.5 times more diverse (i.e., “patchy”) than valley settings. Though each zone certainly contains smaller resource patches (e.g., oak groves, lithic sources, and water), as a whole they comprise large patches that are fundamentally distinct yet relatively nearby adjacent, but very different patches containing very different resources.

To simplify the analyses contained in this paper, the southwestern Sierra Nevada is modeled as containing three main ecosyones subsuming Küchler’s seven biotic zones, each producing distinct resources at different elevations and at different times of the year (Table 1; Fig. 2). The lower montane forest is below winter snowline (1400 m) and contains blue oak (*Quercus douglasii*) parklands, chaparral, and major streams; it yields abundant, seasonal runs of fish, winter deer-hunting opportunities, and spring and summer grass seeds, berries and acorn. The montane forest (between 1400 and 2100 m) is composed mostly of conifers (*Pinus* and *Abies* sp.) and stands of acorn-producing black oak (*Q. kelloggii*). Like lower elevations, the montane forest afforded deer-hunting in the spring, summer, and fall and a rich fall acorn harvest, which was cached in dispersed locations and stored within hamlets (Morgan, 2008). The third is a resource-poor subalpine–alpine zone above 2100 m.

![Location of the study area; Mono groups are in bold italics.](image-url)
Because the Mono occupied the western slope of the Sierra Nevada in ethnographic times and late prehistory (i.e., since about 600 BP and perhaps earlier), they faced not only patchy resource distributions, but also the effects of substantial late Holocene climatic change (Gayton, 1948; Gifford, 1932; Kroeber, 1959; Morgan, 2006). Paleoclimatic and paleoenvironmental data indicate climatic variability and disequilibrium were the norm for at least the last 2000 years, especially during the Medieval Climatic Anomaly (MCA) and Little Ice Age (LIA) (Fig. 3). The MCA was characterized by at least two extreme and persistent droughts interspersed by wetter periods between about 1300 and 650 calBP. The LIA was characterized by cooler conditions and glacial advance between about 650 and 150 calBP (Graumlich and Lloyd, 1996; Graumlich, 1993; Hughes and Brown, 1992). This means the Mono occupied the area during a climatic regime dominated by disequilibrium, variability and a substantial shift within this regime: the transition to and dominance of LIA conditions.

Abundant research on global warming’s effect on North American forests models how biotic composition should change during warm/dry to cool/wet conditions (and vice versa). Qualitatively (and unfortunately not quantitatively) LIA conditions are modeled as resulting in oak communities rapidly contracting, the density of oak in montane forests decreasing, and the distinction between elevation-determined biotic zones becoming more pronounced due to the constriction of plant ranges, the development of distinct alpine and subalpine communities, and more pronounced seasonality associated with increased snowfall (Campbell and McAndrews, 1993; Peterson, 1998; Wooffenden, 1996). This means that during

<table>
<thead>
<tr>
<th>Ecozone</th>
<th>Biotic zone</th>
<th>Elevation</th>
<th>Dominant vegetation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower montane</td>
<td>Blue-oak grey pine forest</td>
<td>Below 1000 m</td>
<td>Quercus douglasii, Pinus sabiniana</td>
</tr>
<tr>
<td></td>
<td>Chaparral</td>
<td>1000–1350 m</td>
<td>Adenostoma fasciculatum, Arctostaphylos sp., Ceanothus sp.</td>
</tr>
<tr>
<td></td>
<td>Sierra yellow pine forest</td>
<td>1000–1400 m</td>
<td>P. ponderosa</td>
</tr>
<tr>
<td>Montane forest</td>
<td>Sierra montane forest</td>
<td>1400–2100 m</td>
<td>Abies concolor, P. lambertiana, P. ponderosa, Q. kelloggii</td>
</tr>
<tr>
<td>Subalpine</td>
<td>Upper montane-subalpine forest</td>
<td>2100–3300 m</td>
<td>Abies magnifica, P. contorta</td>
</tr>
<tr>
<td></td>
<td>Northern jeffrey pine forest</td>
<td>2000–2400 m</td>
<td>P. jeffrey</td>
</tr>
<tr>
<td></td>
<td>Alpine</td>
<td>Above 3300 m</td>
<td>Limited vegetation, e.g., Draba oligosperma, Erigonum ovalifolium</td>
</tr>
</tbody>
</table>

the LIA the distribution of resources essential to Mono subsistence became increasingly constrained to patches exploitable for only short periods each year. For example, grassland and lower-elevation nut-producing trees like blue oak were constrained to elevations below 1000 m (Allen and Breshears, 1998). Sugar pine (Pinus lambertiana) and black oak were constrained between 1000 and 2000 m, in lower elevations by water budgets and at higher elevations by snowpack and shorter growing seasons (Miller et al., 2004; Urban and Miller, 1996). Resource-poor, subalpine red fir (Abies magnifica) and lodgepole pine (Pinus contorta) forests expanded at the expense of more xerically-adapted montane forests containing sugar pine and black oak (Körner, 1998; Overpeck et al., 1990). Finally, treeline elevations migrated downslope, increasing the geographic extent of resource-poor alpine biotic communities (Scuderi, 1987) (Fig. 4).

The result of these transformations was a significant change in resource availability, accessibility and distribution. Increased snowfall lowered average yearly snowline, reducing access to and limiting the productivity of middle and high elevation resources like black oak acorn and sugar pine nut. The constriction of key resources to specific biotic zones severely curtailed their availability in both time and space, in the first case by limiting them to very space-specific resource patches and in the second by increasing the effects of seasonality on resource productivity. This latter phenomenon is expressed in more pronounced variability (in both amplitude and frequency) of masting (i.e., the tendency of nut bearing trees to periodically produce “bumper” yields interspersed by years of poor or absent production) during colder and wetter conditions (Kelly and Sork, 2002; Koenig and Knops, 2005; McKone et al., 1998) (Fig. 5). Overall, LIA conditions led to pronounced variability of key resource production in spatially and temporally discrete resource patches, with no guarantee of adequate production in any given year. Distances between productive resource patches increased as well because the gentle western slope (avg. slope 4°) of the Sierra Nevada results in substantial horizontal distance between elevationally-discrete ecozones. Combined, increased patchiness and increased variance in the environment’s production of key resources resulted in considerable uncertainty regarding resource availability from year to year and from location to location.

**Fig. 3.** Idealized late Holocene Sierra Nevada paleoclimate synthesis.

**Fig. 4.** Graphic representation of modeled changes in ecozone composition and distribution between the MCA and LIA.
Modeling Mono mobility

These conditions result in a mixed set of predictions for Mono mobility. At the most basic ecological level, Mono populations were relatively small and the resources they exploited were patchy and dispersed across the broad western slope of the Sierra Nevada. These conditions tend to favor residential mobility, with populations mapping onto resource patches as they become productive. But the environment the Mono exploited was also highly seasonal, marked by substantial resource depressions in winter months. These conditions suggest the Mono should occupy low-elevation, below snowline residential basins near ecotones maximizing exposure to multiple highly productive resource patches. Here, they would support themselves with logistical foraging, hunting and fishing forays, with storage offsetting winter resource shortfalls. Above snowline resources, however, were also critical to the Mono and available for a short period of time each year. Berries produce in the summer, deer move to higher elevations in the summer and oak and grasses produce harvestable seeds in the fall. Resource distribution here, however, is more dispersed and homogenous than below snowline (SNAP, 1996). Hence the main limit to acquiring resources above snowline is time compression, where a fundamentally homogenous resource base is exploitable for a short period of time. The goal in this environment is simply group sustenance rather than storing enough food to get through the winter, as it is below snowline. Since above snowline the group is not focused on storing food and is trying to exploit what is essentially a homogenous resource macro-patch, residential mobility is favored. Residential mobility allows groups to map onto dispersed re-

Cost–benefit models support this assertion. Bettinger et al. (1997:895) indicate that the one-way travel threshold (beyond which caloric costs outweigh the benefits of resource transport) for dried but unprocessed black oak acorn, the key resource for the Mono, is 3.67 km, a prediction corroborated by Morgan (2008:254) who identifies a mean 3.4 km black oak acorn-focused foraging radius around lower elevation winter settlements. This means that if the Mono wanted to exploit resources, especially black oak acorn in the above-snowline montane forest, the vast majority of which is well more than 3.5 km from lowland winter settlements (the shortest distance from winter settlements to the lower montane forest boundary varies from 0.6 to 3.2 km, averaging 1.6 km; the distance from winter settlements to any given random point (n = 113,760) in the montane forest, however, varies from 0.6 to 47.8 km, averaging 18.6 km), it is more efficient to move residence to the montane forest than transport unprocessed acorn back to a winter village in the lower montane forest. Pre-travel processing could conceivably increase acorn load utility enough to offset greater travel costs, but would have the effect of producing meal extremely prone to spoilage and thus not well suited to storing as an overwintering strategy.

Predictions are more variable with regard to managing risk and coping with uncertainty. More variable conditions result in greater uncertainty (due to poor or absent information) and potential risk (due to increased chances of resource failure) associated with residential moves. Because of this, logistical procurement and long-range logistical hunting thus appear to be the default in mountains, and we might expect this to be the case for the Mono. But variable conditions can also result in potentially greater rewards. For example, substantially greater returns on foraging would be possible when variations in environmental productivity result in increased acorn masting and/or overall greater biotic productivity, meaning residential moves might be used to exploit montane resources outside hamlet logistical radii when such conditions prevail. Variable conditions also favor random moves as a way of optimizing resource encounter rates (Brantingham, 2006), a situation that might also favor correspondingly random residential moves. Similarly, exploitation of larger portions of the landscape has been modeled as an optimal solution to subsistence in fluctuating environments (Armsworth and Roughgarden, 2003), a situation also favoring residential mobility due, once again, to the costs of transporting key resources more than 3.6 km back to settlements. Thus, between occasional, but unpredictable increased chances of reward favoring random-dispersed residential moves and a general climatic-ecological context favoring risk-averse behaviors like logistical procurement, it thus appears that Goland’s argument that unpredictable circumstances favor flexible strategies is applicable in the Mono case and that multiple mobility and procurement strategies should be employed to cope with this variability. In sum, ecological context, black oak acorn return rates, and unpredictable circumstances suggest that effective hunter–gatherer exploitation of the late Holocene Sierra Nevada required a combination of logistical mobility below snowline and residential mobility above snowline, leaving the problem of identifying the presence, absence, and extent of these behaviors.

Analyses

Archaeological approaches to reconstructing mobility have historically centered on settlement pattern analysis using site types and diachronic variations in their distribution across landscapes to identify seasonal, yearly, and chronology-specific changes in land use (Bettinger, 1977; Mortensen, 1972; Thomas, 1973; Willey, 1953). Spatial statistics have been used almost throughout the history of settlement pattern studies to provide objective measures of artifact, site and feature density and distributions, typically using nearest-neighbor and goodness-of-fit tests to measure degrees of association with environmental and other variables thought to condition settlement patterning (Attwell and Fletcher, 1987; Bettinger, 1979; Gould and Yellen, 1987; Hodder and Hassell, 1971; Pinder et al., 1979; Washburn, 1974; but see Voorrips and O’Shea, 1987). This approach was largely abandoned (until recently) due to a perceived misapplication of some statistical methods and a reconceptualization of space by post-proces-
analyses with only the arguably arbitrary conception of what constitutes a site (e.g., Dunnell, 1992) and with taphonomic problems associated with site formation and preservation (see Zvelebil et al., 1992:196–197).

The geographic distribution of milling stations speaks directly to residential choice and logistical field processing. Though mortars are unequivocally associated with field processing, they are also associated with habitation and residence. Larger, more intensively and repeatedly occupied sites contain the greatest number of BRMs (i.e., \( n > 14 \)) and are usually associated with substantial middens, house pit depressions and other residential indicators (Gifford, 1932; McCarthy et al., 1985:307; Morgan, 2006). They thus stand as proxy for residential choice, and by inference, residential mobility. Fewer milling surfaces (i.e., \( <14 \)) are associated with logistical stations used solely for field processing and as temporary campsites (Hindes, 1962; Jackson, 1984; TCR/ACRS, 1984); they thus stand proxy for logistical mobility. This functional distinction allows for reconstructions of Mono logistical and residential moves and recognition of different site types based primarily on BRM counts (Table 2).

Table 2

<table>
<thead>
<tr>
<th>Mobility type</th>
<th>BRM (n)</th>
<th>Site type</th>
<th>Associated features</th>
</tr>
</thead>
<tbody>
<tr>
<td>Residential</td>
<td>25+</td>
<td>Principal camp/hamlet</td>
<td>Midden, housepit, artifact scatter, midden (rare)</td>
</tr>
<tr>
<td></td>
<td>14–24</td>
<td>Subsidiary camp</td>
<td>Artifact scatter, midden (rare)</td>
</tr>
<tr>
<td></td>
<td>1–4</td>
<td>Temporary camp</td>
<td>Lithic scatter</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Processing stations</td>
<td>Lithic scatter</td>
</tr>
</tbody>
</table>

Millling station geographic distribution also speaks directly to seasonality of occupation. Unlike many lower elevation settings where seasonality is reconstructed, with some difficulty, using faunal and floral indicators (e.g., Adams and Bohrer, 1998), movement patterns and settlement in the Sierra Nevada were strongly conditioned by winter snowpack, a fact corroborated by ethnographic sources. Gifford (1932:17) writes that the Mono moved, “Annually from lower winter to higher summer residences which had too much snow in the winter and vice versa.” Multiple ethnographic sources attest to the location of lower-elevation residences, all below average winter snowline (1400 m) in the lower montane forest. Residences here were occupied mainly in the winter, where the ground was free of snow, and where people subsisted mainly on stored acorn gathered in the fall (Gayton, 1948; Gifford, 1932; Merriam, 1955). Ethnographic documentation of highland residence (i.e., in the montane forest and subalpine zones, above winter snowline) is poor (the preceding quotation is among the few references to highland settlement). Residential sites here, though occasionally accessible during the winter during brief thaws interspersing winter storms would have usually been buried under more than a meter or more of snow for 4 months or more each winter, precluding occupation in an area where snow-free habitation sites were available in many cases less than 10 km downslope. Further, biotic productivity in higher elevations is markedly constrained during winter months (i.e., December–March) and migratory game like deer winter in the low county, leaving little incentive to occupy higher elevations. Residential occupation above winter snowline was thus mainly a spring-fall phenomenon constrained by ecological circumstances.

Based on these parameters, analyses focus on the distribution of processing features in a roughly 30 km² study area in the San Joaquin River watershed (Figs. 1 and 2). They use data from intensive surveys (i.e., those with 15 m or less transect spacing) covering over 555 km² of the 1626 km² study area performed over the last 60 years for timber sales and other large projects. Survey coverage was approximately 34% more-or-less equally distributed across study area ecozones Table 3, with smaller portions of the subalpine zone covered mainly due to extremely steep slopes (i.e., greater than 30°). This large sample proportion and relatively consistent coverage between ecozones is believed to accurately reflect milling station distribution in the study area and across ecozones. The first analysis uses nearest-neighbor statistics to determine the distribution of processing sites in different ecozones as a way of ascertaining seasonal variability in population clustering and dispersal, these indicating seasonal variations in residential mobility. The second analysis uses variance-to-mean ratios as a way of objec-

Table 3

<table>
<thead>
<tr>
<th>Ecozone</th>
<th>Area (km²)</th>
<th>Area surveyed (km²)</th>
<th>Survey coverage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower montane</td>
<td>407.19</td>
<td>165.59</td>
<td>40.67</td>
</tr>
<tr>
<td>Montane</td>
<td>309.96</td>
<td>148.33</td>
<td>40.09</td>
</tr>
<tr>
<td>Subalpine</td>
<td>848.25</td>
<td>237.57</td>
<td>28.00</td>
</tr>
<tr>
<td>Total</td>
<td>1626.48</td>
<td>551.49</td>
<td>33.91</td>
</tr>
</tbody>
</table>
Nearest-neighbor

The nearest-neighbor statistic (NN) provides a more objective measure of spatial point patterning than raw density data because it does not rely on arbitrary units of analysis like quadrats. It is derived by measuring the linear distance between every data point and its next nearest-neighbor and dividing the mean of observed distances (dobs) by expected mean distances (dran) between the same number of randomly distributed points. The dran value is one-half the square root of study area size \( (\sqrt{a}) \), divided by number of points \( (n) \) (Clark and Evans, 1954). The resulting formula, still used (Diggle, 2003; Durand et al., 1992), is: \( NN = dobs / 0.5 \sqrt{a/n} \).

Study area boundaries, however, can disallow measurements between points and limit measurements between bounded points, rather than ones distributed in infinite space, a requisite for achieving truly random point distributions (Pinder et al., 1979). Ebdon (1976) accounted for this boundary effect with a correction coefficient, \( C = 0.497 + 0.127 \sqrt{a/n} \), replacing the 0.5 value in the original formula. Using GIS to measure distances between multiple sets of computer-generated random points is an alternative way of generating dran. Regardless of method, NN values less than 1.00 indicate clustering, values greater than 1.00 dispersal, and values near 1.00 random distributions. NN values were generated using all three methods and the nearest-neighbor/event–event distances extension for ArcGis (Sawada, 2002). The analysis generated NN values at multiple scales, from a gross analysis of all study area processing sites, to analyses of the site types identified in Table 2 correlated with the three principal study area ecozones (e.g., Fig. 6).

Results

NN values are consistent regardless of method, though values derived from generated random points are slightly lower than formula values (Table 4). To simplify discussion, the following uses values generated with the correction coefficient formula developed by Ebdon (1976). In the lower montane forest, the NN statistic for all processing sites is 0.79, indicating slight clustering (Fig. 7). Site type NN values range from slightly clustered at 0.77 for logistical sites, to nearly random at 0.92 for residential sites. Overall, sites in the lower montane forest are slightly clustered, indicating winter population aggregation below snowline. In the montane forest, NN values indicate random and even dispersed settlement, varying from 1.04 for all processing sites to 1.37 for residential sites. These values show populations mapping onto dispersed resources when the area is clear of snow. Values for subalpine/high elevation residential sites are highly variable, a result of small sample size \( (n = 12) \). They range from random \( (NN = 1.00) \) for subsidy camps to clustered \( (NN = 0.40) \) for principal camps. Low NN values in the subalpine zone indicate clustering due to association with trans-Sierran trails (Hindes, 1959; Snyder, 2001). Sites here are constrained to the only passable portions of the landscape in these settings: creek and river canyons and alpine passes (Fig. 8) (Morgan, 2006). Together these data indicate lowland winter population aggregation, montane forest spring and summer population dispersal, and high residential mobility associated with trans-Sierra trade and travel.

Variance-to-mean

Variance-to-mean ratios (VMR) provide an objective measure of the scale of point pattern distributions and provide a clearer picture of the size of territories affiliated with different sites and site types. VMR also cope with problems associated with simple spatial analyses that measure density within arbitrary units (e.g., quadrats) of analysis that skew interpretations of clustering, dispersal and the scale at which these phenomena occur simply as a function of quadrat size. VMR are simply the ratio of the variance divided by the mean density of data points per quadrat. Variance, a measure of the spread of the distribution, changes relative to quadrat size. As quadrat size approaches the scale of patterning in the point distribution, the histogram showing the number of points per quadrat becomes bimodal, with some quadrats containing many points and others containing very few or none (Ebert, 1992:191). Here, variance is high relative to the mean; this is the scale of patterning. The scale of patterning in the data is more meaningful than density distribution because it indicates at what scale the points in the distribution are actually clustered.

Methods

VMR were determined using ArcGis software. BRM geographic distribution was entered into a spreadsheet using site UTM coordinates as \( x \) and \( y \) coordinates for BRM location. At sites with more than one BRM, northing and easting values were estimated by either adding or subtracting one meter per BRM from each UTM value, so that at no site were BRMs more than 100 m from the UTM marking the center point of the site. Though not precisely locating each BRM, these locations are certainly within the margin of error of hand-held GPS units and the map measurements from which UTMs were originally derived. More importantly, these methods quantify every study area BRM without relying on the somewhat arbitrary site definitions used by the multiple studies contributing to the database. The resulting data were subdivided by ecozone. Six grids, 0.05, 0.10, 0.25, 0.50, 1.00, 2.50, and 5.00 km\(^2\), were generated and superimposed over the study area and then queried to determine the number of mortars in each quadrat (e.g., Fig. 8). This resulted in a database of the density of mortars per quadrat in each ecozone at six scales of analysis; VMR were derived from these data (Table 5).

Results

Results indicate substantial differences in settlement and processing behaviors by ecozone. The VMR in the lower montane ecozone peaks at 1 km. The VMR in the montane forest and alpine zones peaks at 2.5 km (Fig. 9). Together, these data indicate that BRMs are clustered in 1 km\(^2\) areas in the lower elevations of the study area, the area containing Mono winter settlements. Above snowline, mortars cluster in 2.5 km\(^2\) areas, indicating greater dispersal of processing sites in montane forest and subalpine ecozones. Together, scales of patterning indicate population clustering below snowline in winter and dispersal above snowline in spring, summer and fall, with dispersed summer settlements and processing stations patterned at a scale 2.5 times greater than winter camps, hamlets, and processing stations.

Synthesis and conclusion

The onset of LIA conditions some 600 years ago resulted in a set of circumstances particularly challenging for hunter-gatherers: how to best average increased variance in temporal and spatial resource distributions. Analyses of processing site and processing surface distributions as proxy measures of Mono mobility indicate a multifaceted approach to solving these problems. NN values indicate clustering, dispersal, and clustering once again of processing sites in lower montane, montane forest, and subalpine ecozones,
respectively. This distribution is partly predicated, of course, on correlation between local environmental variables and settlement choice (Premo, 2004). Previous research in the area indicates that site locations, especially processing site locations, are strongly associated with chaparral and coniferous forest vegetation, stream terraces and midslope landforms, and proximity to perennial streams and trans-Sierran travel corridors (Crist, 1981; Jackson, 1984, 1988; Hull and Mundy, 1985; Pilgram, 1987). The current results, however, go beyond this kind of determinism and clearly show how populations used different ecozones on a seasonal basis: lowland population aggregation (clustering) below snowline in winter, dispersal in spring to map onto seasonal mid-elevation montane resources, and subalpine–alpine travel along narrow trail corridors (again, indicated by clustering along travel corridors). Interestingly, these results indicate that processing sites in the montane forest are distributed in a random-dispersed pattern, suggesting that at these landscape scales behavior determines settlement as much as does correlation with localized environmental variables. VMR indicate the scale of patterning within this system, with BRMs clustered in areas 2.5 times smaller in the lower montane forest than in montane forest and subalpine zones. This indicates not only substantial lowland settlement clustering, but also substantially smaller logistical catchments in the lower montane forest. Together, these data describe seasonal, intensive, semi-sed-
entary logistical exploitation of lower montane settings and substantial residential mobility in the montane forest in spring, summer and fall.

This mixed mobility pattern conforms to expectations regarding the most effective ways to average pronounced spatial and temporal resource variability. Increased sedentism, few residential moves and logistical mobility are ways of averaging temporal resource variance in seasonal settings, particularly where resources are abundant and diverse, as they are in the lower montane forest. Winter Mono settlement patterns conform to this expectation: clustered site distributions below snowline indicate seasonal population aggregations relying on logistical forays and cached and stored foodstuffs to compensate for winter resource shortfalls (see Morgan (2008) for an analysis of Mono logistical mobility and storage behaviors). Conversely, when low population densities face extreme environmental conditions and highly unpredictable but homogenous resource bases, mapping onto resources is modeled as the most effective way to average resource shortfalls, particularly when these moves are beyond the distance at which resources can be efficiently moved back to camp. This is the behavior seen in the random-dispersed settlements and camps in the montane forest. This pattern recalls the most efficient way to optimize encounter rates with diffuse or randomly distributed resources, especially when foreknowledge of environmental productivity and resource distribution is poor or absent (Brantingham, 2006), a situation exacerbated by LIA induced uncertainty. Subalpine mobility appears to be conditioned less by subsistence and more by travel across the Sierran crest along narrow travel corridors.

What makes these findings particularly interesting is the fact that these patterns appear to have changed substantially in the last 1000 years or so. Though comparable data are not yet available at the resolution presented in this study, a fairly substantial body of literature indicates that from about 3500–1350 calBP the western

### Table 4
Processing site NN values by ecozone.

<table>
<thead>
<tr>
<th>Site type</th>
<th>Site count</th>
<th>Mean observed distance</th>
<th>Mean random distance</th>
<th>Expected (traditional formula)</th>
<th>Expected (coefficient formula)</th>
<th>NN (random points)</th>
<th>NN (traditional formula)</th>
<th>NN (coefficient formula)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Lower montane forest</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Residential</td>
<td>95</td>
<td>1001.70</td>
<td>1281.80</td>
<td>1035.16</td>
<td>1082.90</td>
<td>0.78</td>
<td>0.96</td>
<td>0.92</td>
</tr>
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<td>Principal camp</td>
<td>44</td>
<td>1689.00</td>
<td>1901.80</td>
<td>1521.05</td>
<td>1628.41</td>
<td>0.88</td>
<td>1.11</td>
<td>1.03</td>
</tr>
<tr>
<td>Subsidiary camp</td>
<td>51</td>
<td>1370.90</td>
<td>1520.90</td>
<td>1412.81</td>
<td>1504.84</td>
<td>0.90</td>
<td>0.97</td>
<td>0.91</td>
</tr>
<tr>
<td>Logistical</td>
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<td>721.80</td>
<td>1086.90</td>
<td>891.79</td>
<td>926.48</td>
<td>0.66</td>
<td>0.80</td>
<td>0.77</td>
</tr>
<tr>
<td>Temporary camp</td>
<td>77</td>
<td>937.40</td>
<td>1371.90</td>
<td>1149.80</td>
<td>1209.47</td>
<td>0.68</td>
<td>0.81</td>
<td>0.77</td>
</tr>
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<td>Processing station</td>
<td>51</td>
<td>1417.10</td>
<td>1697.00</td>
<td>1412.81</td>
<td>1504.84</td>
<td>0.83</td>
<td>1.00</td>
<td>0.94</td>
</tr>
<tr>
<td>All processing sites</td>
<td>223</td>
<td>548.50</td>
<td>716.30</td>
<td>675.64</td>
<td>694.57</td>
<td>0.76</td>
<td>0.81</td>
<td>0.79</td>
</tr>
<tr>
<td><strong>Montane forest</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Residential</td>
<td>28</td>
<td>2716.80</td>
<td>2506.90</td>
<td>1817.47</td>
<td>1981.05</td>
<td>1.08</td>
<td>1.49</td>
<td>1.37</td>
</tr>
<tr>
<td>Principal camp</td>
<td>10</td>
<td>5794.30</td>
<td>5479.00</td>
<td>3041.21</td>
<td>3511.52</td>
<td>1.05</td>
<td>1.90</td>
<td>1.65</td>
</tr>
<tr>
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<td>18</td>
<td>3103.50</td>
<td>2484.40</td>
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<td>2524.60</td>
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<td>1.22</td>
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<tr>
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<td>1384.60</td>
<td>1049.32</td>
<td>1101.18</td>
<td>0.89</td>
<td>1.17</td>
<td>1.12</td>
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<td>2287.60</td>
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<td>1.34</td>
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<td>47</td>
<td>1539.40</td>
<td>1863.60</td>
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<td>1498.34</td>
<td>0.82</td>
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<td>1.02</td>
</tr>
<tr>
<td>All processing sites</td>
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<td>993.40</td>
<td>1141.80</td>
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<td>946.90</td>
<td>0.87</td>
<td>1.09</td>
<td>1.04</td>
</tr>
<tr>
<td><strong>Subalpine</strong></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Residential</td>
<td>12</td>
<td>4552.70</td>
<td>5911.70</td>
<td>4203.78</td>
<td>4795.03</td>
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<td>0.94</td>
</tr>
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<td>0.50</td>
<td>0.40</td>
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<td>8</td>
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<td>6224.70</td>
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<td>6042.38</td>
<td>0.97</td>
<td>1.18</td>
<td>1.00</td>
</tr>
<tr>
<td>Logistical</td>
<td>72</td>
<td>1216.70</td>
<td>1899.10</td>
<td>1716.18</td>
<td>1808.63</td>
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<td>0.70</td>
<td>0.67</td>
</tr>
<tr>
<td>Temporary camp</td>
<td>20</td>
<td>2544.90</td>
<td>4269.70</td>
<td>3256.24</td>
<td>3606.58</td>
<td>0.59</td>
<td>0.78</td>
<td>0.70</td>
</tr>
<tr>
<td>Processing station</td>
<td>52</td>
<td>1611.10</td>
<td>2091.00</td>
<td>2019.43</td>
<td>2149.58</td>
<td>0.77</td>
<td>0.79</td>
<td>0.75</td>
</tr>
<tr>
<td>All processing sites</td>
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<td>1844.50</td>
<td>1588.88</td>
<td>1667.41</td>
<td>0.64</td>
<td>0.75</td>
<td>0.71</td>
</tr>
</tbody>
</table>

Fig. 7. NN values, by site type and ecozone.
slope of the southern and central Sierra Nevada saw more intensive use and occupation of large, semi-permanent villages in lowland, foothill settings (i.e., below 1000 m) and long-range logistical hunting in the highlands (Moratto, 1972; Moratto et al., 1978; Stevens, 2003). Data from excavations in the study area point to abandonments of some montane forest locales between 1050 and 775 calBP, during the MCA, and very intensive use of these same settings by the Mono during the LIA (Caputo, 1994; Goldberg and Moratto, 1984; Jackson, 1983; Jackson and Holson, 1984; Jones and Origer, 2001). Use of high elevations intensified after 1350 calBP, with larger, seasonal residential sites being occupied, particularly after 650 BP and the onset of the LIA (Stevens, 2002; Stevens, 2005). So prior to the LIA, adaptive patterns were more typical of seasonal, and especially mountain environments, focused on logistical procurement and long-range logistical hunting in the highlands.

But during the LIA, the strategy described in the current study developed, with more intensive use of highland settings and a mixed logistical–residential strategy that intensively exploited the diverse environments of the western Sierra Nevada. From an ecological perspective, these mobility patterns are clearly effective means of coping with the constraints posed by mountain environments. They averaged temporal variance in resource availability in lower elevations by winter population fusion, logistical mobility, and storage. They averaged pronounced spatial variability of resource productivity with spring, summer and fall population dispersal to exploit resources in montane forests, supporting the idea that higher elevations are indeed essential components of montane hunter–gatherer lifeways (e.g., Aldenderfer, 1999; Wright et al., 1980). The way the Mono exploited the Sierra Nevada during the LIA, however, was predicated only in part on logistical mobility, in contrast to the strategies seen in most mountain environments. Residential mobility in higher altitude settings might appear surprising during the LIA, given shorter growing seasons and limits on mobility due to increased snowfall and even glacial advance. This pattern is expected, however, due to the distances between higher elevation resource patches and larger winter settlements: it is easier to move people to resources than to move resources to larger, centralized settlements, mainly because they are well beyond the 3.4 km foraging radius of hamlets in the lower montane ecozone. In any event, these patterns support the assertion that climatic conditions are, due to their effect on habitat quality and resource distribution, the basic limiting factors conditioning hunter–gatherer mobility (Grove, 2009:7).

These conclusions also speak to the nature of hunter–gatherer response to risk and uncertainty. That the LIA favored Goland’s (1991) “flexible strategies” is clearly exhibited in the multifaceted Mono mobility pattern. Here, diverse mobility options are a risk-averse behavior ensuring solution to any number of spatial and temporal resource fluctuations and failures, clearly a way of coping with uncertainty, particularly of the kind found in montane settings. Mono residential mobility, however, is anomalous as far as most montane foragers go, perhaps a behavior derived from their cultural and linguistic affiliates in the western Great Basin, the Nu-
mic-speaking Shoshone and Paiute, each of whom established high-altitude residential bases in the very late Holocene (in the Alta Toquima and White Mountains, respectively) (Fig. 10).

Ultimately, this study elicits some fundamental observations and questions regarding the ecology and evolution of hunter–gatherer responses to environmental variability over larger spans of time. Though linking climate change to cultural dynamics can be problematic (see Anderson et al., 2007:12–18), the current study suggests that the shift from MCA conditions (a drought-prone, stressing period associated with substantial cultural disruptions in California and beyond [e.g., Jones et al., 1999]) to LIA conditions (a period often regarded as one of regional environmental amelioration) brought about resource stress due to increased snowfall and more unpredictable resource productivity in California’s mountains, suggesting good times are only good (and bad times bad) relative to specific ecological context. The study also suggests that hypervariable climatic conditions may favor risk reducing strategies, a possibility that has important implications for human socioeconomic evolution. For example, if the LIA is something of a small-scale analog for hypervariable Pleistocene climatic conditions dominating so much of human evolution and prehistory (e.g., Grafenstein et al., 1999), it follows that Pleistocene conditions may have also favored risk-averse behaviors. This could conceivably explain remarkably conservative Pleistocene behaviors like East Asian core/flake (or flake/shatter) technologies, which per-

### Table 5

<table>
<thead>
<tr>
<th>Quadrat size (km²)</th>
<th>Quadrats (n)</th>
<th>Mean</th>
<th>Variance</th>
<th>VMR</th>
</tr>
</thead>
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<td>168,771</td>
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<td>6739</td>
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<td>0.50</td>
<td>1699</td>
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<td>135.220</td>
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<td>10.259</td>
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<td></td>
<td>2.50</td>
<td>69</td>
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<td>1135.893</td>
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<td>255.882</td>
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</tr>
<tr>
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<td>33</td>
<td>17.273</td>
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</tr>
</tbody>
</table>

![Fig. 9. Bedrock mortar VMR by ecozone.](image)

![Fig. 10. Map showing the distribution of Numic-speaking peoples (hatched) and evidence of high-altitude residential mobility (See above-mentioned references for further information).](image)
sisted nearly unchanged for more than 50,000 years (Seong, 2004): it may have been simply too risky to adopt new tools that may (or may not) do a job better than existing technologies. It follows that less climatically-variable (and thus more predictable) Holocene conditions may have favored the more optimizing (and arguably more risky — see Bettinger 2006:313) behaviors like sedentism, agriculture and other intensified behaviors affiliated with the evolution of more complex societies (e.g., Schurr and Schoeninger, 1995). Following this logic, the persistence (if not the adoption) of high-risk, but potentially higher-yield economic behaviors would thus be favored either when times were predictable enough and/or when surplus production and storage were great enough to insure against the uncertainty and higher risks of failure associated with such behaviors (e.g., Richerson et al. 2001; Halstead, 1989).

Finally, if risk-averse behaviors are ways of averaging the multiple possible outcomes of decisions (the number of which increases under variable conditions), they are not necessarily disposed toward maximizing energetic return relative to labor input. Rather, they may also be target-oriented (e.g., storing enough food to make it through the winter, ensuring minimum daily caloric requirements are met, obtaining sufficient water or firewood.). In this way they are geared towards economic satisfying over optimizing, in the former an economic strategy that is particularly effective when information on optimal solutions is difficult (i.e., costly) to procure, such as when variable climatic (and perhaps social or other) conditions prevail. If this is the case, then it is conceivable that climate change and variability favor not economic maximizing or even efficiency but economic security. Security, of course, comes with its own costs and rewards, but is clearly unlike the optimizing behaviors associated with the evolution of complex hunter–gatherer, agricultural, and industrial economies during the Holocene.

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