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Reconstructing prehistoric hunter–gatherer foraging radii: a case study from California's southern Sierra Nevada

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Abstract

The concept of the foraging radius is essential to understanding hunter–gatherer settlement, subsistence, and sociocultural complexity yet is notoriously difficult to reconstruct archaeologically. Late prehistoric Western Mono foraging radii in the southern Sierra Nevada were reconstructed using GIS analysis of least-cost path distances between dispersed caching features and centralized residential features. Mean distances from settlements to caches exhibit a bimodal distribution, with peaks between 0.5 and 5.0 km, and 6.0 and 8.5 km, the former representing a caching limit and the latter a foraging limit around major settlements. Combined, these data demarcate a two-part foraging radius predicated not only on sustaining winter group aggregations but also on facilitating spring and summer residential moves. These results show the efficacy of using features and simple GIS-based spatial analyses to reconstruct prehistoric foraging radii and provide the means to model the energetics of different foraging behaviors, these speaking strongly to the social and economic factors conditioning the development of complex hunter–gatherer societies.

Keywords: Foraging Radius; Mobility; Hunter–gatherer; Western Mono; Sierra Nevada; Caching

The concept of the foraging radius is common to worldwide archaeological and anthropological hunter–gatherer research and is key to understanding the economics and ecology of hunter–gatherer subsistence (Kelly, 1998). It is also a critical component of models identifying differences between logistical and residential mobility and thus essential to the epistemology of hunter–gatherer cultural evolution (Binford, 1980) and to understanding the development of complex, logistically organized subsistence behaviors (Zeanah, 2004). And while easy to recognize in ethnographic or historical settings, it has proven exceedingly difficult to identify in prehistoric ones, this due in large part to the difficulty of relating material correlates of logistical behavior to residential bases in a spatially significant way. Recent research in the southern Sierra Nevada of California, however, has reconstructed logistical foraging radii around Western Mono settlements using GIS to analyze spatial relationships between caching features and settlements. This research shows not only the efficacy of using archaeological features in concert with terrain modeling and spatial analysis to reconstruct prehistoric foraging radii, but also helps model the social, economic, and ecological factors conditioning hunter–gatherer foraging patterns.

The term foraging radius refers to the daily distance hunter–gatherers travel from residential bases – the places where they sleep and where their family and/or larger social group resides – in order to obtain food and other requisites for survival. The term itself presupposes a logistical subsistence focus, with other activities (e.g., toolstone or firewood procurement) embedded within these forays (Binford, 1982). Ethnographic data and energetic analysis indicate foraging radii typically extend about 6–10 km from residential bases (Kelly, 1995). Logistical foraging behaviors delineating foraging radii around camps, though common to nearly all hunter–gatherers, are usually considered markers of more sedentary (and thus ostensibly more complex)

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groups (Bettinger, 1999; Bettinger and Baumhoff, 1982; Keeley, 1988; Kelly, 1992, 1998). Because of this, reconstructing prehistoric foraging radii solves not only a vexing methodological problem, but also provides a means of identifying the behaviors associated with the evolution of hunter–gatherer sociocultural complexity.

Ethnographic and archaeological studies of human foraging focus mostly on identifying foraging radii and the types of mobility associated with different foraging behaviors. Julian Steward was among the first to record daily foraging trips from Paiute settlements in Owens Valley, noting that these rarely exceeded 3.6 km one-way (Steward, 1933, 1938a). Lee (1968, 1979) subsequently recorded a 9.6 km foraging radius around !Kung settlements in the Kalahari. Similar information was recorded by ethnographers working in Africa (e.g., Harako, 1981; Hitchcock and Ebert, 1989), Australia (e.g., Gould, 1969; Tindale, 1972), and South America (e.g., Hawkes et al., 1982). But it was Binford (1977, 1978) who operationalized foraging pattern identification in archaeology with his analysis of Arctic foraging behaviors and subsequent modeling of residential versus logistical mobility as characteristics of foragers and collectors, respectively (Binford, 1979, 1980, 1982). Archaeologists seized on Binford's idea, employing some form of the forager–collector model in a multitude of settlement pattern studies (e.g., Thomas, 1983). Others looked for material correlates of different mobility strategies, often equating bifacial stone tool technologies with residentially mobile behaviors (e.g., Cowan, 1999; Kelly, 1988; Parry and Kelly, 1987; Rasic and Andrefsky, 2001). Still others measured distances between habitation sites in order to identify polygonal catchments around settlements, roughly equating these with foraging radii (e.g., Tartaglia, 1980; Tiffany and Abbott, 1982). More recently, the concept, if not empirical evidence for the foraging radius, was used to predict yearly Paleoindian residential moves (Surovell, 2000).

Recent foraging research, however, focuses on recognizing variability in foraging goals, arguing that gross descriptions of hunter–gatherer mobility (i.e., residential versus logistical) may conceal intragroup foraging variability (Zeanah, 2002, 2004). This research draws on the fact that most hunting and gathering societies divide labor by sex, with women's foraging typically geared towards efficient household provisioning and men's often focused on garnering prestige by sharing meat, a practice seemingly without positive economic return (Hawkes, 1991; McGuire and Hildebrandt, 2005). This arguably has important implications regarding where hunter–gatherers should choose to reside, with several researchers arguing that central place foragers should situate their domiciles so as to maximize the foraging returns of women while at the same time facilitating men's long-distance hunting (Elston and Zeanah, 2002; Zeanah, 2000, 2004). It also implies that women's foraging radii should be configured so as to provide positive economic return on foraging labor. In such a system, women's economic focus both pays for the "paradoxical" economics of men's hunting and also allows for group accumulations large enough to make male show-off behavior effective (Hildebrandt and McGuire, 2002). Once such a dichotomous system is established, it helps "Big Man" or chiefly status develop, meaning co-opted women's labor effectively "pays" for the development of institutionalized leadership roles (Jackson, 1991; McCarthy, 1993), a fundamental attribute of more complex social systems (Price and Brown, 1985).

Thus the import of foraging radius identification is twofold. First, it helps model the basic economics of hunter–gatherer subsistence, this predicated in large part on the size and configuration of different foraging radii. Second, it speaks to the ways different types of foraging contributed to the maintenance, reproduction, and evolution of hunter–gatherer societies on economic, social, and political levels. The current study succeeds in identifying foraging radii and addressing these perspectives because it takes advantage of two things: it does not exclusively rely on the concept of a site in its analysis and it uses the now commonplace, but no less revolutionary, tool of GIS to analyze spatial relationships between features in order to reconstruct foraging patterns around residential bases. In the first case, definitions of residential bases and stations are based on stationary features with obvious functional associations rather than the more abstract and problematic category of the site (Thomas, 1973), thus removing one layer of subjectivity in tying archaeological signatures to behavior (e.g., Binford, 1981; Kent, 1999; Smith and McNees, 1999). In the second case, it uses terrain modeling derived from digital elevation models to measure distances between archaeological signatures, thus taking into account the spatial relationships between features and residential sites as well as the energetics of traveling between these locales.

1. The Western Mono, settlement, and storage

The Western Mono, linguistic and cultural relatives of Owens Valley Paiute, live on the west slope of the Sierra Nevada in the San Joaquin, Kings, and Kaweah River watersheds (Fig. 1). The Mono are recent migrants to the area, moving west from Owens Valley in the last 600 years or so (Kroeber, 1959; Lamb, 1958; Morgan, 2006). Historically, Mono groups aggregated in relatively large winter hamlets just below snowline, dispersed in spring and summer to higher elevation camps to hunt, gather, and travel, and intensively harvested acorn, particularly black oak (*Quercus kelloggii*) acorn in the fall. Mono residential moves were key to exploiting their mountain environment, where environmental productivity is constrained not only by season, but also by elevation, with productivity moving upslope by environmental zone into summer.

Mono settlement focused on the household, an amalgam of related people, usually a nuclear family and a few close kin, living in small, cedar bark or brush huts. Households tended to group together, forming small camps or larger hamlets, usually with no more than eight households and 39 people to a hamlet (Gifford, 1932:17). Hamlets tended to cluster around springs, streams, stream confluences, and benches or flats along canyon margins (Hindes, 1959). Hamlets were provisioned, to a large extent, by food stored in winter settlement granaries and in more dispersed caches (Gayton, 1948; Gifford, 1932). This

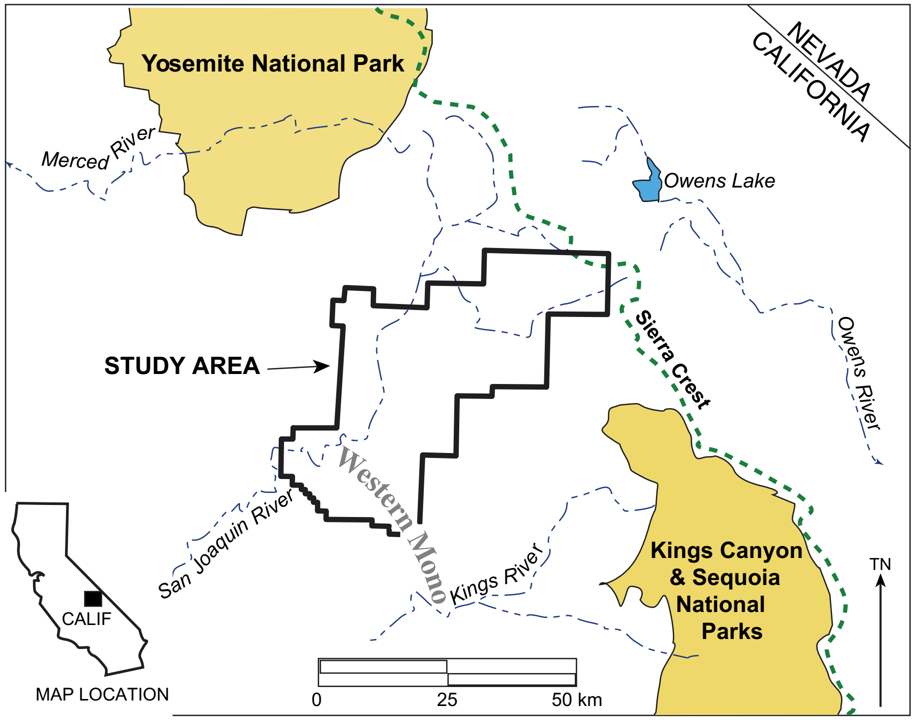

Fig. 1. Study area location.

study looks at the latter mainly because these are the types of storage that leave distinctive archaeological signatures and because they are usually situated away from settlements, suggesting association with logistical foraging.

Caches consist of a rock ring substructure (Fig. 2) and a woven-grass superstructure filled with dried acorns (Fresno Bee, 1936). Rock ring acorn cache foundations occur as isolated features, in association with two to four other rings, and occasionally with as many as 17. They are found almost exclusively on large, open, south or southwest-facing granite exposures particularly conducive to drying acorn prior to caching. Caches are found between 1000 and 1600 m elevation, a range encompassing average winter snowline, suggesting foods stored in some caches were largely inaccessible for at least part of the winter (Morgan, 2006).

The Mono also occupied middle and high Sierran locales above winter snowline in the spring, summer, and fall. A number of historical and ethnographic sources refer to Mono and Paiute use of higher elevations to hunt, camp, travel, or trade (Brewer, 1866; Gifford, 1932, n.d.; Hindes, 1959; Steward,

Fig. 2. Western Mono acorn cache foundation.

1933, 1934, 1938a,b), but information is sparse regarding the types of settlements used at higher elevations and the types of occupation these might have represented. The best evidence for Mono occupation of altitudes above 1400 m is thus archaeological. There are abundant archeological sites in the South Fork San Joaquin River canyon and in nearby montane basins above winter snowline. Many of these sites contain one or more bedrock acorn processing stations. At least one site from each basin contains Desert Series projectile points, brownware pottery, or steatite beads or vessel fragments indicative of Mono occupation (Hindes, 1962; Morgan, 2006). It is thus clear that the Mono used and occupied elevations above snowline in spring, summer and fall and that they exploited resources from montane, subalpine, and even alpine settings on a seasonal basis.

2. Modeling caching behavior in the context of settlement choice

Reconstructing Mono foraging radii – the area of land exploited around hamlets and camps – is informed by central place foraging (CPF) theory (Orians and Pearson, 1979) and its application to modeling resource transport behaviors. Anthropological CPF models operate on the assumption that foragers seek to maximize resource utility relative to procurement, transport and processing costs when operating from central places. At their most basic level CPF models see that the benefit of transported food is derived from the calories they contain and that a large cost to foragers operating logistically is travel time, which is a function primarily of distance. The simplest of these models thus argues that the caloric cost of transporting food should not exceed the calories contained in a load of transported food, this resulting in a maximum transport distance (essentially a maximum foraging radius) ranging from 37 to 812 km for Great Basin gathered foodstuffs (Jones and Madsen, 1989). More complex models identify at what distance and to what extent field processing (consisting of removing low-utility bulk that thereby increases the caloric benefit contained in a given load of foodstuffs) is more efficient than immediate transport back to central places (Barlow and Metcalfe, 1996; Metcalfe and Barlow, 1992). These models argue that when proximal to a central place it is more efficient to transport unprocessed foods because transport costs (these based mostly on distance) are low. But distal from a central place, the benefit of field processing is clear: increased load utility (gained by removing low-utility bulk) "pays" for increased travel costs, this resulting in a radius around central places where field processing provides greater economic returns than immediate transport. At this distance, which is variable for different foodstuffs due to their morphology, caloric content, and load size (but is about 3.67 km for a typical 36 kg load of dried black oak acorn [Bettinger et al., 1997]), increased evidence of field processing (e.g., processing stations and milling tools) is expected.

When it comes to modeling acorn caching behaviors, the applicability of these models is clear. Given that the costs of acorn harvesting, processing, and storage are fixed (McCarthy, 1993),

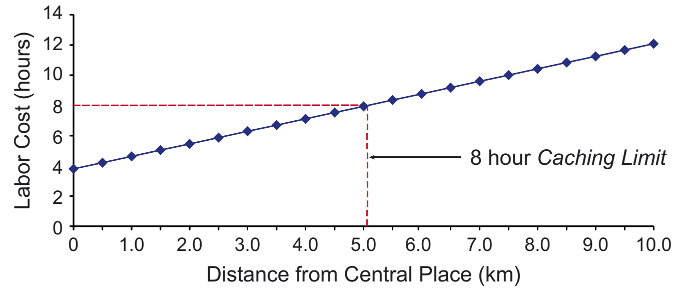

Fig. 3. Caching and transport costs correlated with distance from central place.

decisions regarding when and where to cache are most obviously conditioned by the distance to where that resource is going to be used; that is, where the benefit of the resource is going to be extracted. In other words, caching is a lot like field processing: close to central places, it is more efficient to transport acorn back to camp, but further from central places, it is more efficient to cache because of increased associated travel costs. This means that if an optimizing logistical forager is using cached resources at a central place, such as a Mono winter hamlet, distances to caches should be those that maximize daily returns on the costs of acorn caching from central places, meaning caches should be clustered around winter hamlets at the distance where caching becomes economically advantageous.

Following this logic, there are four costs associated with acorn caching: (1) round trip travel time to and from grove, (2) handling time (i.e., harvest and drying time), (3) time to build and fill cache, and (4) round trip travel time to re-access caches and return with acorn. Handling time and building time are a fixed cost of approximately 3.8 h for 36 kg, or enough black oak acorn to fill a Mono burden basket (Bettinger et al., 1997; McCarthy, 1993). Travel times vary depending on whether the path is uphill and whether the burden basket

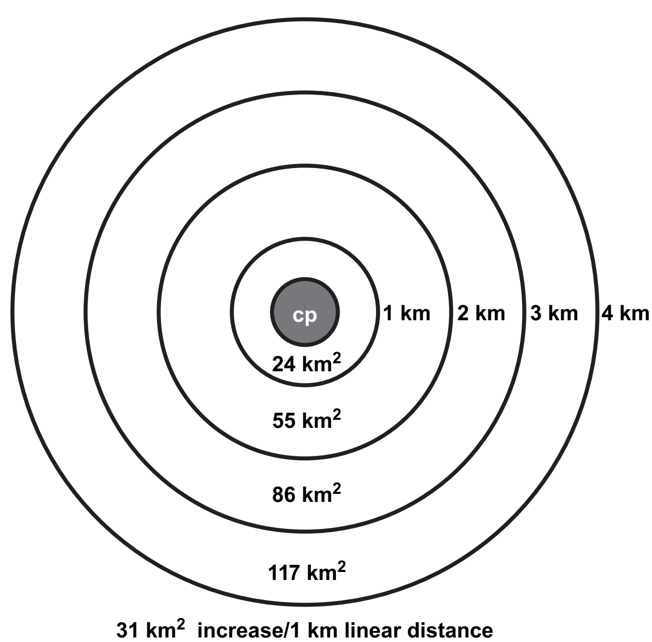

Fig. 4. Linear increase in area per ring-shaped parcel.

is empty or full, but are more or less constant when averaged across the entire trip. The overall cost of handling, caching, and transporting acorn to a central place is simply the sum of fixed labor costs and the linear increase of travel costs with distance. This is expressed in the formula: $C = h + b + 4d(k)$, where C is total cost in time, h is handling time, b is building time, d is distance, and k is the rate of travel. The value d is multiplied by four because it takes a maximum of two round trips to build caches, return to central places, and re-access caches to bring acorn back to camp. With handling costs fixed at 3.8 h/load and a rate of travel set at an optimal 4.7 km/h (Bastien et al., 2005), the formula is simplified as: $C = 3.8\ \mathrm{h} + 4d(4.7\ \mathrm{km/h})$. Fig. 3 aggregates these costs, measured in time, by distance from central place: at approximately 5 km from central place, caching and transport costs are 8 h. Because hunter–gatherers typically work no more than about 8 h a day (Hill et al., 1985; Kelly, 1995:20), this distance equates with a predicted *caching limit* around winter settlements.

On a more fundamental level, caches should be distributed in such a manner as to be easily constructed, filled, and re-accessed from central places. Specifically, the time invested in caching acorn in dispersed locations should comprise no more than a day's labor to build, fill, and later re-access cached acorn, this again based on the assumption that hunter–gatherers tend to work no more than 8 h a day. In its simplest sense then, caches should be no more than a half-day round trip from winter settlements, with the other half-day left for other activities. Using this logic, a central place cacher walking 4.7 km/h travels 18.8 km round trip in half a workday (4 h), or 9.4 km one-way, this latter figure the predicted *foraging limit* encircling winter settlements.

If caching is not oriented towards provisioning winter settlements, however, the overall number of caches should increase with distance from a central place. An easy way to model this is by looking at area as a function of distance from central place. Area increases exponentially with distance from a central point. But when area around a central place is divided into concentric ring-shaped parcels (Fig. 4), the relationship of the area of each ring to the next is linear, increasing by 1.57 km^2 per 0.5 km wide parcel. If caches are distributed evenly, then their frequency per ring-shaped parcel should increase linearly as well. This means that for a sample of 320 caches in a 10-km radius around a central place, there should be an additional 1.6 caches per 0.5 km wide parcel of land. This comprises the null hypothesis for the analysis. Combined then, central place travel and foraging costs predict a 9.4-km foraging limit and a 5-km caching limit around winter settlements. Alternatively, if caches are not conditioned by proximity to settlements and are instead evenly distributed on the landscape, their density with distance from settlements should increase linearly as a function of area.

3. Procedures

In order to test these hypotheses, distances to caches from central places (i.e., winter settlements and principal camps) were measured to determine the size of caching-oriented logistical foraging radii. The analysis used surface survey data collected over the last 60 years on the upper San Joaquin River watershed in the southern Sierra Nevada, California. The study area comprises a 50 by 50 km cross-section of the Western slope of the range, with elevations ranging from 420 to 4008 m. Research recorded location, assemblage, and component data from cache sites and sites with bedrock mortars, the idea being that caches are direct proxies for dispersed storage behaviors and that sites and clusters of sites with particularly high bedrock milling surface counts indicate Mono settlements (e.g., Elsasser, 1960; Gifford, 1932; Hindes, 1962). This resulted in a database of 320 acorn caches and 420 sites containing bedrock milling surfaces. Based on the

Table 1
Study area winter settlement areas

Name	General location	Associated Mono hamlets/home places	Reference	Criteria[a]
Blue Canyon	Mouth of Blue Canyon on Big Creek	Too-Hook-Much	Merriam, n.d.; U.S. Census Bureau, 1900, 1910	1, 2, 3
Providence Creek	Confluence of Providence and Big Creeks in Blue Canyon	Unknown	Merriam, n.d.; U.S. Census Bureau, 1900, 1910	1, 2, 3
Rush Creek	Rush Creek canyon southwest of Soaproot Saddle	Unknown	Merriam, n.d.; U.S. Census Bureau, 1900, 1910	1, 2, 3
Sam Daniels	Confluence of Willow Creek and San Joaquin River	Tasineu, Sagwanoi	Gifford, 1932, n.d.; Lee, 1998	1, 2, 3
Lerona	South slope San Joaquin River canyon	Hoo Ke pay	Theodoratus et al., 1978; Theodoratus, 1982	1, 2, 3
Jose Basin	Jose Creek watershed	Tao-po-na	Theodoratus et al., 1978	1, 2, 3
Stevenson-Dawn	South slope San Joaquin River canyon	Ku-pu-tu-gita or Ku-pura-tu-gewata	Theodoratus et al., 1978	1, 2, 3
Chawanakee Flats	Confluence of Big Creek and San Joaquin River	Chuwahni	Theodoratus, 1982	1, 2, 3
Hogue Ranch	Ross Creek west slope San Joaquin River canyon	Pakasanina	Theodoratus et al., 1978	1, 2, 3
Rock Creek	Rock Creek, west slope San Joaquin River canyon	"Paoso" (place name)	Theodoratus et al., 1978	1, 2, 3
Logan meadow	Chiquito Creek at Mammoth Pool Reservoir	Cha:tiniu	Lee, 1998	1, 2, 3

[a] (1) Housepit depressions and/or midden soils; (2) one site or a cluster of sites separated by no more than 350 m containing a total of 101 bedrock mortars; and (3) recorded in ethnographic literature or U.S. Census as a settlement location, hamlet, or home place.

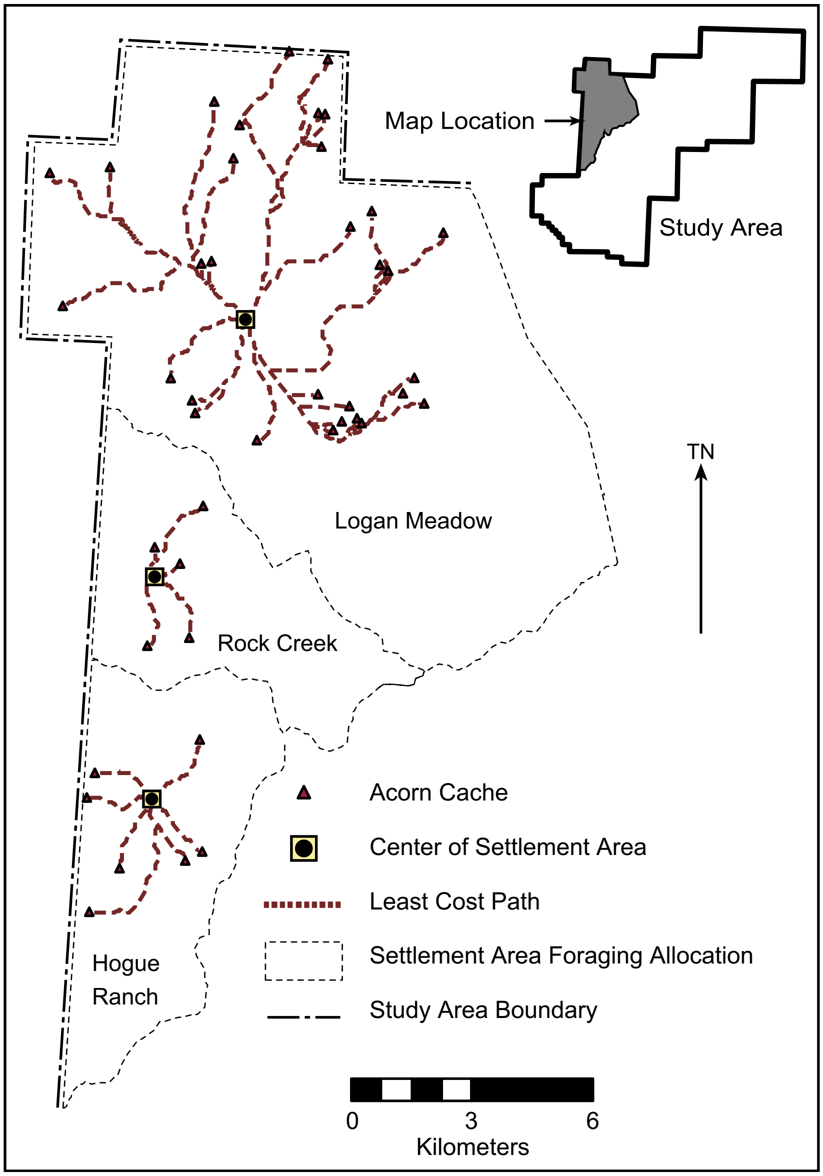

Fig. 5. Map showing least cost paths to acorn caches and settlement area foraging allocations.

high proportion of area surveyed (approximately 30% equally distributed in all elevation ranges) it is believed these data are a representative sample.

The definition of what comprises the unit of analysis in a study can have pronounced effects on geospatial analysis (e.g., Ebert, 1992). In this study, caches, winter settlement areas, and principal camps are used to analyze caching behaviors. Caches are rock rings and have already been described. Attributes that define a winter settlement are based on the assumptions that they were occupied in winter and thus would have to be below average snowline (1400 m) and that they were the locus of substantial population aggregations and thus should show clear evidence of habitation (this is evidenced by the presence of housepits, midden soils, and milling stations with high bedrock milling surface counts). Winter settlements are thus defined as single sites or clusters of sites separated by no more than 350 m together containing 101 or more milling surfaces. At least one site in each cluster must also contain midden soils and/or housepit depressions. Lastly, winter habitations are recorded as Mono villages, hamlets, or settlement areas in ethnographic literature and U.S. Census records. According to these criteria, it is clear that Mono winter habitations cluster in 11 settlement areas (Table 1) at relatively flat, well-watered locales in and around the steep and incised San Joaquin River canyon.

Table 2
Descriptive statistics for least cost paths analysis

Analysis	Sample size	Minimum (m)	Maximum (m)	Mean (m)	Median (m)
Largest site	295	100	8379	3394	2878
Area center	295	213	8377	3353	2875
Site center	295	239	8894	3451	2863

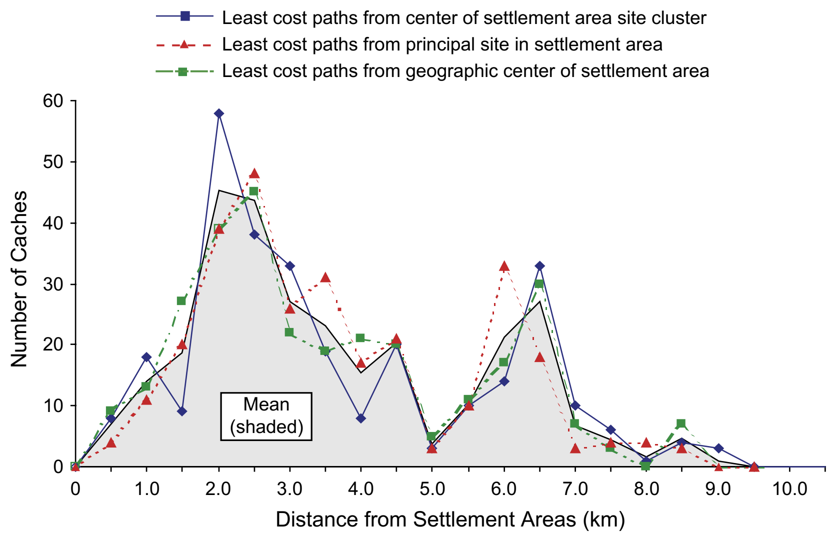

Fig. 6. Histogram of least cost paths from winter settlements to caches.

Principal camps are sites or clusters of sites more than 350 m from winter settlements containing 14 or more bedrock mortars, a lithic scatter and/or midden soils. Using high bedrock milling surface counts as demographic proxies is well established in the Sierra Nevada and in California in general (Bennyhoff, 1956; Elsasser, 1958, 1960; Haney, 1992; Hindes, 1962; Moratto, 1972). Equating sites with 14 or more milling surfaces with principal camps is also well established in local archaeological parlance and supported by functional and settlement pattern analyses (Jackson, 1984; Morgan, 2006). Use of this site type is important in that it identifies habitation sites without relying exclusively on ethnographic information or on the clustered distribution of sites in settlements below snowline. Importantly, it also allows for reconstruction and analysis of habitation above snowline.

Measurements were made using ArcMap GIS software, a method shown to have multiple applications toward archaeological settlement pattern analysis (e.g., Anderson and Gillam, 2000; Jones, 2006). The location of each site and feature was derived from UTM data. Operating on the assumption that linear distance is not the best descriptor of distance in mountain environments characterized by steep slopes, distances from winter settlements were measured using least-cost paths developed using the spatial analyst extension in ArcGis, ArcMap version 9.1 software. Using this extension, least cost paths model the most economical path between two points given the cost of traveling over uneven terrain (see ESRI, 2001:11 for an explanation of the least cost path function). Travel costs were based on distance and on slopes derived from 30 m resolution digital elevation models of the study area, with slope values measuring the cost of traveling over increasingly steep terrain. Generating least cost paths from these data also allocates parcels of terrain to central places, this resulting in catchments containing groups of caches associated with each settlement area (Fig. 5).

In order to account for the fact that Mono winter hamlets were moved from year to year within the relatively narrow confines of larger settlement areas and thus could conceivably skew the association of any one winter village to a particular set of caches, the analysis was run three times. The first was from the most complex site in the settlement area (i.e., the site with the greatest number of bedrock milling surfaces and habitation features). The second was from the geographic center of each settlement area, this is based on the area of habitable terrain (i.e., less than 10 degree slope) in these areas. The third was from the center of the settlement cluster in each settlement

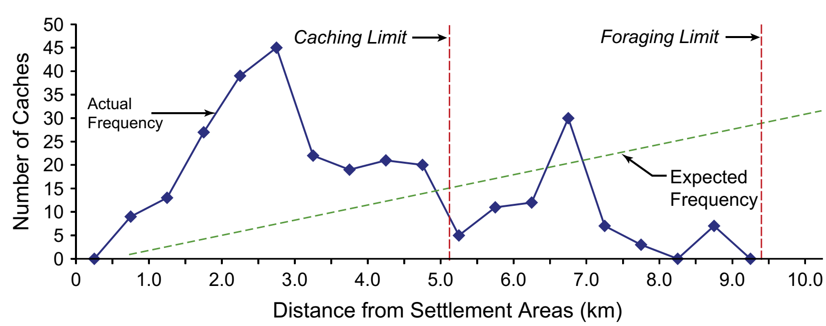

Fig. 7. Histogram showing actual versus expected frequencies of caches relative to distance from winter settlements and cache distribution correlated with predicted caching and foraging limits.

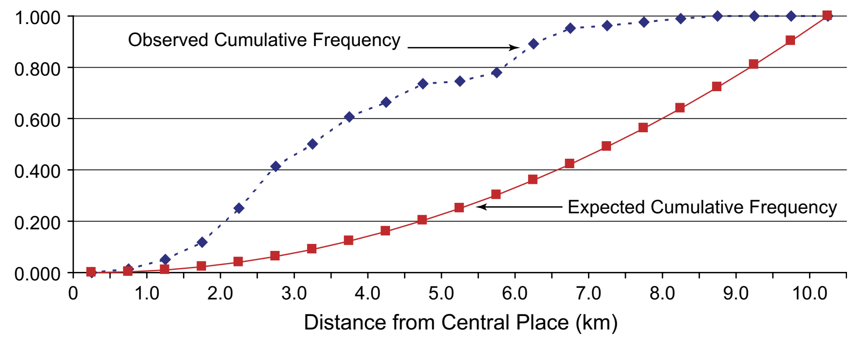

Fig. 8. K−S test results: expected versus observed cumulative frequency.

area, this is based on the geographic center (derived as above), of the archaeological sites with bedrock mortars in the settlement area.

4. Results and analysis

Analysis results are strongly correlated (Table 2), indicating that specific sites in winter settlement areas do not condition association with particular sets of caches. Analysis of variance between mean distances to caches from the most complex site in each settlement area, the geographic center of each settlement area, and the center of each settlement's site cluster suggests that the mean distance from caches to settlement areas is equivalent for each of the data sets ($p = 0.833$; $\alpha = 0.5$) (Fig. 6). Based on the strong correlation between data sets, the following uses data derived from measurements taken from the geographic center of each winter settlement area. Using this data set is based on three factors: (1) it correlates most strongly to the mean of the three data sets; (2) it removes any problems associated with survey strategies which may have missed sites; and (3) it does not favor single sites to the exclusion of others. Using this data set, distances to caches from settlements range from 0.5 to 8.3 km, averaging 3.4 km. The distribution of caches relative to central places, however, is bimodal, with peaks at 2.4 and 6.5 km.

These data clearly indicate that the observed distribution of caches relative to winter settlements is greater than the expected distribution based on area alone in the 0.5−5 km and 6.0−7.0 km range (Fig. 7). A Kolmogorov−Smirnov (K−S) cumulative frequency test of observed versus expected distributions provides a test statistic, d, of 0.533. This value indicates that the two categories are significantly different at significance levels (α) 0.05 (critical value = 0.112), 0.01 (critical value = 0.1342), and 0.001 (critical value = 0.1616) (Fig. 8). These data strongly suggest that cache distribution is not predicated on area, but is rather conditioned by another factor, most obviously distance to winter settlement area.

Restriction of caches to the predicted 9.4 km foraging limit around winter settlements suggests that cache distribution is strongly correlated with proximity to winter settlements. The first mode in the cache distribution ranges from 0.5 to 5.0 km, with a mean of 2.4 km from central place. When looked at in light of costs associated with caching from a central place, the number of caches drops precipitously past the 8-h mark, suggesting that the first mode in the cache distribution corresponds to the predicted caching limit around winter settlement areas (Fig. 7).

Analysis of the second, distal mode relative to snowline elevation and principal camps suggests that this distribution is conditioned by seasonal residential moves. Caches above average winter snowline account for nearly all caches more than 5 km from winter settlements (Fig. 9). Looked at more closely, 65 caches account for the second mode in the cache distribution. Of these 65 caches, 55 (84.6%) are between 0.2 and 2.7 km (measured by least cost paths) from principal camps above snowline (Fig. 10). The mean distance of these caches from principal camps above snowline is 1.5 km, indicating higher elevation caches map onto these camps. Combined,

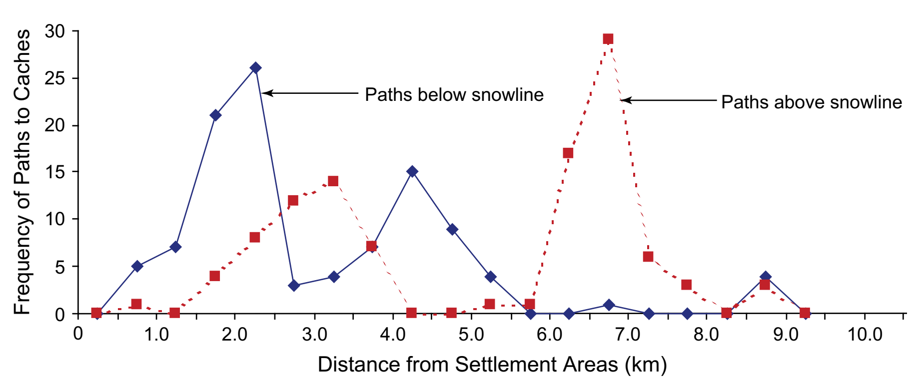

Fig. 9. Comparison of cache distributions above and below snowline.

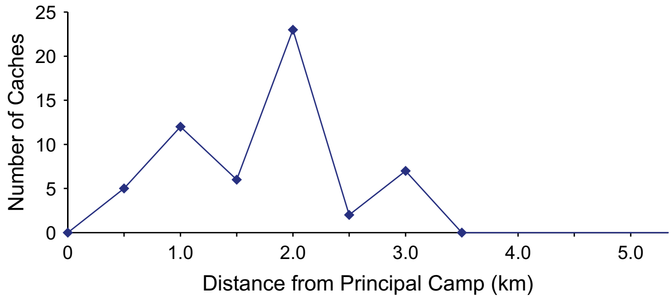

Fig. 10. Cache distribution relative to summer principal camps.

these data strongly suggest that higher elevation caches between 5 and 7 km from winter settlements were used in part to provision residential camps above snowline.

Three main points are derived from these analyses. The first is that caches are confined to a 9 km foraging radius around winter settlements. This allows 4 h round trip travel time from winter settlements and 4 h foraging time per day, a division of travel and foraging time consistent with ethnographic descriptions of hunter–gatherer behavior (e.g., Kelly, 1995). The mean distance from winter settlements to caches is 3.4 km, close to the average daily foraging radius recorded by Steward (1933, 1938a) for the Owens Valley Paiute as well as the one-way travel threshold Bettinger et al. (1997) identified for transporting loads of dried black oak acorn. The second is that the first mode in the observed distribution, between 0.5 and 5 km, corresponds to the 5 km caching limit predicted by the sum of caching travel and labor costs. This suggests that the bulk of caching behavior was geared towards providing a distribution of cached foodstuffs optimizing caching and travel time within winter settlement foraging radii and that food cached within these radii was principally associated with provisioning winter settlements. The third is that the second mode in the overall cache distribution, between 5 and 9 km, though within the maximum foraging limit of winter settlements, was geared towards provisioning camps above snowline that were occupied in the spring, summer, and fall. The caches in this second mode account for most of the caches above snowline and are associated with principal camps at higher elevations, suggesting that they served as a source of reliable food for spring residential moves. Together, these data indicate that acorn caching was geared towards creating and maintaining a reliable source of cached acorn in a foraging radius maximizing labor returns around winter settlements. Caches were subsidiarily used to provision camps occupied in spring, summer and perhaps fall.

5. Conclusion

This study shows the efficacy of using archaeological features and GIS to reconstruct prehistoric foraging radii. Using in situ features accurately maps very specific behaviors: caching is directly associated with rock rings and residence is associated

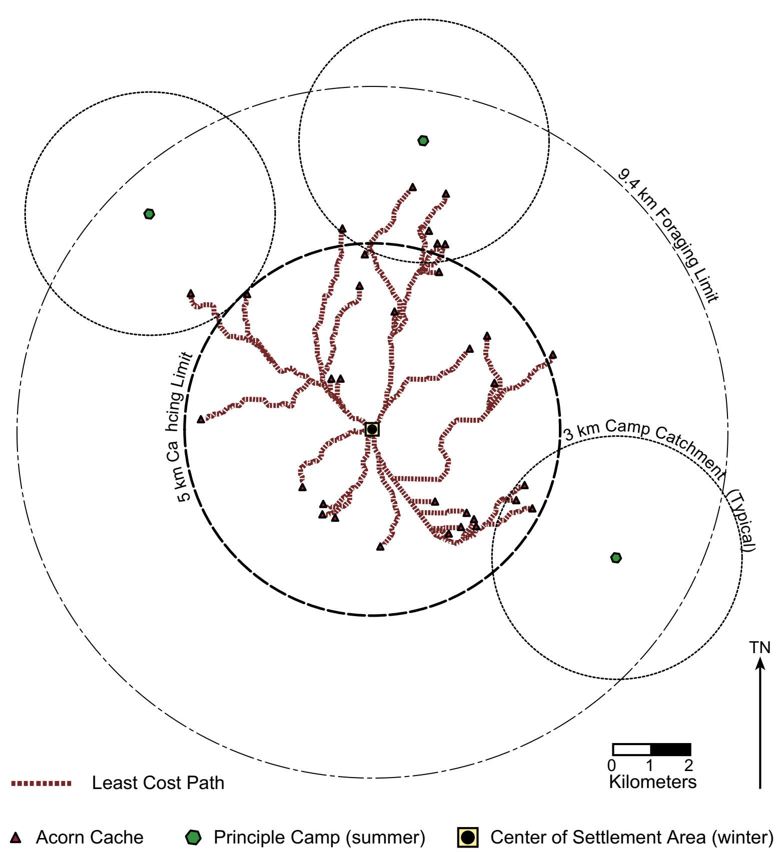

Fig. 11. Map of logan meadow least cost paths and idealized caching, foraging, and camp catchment limits.

with intensive processing behaviors resulting in high bedrock milling surface counts, housepits, and well-developed midden soils. Least cost paths developed with GIS accurately measure distances walked by Mono cachers and are thus good proxies of the most essential component of CPF models: travel time. Travel times play a vital role in determining distances between caches and settlements, resulting in a 9-km foraging radius around winter settlements marked by modes at 2.4 and 6.5 km, the first corresponding to a caching limit determined by acorn harvest and transport costs and the latter associated with higher elevation camps but also within winter settlement foraging limits (Fig. 11).

These attributes of Mono caching behavior speak strongly to the socioeconomics of foraging goal variability and to the association of mobility to other markers of sociocultural complexity in hunter–gatherer groups. Because the first mode of the cache distribution is associated with provisioning winter settlements (and because acorn harvest is traditionally performed by women), it is likely geared towards meeting women's foraging goals. Thus women's foraging paid for winter population aggregation and seasonal sedentism by efficiently caching foodstuffs in logistical foraging radii around winter settlements. The second mode of the cache distribution provisioned camps only habitable in spring, summer, and fall that were essential to exploiting a mountain environment where higher elevation resources were available in very time and space limited patches each summer. Caching thus paid for winter population aggregation and seasonally sedentary behaviors while facilitating spring and summer residential and logistical mobility, a dichotomy calling into question prevailing views on the relationship between storage and sedentism (Testart, 1982; but see Eerkens, 2003) and providing a clear case where ostensibly ''complex'' behaviors like storage are associated with ''simpler'' behaviors like residential mobility.

Mono caching also evinces a case where women's foraging helped underwrite men's economic focus. It is clear that women's logistical caching sustained Mono populations, allowing for alternative, perhaps less efficient labor by their male counterparts. Caching also helped provision summer residential bases from which long-distance hunting forays and trans-Sierran trading trips began, behaviors typically associated with men. This would allow men to hunt the high country and foster trade relationships with outside groups, both means of garnering prestige in Mono and other hunter–gatherer societies, particularly those in late prehistoric California. It is thus conceivable that the foraging radii identified in this study show how women's foraging helped pay for the development and maintenance of status distinctions in prehistoric California, and perhaps in other complex hunting and gathering societies as well.

Reconstructing men's long-distance foraging patterns is of course essential to modeling the other side of this system, perhaps by measuring distances from central places to hunting blinds, tool re-sharpening areas, or butchering locales. Despite problems associated with maintaining temporal control and with linking hunting locations to specific central places, doing so would help model the relative efficiency of men's labor, thus showing whether the energetics of men's foraging are really as ''paradoxical'' as they are claimed. This would also allow comparison of the returns on men's and women's foraging and thus be a good way of testing whether women's foraging really underwrites men's prestige-oriented labor and the development of associated forms of status and authority. Ultimately, such comparisons will rely on reconstructing prehistoric foraging radii using a combination of features or other middle-range markers of specific foraging behaviors, CPF models, and GIS to determine the economic returns on different prehistoric foraging strategies. Such reconstructions show promise not only for modeling the economics of past land use patterns but also for modeling the social and ecological contexts resulting in the development of complex hunting and gathering societies.

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