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Plant Utility Indices: Two Great Basin Examples

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Collection and processing experiments conducted with two Great Basin plant foods, pinyon and pickleweed, are reported, and their implications for expecting and interpreting variation in plant macrofossil assemblages produced by central-place foragers are discussed. Our results suggest that archaeologists should expect inter-assemblage and inter-taxonomic variation in the deposition of plant remains as a result of differences in the costs and benefits of field processing plant resources for transport. Estimates of the net caloric return rates associated with field processing and transporting loads of pinyon and pickleweed also suggest that processing characteristics may determine which resources are more likely to affect the locations of residential camps, and which may be efficiently exploited through logistic procurement.

Keywords: CENTRAL-PLACE FORAGING, PLANT MACROFOSSILS, CALORIC RETURN RATES, OPTIMAL FORAGING THEORY.

Introduction

In the last 20 years the quantity of plant remains recovered from archaeological sites has increased dramatically. Paleoethnobotanists have developed more efficient and less destructive methods to retrieve plant specimens from archaeological sites and are employing more sophisticated statistical techniques to identify temporal and spatial patterning in macrofossil assemblages (Ford, 1988; Hastorf & Popper, 1988; Pearsall, 1989). Although the measures of taxonomic variation employed in the analysis of macrofossil assemblages vary (e.g. frequency, ubiquity or proportion of taxa represented), differences in the types and quantities of these remains are routinely investigated to recover information about the role of plant resources in prehistoric economies.

Researchers have identified a number of behavioural and post-depositional processes that likely contribute to inter- and intra-site patterning in the distribution of plant remains in archaeological sites. Studies of behaviours that structure the deposition of plant remains include investigations of the process of selecting plant resources for consumption (O'Connell & Hawkes, 1981; Hawkes, Hill & O'Connell, 1982; Hawkes, 1987); the types of plant waste associated with harvesting and processing cereal grains (Hillman, 1981; Harlan, 1989; Sikkink, 1989; Hillman, Colledge & Harris, 1989); and the use of different areas of residential sites for storage, processing, consumption and waste disposal (Hillman, 1984; Jones, 1984; Hastorf, 1988; Sikkink, 1988, 1989). In addition, some researchers have discussed the potential effects of natural agents of deposition, differential preservation, and cleaning by site residents on macrofossil assemblages (e.g. Dennell, 1972; Hally, 1981; Pearsall, 1988; Metcalfe & Heath, 1990).

This study investigates another aspect of plant processing activities likely to introduce patterning in the types and quantities of plant waste deposited in archaeological sites. Field processing is the removal of waste or low utility parts (e.g. hulls, chaff or shells) from resources at the location of procurement. If prehistoric foragers or farmers sometimes processed all or some subset of these parts from collected plant foods before transporting them, the potential effects of these behaviours on the subsequent removal and deposition of plant remains at residential sites may be significant.

We present the methods and results of processing experiments with two plant resources often recovered from archaeological sites in the Great Basin of western North America. Pinyon pine (*Pinus monophylla*) and pickleweed (*Allenrolfea occidentalis*) were collected from wild stands of plants growing in the vicinity of the Great Salt Lake (Figure 1) and experimentally processed using techniques and equipment chosen to approximate those used by prehistoric foragers.

The experiments were conducted to estimate increases in the economic utility of pinyon and pickleweed with time spent field processing, and associated changes in the types and quantities of inedible waste remaining with pine nuts and pickleweed seeds. We develop expectations about the circumtances in which prehistoric foragers operating from base camps should have removed different components of these plants at locations of procurement, and describe the types and relative quantities of waste associated with pinyon and pickleweed at different processing stages.

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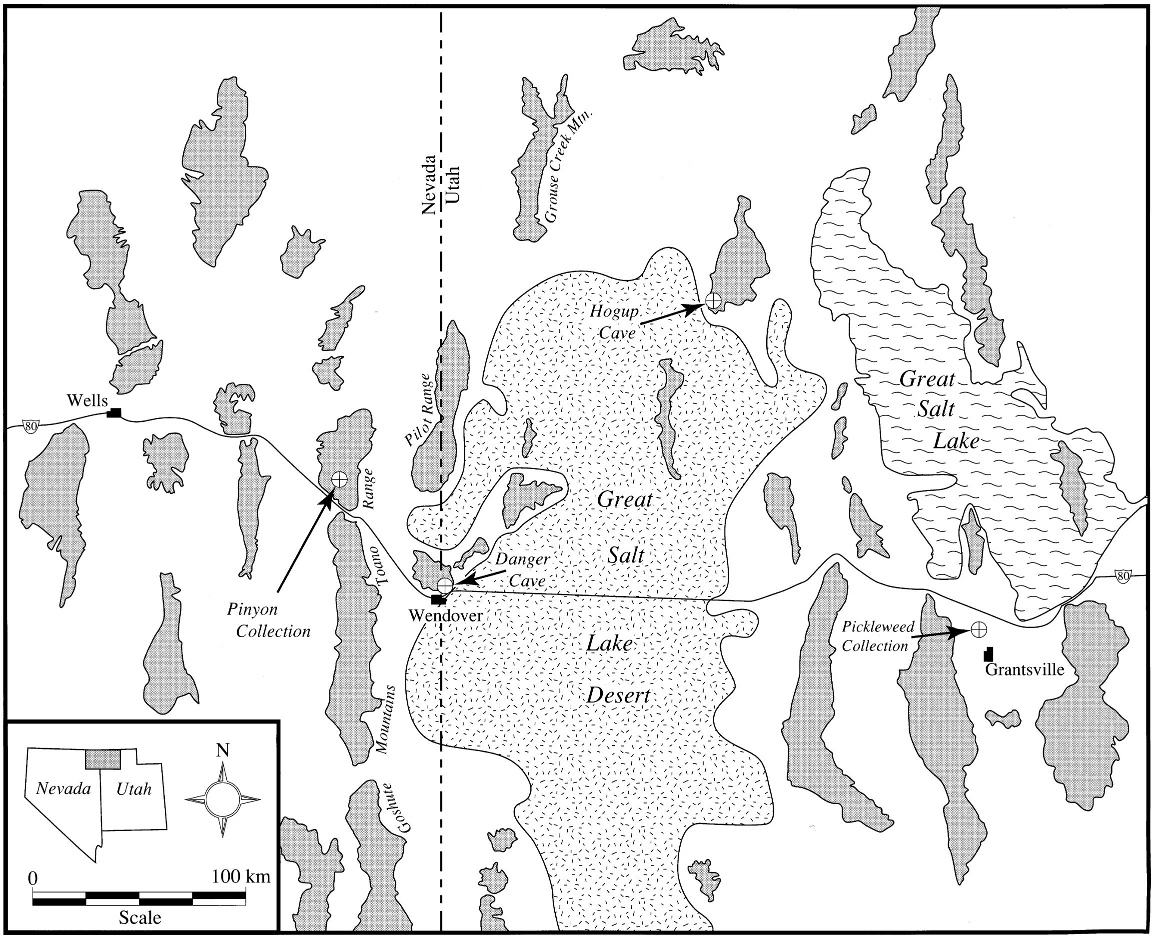

Figure 1. Map of the Great Salt Lake Desert and surrounding area. Macrofossil assemblages from Danger and Hogup Caves yielded large quantities of pickleweed plant parts, but very little pinyon waste. Pinyon cones with nuts were collected for the processing experiments from a grove in the Toana Range northeast of Wendover, Nevada. Pickleweed plants were collected from a patch north of Grantsville, Utah.

We also explore relationships between the costs and benefits of collecting, field processing and transporting loads of these resources to base camps and the implications for overall efficiency while foraging.

The results of these experiments indicate that archaeologists should expect patterned variation in macrofossil assemblages simply as a function of differences in the processing characteristics and spatial distribution of plant resources. We predict fairly dramatic differences in the types and quantities of pinyon remains recovered from sites within pinyon groves versus sites located within several days travel from the grove, with very little waste expected in more distant sites. In contrast, we expect large quantities of waste to have been carried with pickleweed seed even if the resource was transported great distances.

Our analyses also suggest that the caloric return rates associated with exploiting plant foods vary dramatically with different stages of field processing and transport distances. Foragers would always have gained greater amounts of food energy per time spent in acquisition and processing if they moved residences to pinyon and pickleweed patches while exploiting them. On the other hand, foragers exploiting these resources simultaneously would have increased caloric return rates by locating residential sites on pickleweed patches and field processing and transporting pine nuts up to large distances, even if pinyon was an important component of the diet. Where differences in the costs and benefits of field processing and transport vary greatly between resources, plant utility indices may provide the basis for developing inferences about which resources should have the greatest influence on the locations of residential sites.

The Problem: Great Basin Subsistence

Reconstructions of prehistoric subsistence in the eastern Great Basin, especially during the Archaic period from approximately 9000 to 1500 years, are largely based on assemblages recovered from deeply stratified cave sites located near springs at the edges of lake basins and salt flats (Jennings, 1978; Madsen, 1982; Aikens & Madsen, 1986). Sites such as Danger (Jennings, 1957, 1978; Fry, 1976; Hall, 1988) and Hogup Caves (Aikens, 1970; Fry, 1976; Aikens & Madsen, 1986) yielded large collections of plant and animal remains associated with cultural deposits, including pinyon and pickleweed (Figure 1). Local archaeologists routinely develop inferences about the importance of plant resources in prehistoric diets based on patterned variation in the types and quantities of plant parts recovered from these sites. When pinyon cones and hulls are rare, either absolutely or relative to the remains of other species, this is generally interpreted as evidence that pine nuts did not play a significant role in the diet of site occupants (e.g. Harper & Alder, 1970: 218; Madsen, 1982: 216). Similarly, large quantities of pickleweed chaff and plant parts in cultural deposits, and seeds and plant parts in coprolites, have led researchers to hypothesize that pickleweed was an important component of prehistoric diets (Jennings, 1957: 64, 1978: 30; Harper & Alder, 1970; Fry, 1970, 1976; Madsen, 1982: 214; Bettinger, 1993).

These interpretations present a striking contrast with historic accounts of aboriginal plant use. Pine nuts are consistently identified as an important food source, and ethnographic studies and observations made by explorers and early settlers throughout the Great Basin indicate that local pinyon crops often provided the primary source of winter food (e.g. Steward, 1938; Wheat, 1967; Fowler, 1989). In contrast, references to the use of pickleweed are rare. Several older Northern Paiute informants identified pickleweed seeds as a food that had been collected in the past (Stewart, 1941), and a Gosiute story entitled ‘‘The Pickleweed Winter’’ suggests that pickleweed was an important winter food ‘‘long ago’’ (Miller, 1972: 44–46). The story describes an apparently unusual event when pickleweed seeds were concentrated in windrows along the salt flats by melting snow, allowing it to be gathered in large quantities. ‘‘During the winter, one ate all he wanted. It was over there at Big Springs . . . they called it the pickleweed winter. They ate it with pine nuts, they say. They ate it with jack rabbits. Times were good, they say’’ (Miller, 1972: 45). On the other hand, pickleweed was excluded in the most detailed list and description of plant foods used by Gosiutes (Chamberlin, 1911), and Julian Steward asserted that the seed bearing shrubs of the salt flats, including pickleweed, ‘‘are worthless for food’’ (Steward, 1938: 17).*

These accounts suggest that the importance of pickleweed varied through time even in locations where the plant is locally abundant. It appears to have been dropped from the diets of indigenous people completely around the time that Euro-Americans settled in the region, while pinyon continued to comprise a large portion of aboriginal diets in the early 1900s and is still collected commercially and for private consumption (Lanner, 1981).

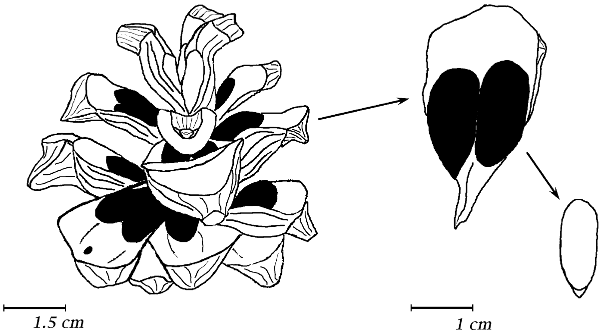

Figure 2. Open pinyon cone with nuts (*Pinus monophylla*), enlarged cone scale with nuts, and hulled nutmeat. The woody cone, cone scales, and hulls are waste; the soft, white nutmeat is the edible component of pinyon.

One possible explanation of the apparent difference between these observations and the representation of pinyon and pickleweed in macrofossil assemblages is that pinyon was locally less abundant during the time the sites were occupied. Alternatively, patches of these resources are often separated by substantial distances, and they may have been differentially processed near procurement locations. If so, differences in the types and quantity of pinyon and pickleweed remains in archaeological sites may reflect variation in the amount of time prehistoric foragers spent removing low utility but archaeologically visible plant parts from these resources prior to transporting them to base camps, regardless of their relative importance in past diets.

Pinyon

Single-leaf pinyon are relatively small, scrubby pines found interspersed with juniper trees or in sparse groves in many of the foothills and small mountain ranges of the Great Basin. Beginning in the early fall, these pines are sometimes laden with green, sappy cones bearing pine nuts. As autumn progresses, the cones dry and turn brown, opening and releasing the nuts (Lanner, 1981). An early, hard freeze will hasten this process.

Pinyon cones may grow singly or in clusters, range in size from about 4 to 7 cm in length, and usually contain between 6 and 16 nuts (Figure 2). The nuts occur either singly or in pairs on the cone scales, and are about 2 cm long and 1 cm wide. Each nut consists of a nutmeat surrounded by a soft leathery covering (nucellus) and a hard, brittle shell (integument or seed coat) (Sporne, 1965; Farjon, 1984). The plant parts relevant to this study are the cones, shells, and nutmeats. Nutmeat is the only edible component with energetic value to humans; the other components are waste.

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*Robert Bettinger (personal communication) has suggested Chamberlin or his informants incorrectly identified pickleweed (*Allenrolfea occidentalis*) as ‘‘brittlewort or samphire (*Salicornia herbacea*)’’, or perhaps included it in descriptions of aboriginal use of the latter plant (Chamberlin, 1911: 340, 380). Although the plants are morphologically distinct, *Salicornia* is found today in very wet locations on salt flats, sometimes within pickleweed communities.

There are several detailed accounts of aboriginal processing techniques (Palmer, 1878; Coville, 1892; Dutcher, 1893; Chamberlin, 1911; Wheat, 1967; Fowler, 1989), from which the following was synthesized.

Pinyon nuts were often gathered when the cones were still green, requiring that the cones be knocked or picked from the trees. They were then either placed in piles or storage pits and left to open by drying, or were opened by exposure to fire. After the cones were open, the nuts were removed either by shaking the cones, beating the cones with a stick, or beating a container filled with cones with a stick. Pinyon nuts were also gathered when the cones were brown and open. The pine nuts were collected by picking them off the ground after they had fallen, and/or placing mats under the tree and beating and shaking the nuts out of the cones on the trees. Once the nuts were separated from the cones, they were either dried and stored, or parched in a tray with hot coals. After parching, the shells were separated from the nutmeats with a mano and metate, and removed by winnowing. The nutmeats were again parched, ground and eaten.

Pickleweed

Pickleweed is a perennial shrub of the Goosefoot family that occupies a fairly exclusive niche in the poorly drained sediments of Great Basin salt flats (Figure 3). Pickleweed plants grow in circular, sparsely distributed clumps, trapping sediments and creating low mounds on the desert floor. Rarely more than 50 cm tall, but often spreading to a diameter of greater than a meter, clumps of bright green, succulent pickleweed plants are often conspicuous across otherwise barren stretches of salt or alkali flats in late summer to early fall. Each plant has numerous jointed, vertical branches supported by a shallow woody root system. In late fall pickleweed turns reddish and the seed-bearing spikes at the terminal ends of branches become dry and brittle.

Each branch of the plant has *c.* 90 to 120 inconspicuous flower spikes (Figure 4). Each spike has *c.* 30 to 60 seeds arranged in a linear spiral. The tiny, black seeds range from about 0·4 to 0·9 mm in diameter. Each seed is encased in a pericarp, which in turn is encased within three specialized leaves called bracts. When dried, the pericarps and bracts are thin papery shells, or chaff, that can be separated from seeds by hand-rubbing and removed by winnowing. The components of pickleweed relevant to this study are branches, spikes, bracts, pericarps, and seeds. Seeds are assumed to be the only component having nutritional value for humans; the other components were assigned a caloric value of zero.

Figure 3. Caprielle and Aaron Barlow in pickleweed patch near Grantsville, Utah.

We failed to locate any description of how pickleweed was processed by natives of the Great Basin. However, ethnographic descriptions of the aboriginal procurement and processing of small seed plants in the Great Basin contain a number of striking similarities in technique. Perhaps the most variable is the method of procurement, which ranges from beating or threshing the seeds from plants to collecting whole plants by pulling them out of the ground, roots and all. When entire plants were collected, they were generally processed in the following manner (from Fowler, 1989: 46–49). First, the plants were allowed to dry for several days to a week. Once dry, the seeds were separated from other plant parts by beating, pounding, grinding, or hand ‘‘crushing’’ and the chaff was removed by winnowing in a tray. When seeds were encased in a hard hull, the seeds were next parched in a tray, the hulls cracked using a metate, and the hulls removed by winnowing. The seeds were then either stored for later use, or parched again, ground and eaten. These general steps guided the experimental processing procedures developed for pickleweed.

The Field Processing/Transport Model

Recently, we cast the problem of the differential utility and transport of resource components in very general terms: when should central-place foragers remove low

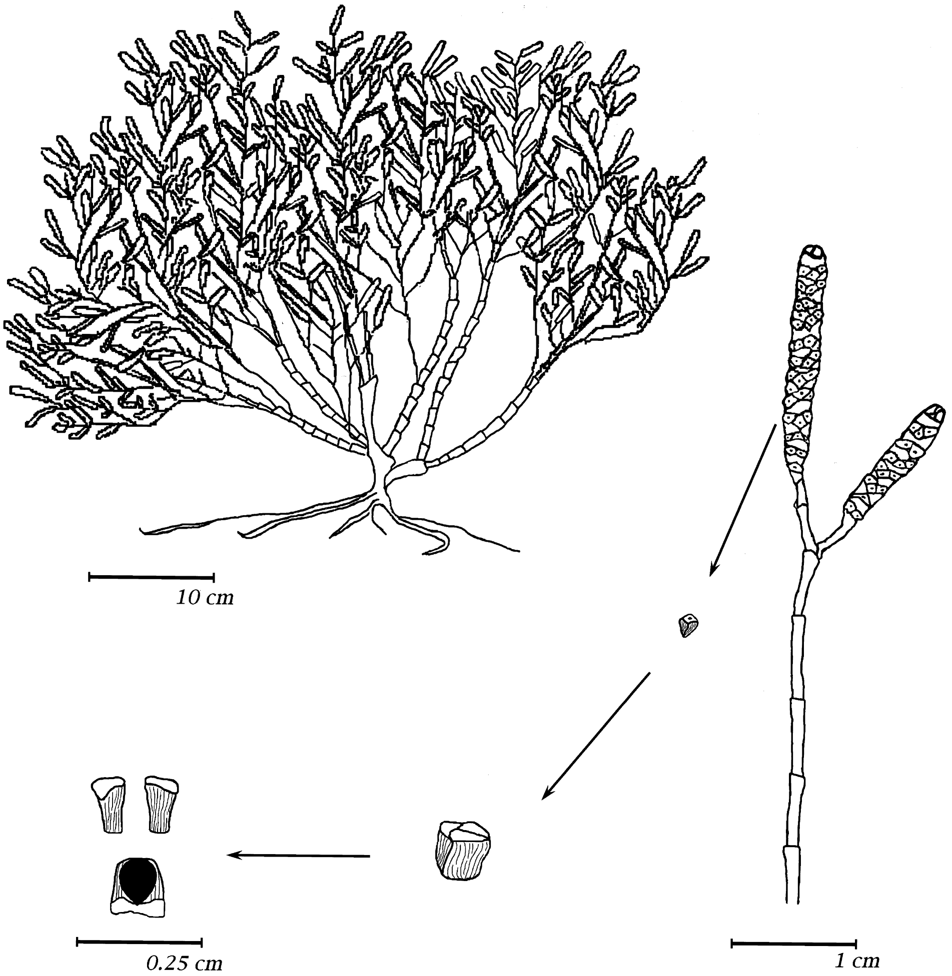

Figure 4. Dried pickleweed plant (*Allenrolfea occidentalis*), enlarged branchlet with flower spikes, and papery bracts encasing the pickleweed seed. The jointed plant parts and chaff created from crushing the bracts are waste; the tiny, flat seed is the edible component.

utility parts at procurement locations, and what are the archaeological implications of processing resources in the field? Based on a series of explicit assumptions, we developed an optimality model that predicts variation in field processing behaviour with differences in round-trip travel time between the place of procurement and consumption, and increases in the utility of a resource with processing time, as the critical factors structuring the type and amount of waste components returned to residential camps (Metcalfe, 1989; Metcalfe & Barlow, 1992).

A resource's utility function is simply the relationship between time spent field processing and the resulting increase in the utility of the transported load. When the collected resource consists of a number of different parts of varying utility, the field processing/transport tradeoff may determine the types and quantities of parts returned to a central-place foragers camp, and therefore the composition of assemblages that enter the archaeological record. For a load of food resource, utility can be measured in calories. In this case, *the model predicts that collectors will spend the amount of time field processing that yields the maximum calories per hour spent travelling to the resource patch, collecting and field processing the resource, and transporting it back to camp.*

To develop expectations about when different parts of pinyon or pickleweed should be discarded at procurement locations, we measured changes in the utilities of these resources associated with processing time (Metcalfe & Barlow, 1992). We constructed utility functions by calculating the caloric values of these resources at different processing stages and plotting caloric value against the amount of time required to accomplish each processing stage (Figures 5 & 6).

Calculating utility

For resources with only one edible component (e.g. pinyon nutmeats and pickleweed seeds), changes in utility can be calculated by determining the proportional weight of nutmeats or seeds in the resource after

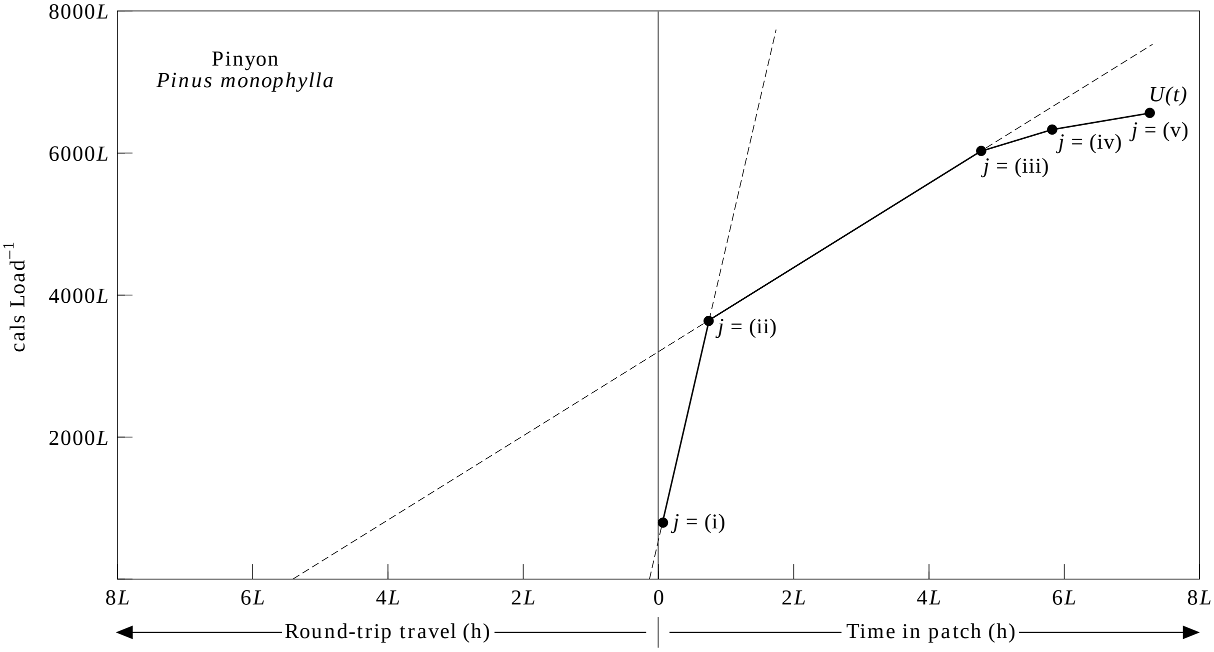

Figure 5. Changes in the utility of pinyon with field processing time. The right side of the graph displays increases in the calories per load of pinyon with field processing time. The two dashed lines drawn through the x-axis on the left side of the graph indicate the hours of round-trip travel time between an archaeological site and a pinyon grove and when removing pine nuts from cones [j=(ii)] and hulling pine nuts [j=(iii)] are expected at the grove.

each processing stage and the caloric value of the nutmeats or seeds. The general equation presented in Metcalfe and Barlow (1992: 347) for calculating the utility of a load at any processing stage was simplified to:

$$y_j = \alpha\beta_j L \qquad (1)$$

where y_j is the utility of the load at processing stage j, α is the caloric value of nuts or seeds measured in calories per kilogram, β_j is the proportion of the resource at processing stage j made up of nuts or seeds, and L is the weight of the transported load.* This equation monitors the benefit associated with field processing: increases in the utility of resource in terms of the total number of calories transported per load.

Calculating cost

The cost of collecting and field processing a load of resource can be calculated by recording the weight of the resource after collection and each processing stage, and the time spent during each of these procedures. This equation was also simplified from the general case presented in Metcalfe and Barlow (1992: 348). Here:

$$x_j = \frac{t_j}{w_j} L \qquad (2)$$

where x_j is the time spent collecting and field processing a load of resource to processing stage j, t_j is the time required to collect and field process a sample of the resource to stage j and w_j is the weight of that sample after stage j of processing.

Calculating the benefits and costs of field processing resources for transport using Equations (1) and (2) requires an estimate of load size (L): the amount of resource foragers carry from the resource patch to the residential site. For this study, weights of 3 and 15 kg were selected for the minimum and maximum weights of potential load sizes. There are several reasons for this. First, weight was chosen rather than volume because it was easy to measure the entire range of package types encountered during the processing experiments (i.e. pine cones to nutmeats and whole plants to pickleweed seeds) with a consistent level of precision. Comparable measures of changes in the weight of resource samples, and the proportions of edible components in those samples with processing

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*Equations (1) and (2) are less complex than those presented in Metcalfe & Barlow (1992) because it is not necessary to deal with multiple components with varying utility; only one component in each plant was modelled as having utility. However, for those interested in using plant utility indices to better understand prehistoric behaviour, we caution that these simpler equations focus attention on the utility of a load of the resource rather than the individual components of plants. As with animals, some plant resources have several edible components which may vary in utility to the consumer. Archaeologists must use these equations thoughtfully because it is variation in the types and frequencies of the waste components that is likely to be most informative for interpreting prehistoric land use patterns (Metcalfe & Barlow, 1992: 341, 352–353). In this study, we qualitatively characterized the types and frequencies of waste components after each stage of processing. Quantitative estimates would have allowed a more precise description of the proportions of waste components associated with each processing stage.

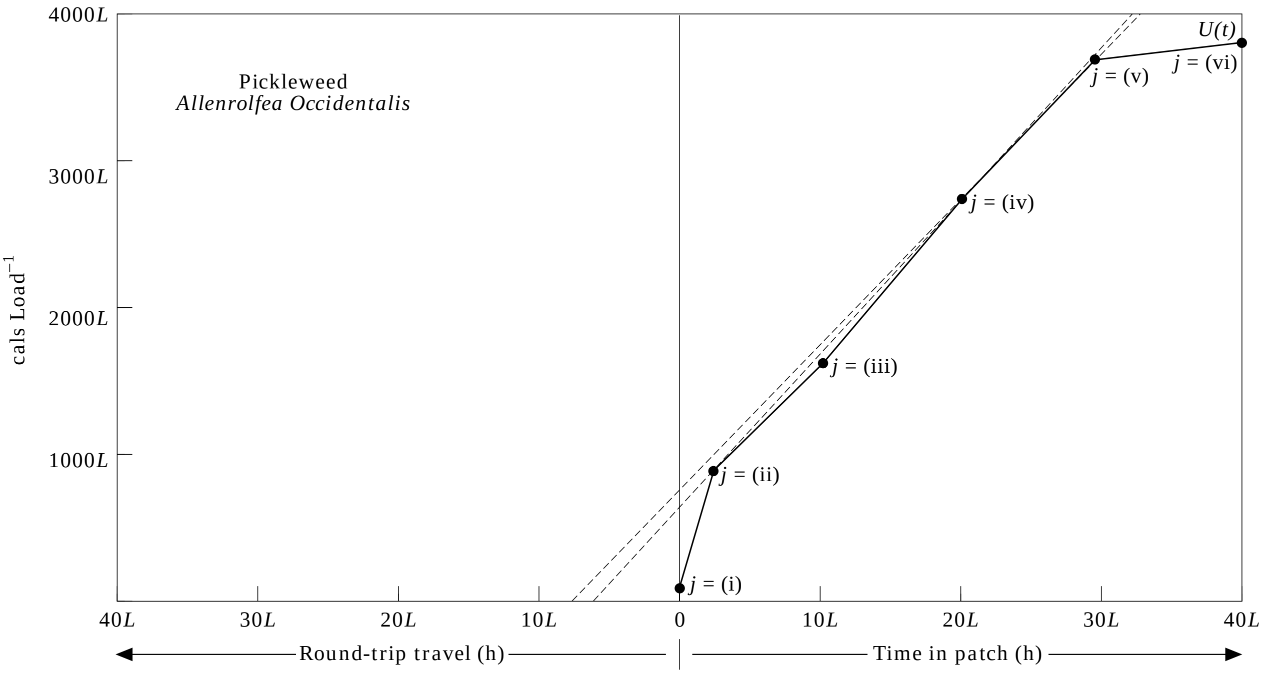

Figure 6. Changes in the utility of pickleweed with field processing time. Stripping the plants and removing large branch parts to produce loads that consist of 23% seed by weight, or 10% by volume [j=(ii)], is expected for very small round-trip travel times between sites and pickleweed patches. The dashed lines drawn through the x-axis indicate the minimum travel times when winnowing to produce loads of approximately 70% [j=(iv)] or 90% [j=(v)] seed is expected at the patch.

time, allowed us to construct comparable utility functions for pinyon and pickleweed. Second, historical descriptions indicate Great Basin women typically carried plant foods in large, conical burden baskets (Steward, 1938; Wheat, 1967; Fowler, 1989; Jones & Madsen, 1989). Three to 15 kg appears to be a reasonable estimate of the weight of burden baskets filled with pinyon and pickleweed (Barlow *et al*., 1993),* and encompasses the range of load sizes typically carried by modern female hunter–gatherers who transport plant resources on a regular basis (Lee, 1969; Blurton Jones & Sibley, 1978; O'Connell & Hawkes, 1981; Hawkes, O'Connell & Blurton Jones, 1989).

Predicting field processing stages

Once the benefits (y_j) and costs (x_j) associated with field processing pinyon and pickleweed were calculated, they were used to develop expectations about when the various processing stages should occur prior to transport. By determining the minimum amount of travel and transport time when field processing would increase the amount of Calories returned to camp per hour spent in travel, collection, field processing and transport, relationships between round-trip travel time and expected field processing stages were modelled (Figures 5 & 6). The expected minimum round-trip travel times (z_j) when each processing stage (j) will increase the caloric return rate for time spent away from camp can be calculated by modifying the equation in Metcalfe & Barlow (1992: 344) to the more general form:

$$z_j = \frac{y_{j-1}x_j - y_j\, x_{j-1}}{y_j - y_{j-1}} \qquad (3)$$

Equation (3) was used to calculate the minimum travel and transport times when different stages of field processing pinyon and pickleweed were expected to occur at procurement locations. By identifying the types and quantities of plant parts remaining with pine nuts and pickleweed seeds at each processing stage, we also developed expectations about relationships between transport distance and the range and relative quantities of waste in macrofossil assemblages.

Processing Experiments

Pinyon

The pinyon processing experiments were conducted on closed to partially open green cones collected in the Toana Range northwest of Wendover, Nevada (Figure 1). Cones were picked from trees in September, before

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*We calculated the volumes of 18 used burden baskets from museum collections and catalog descriptions, and employed weight per unit volume measures to estimate the weights of basketloads of pinyon and pickleweed (Barlow, Henriksen & Metcalfe, 1993). The estimated weights of most basketloads range from 3 to 20 kg, and the average basket could hold approximately 6 kg of unprocessed cones, or 18 kg of processed nuts or seeds if filled to the rim.

Table 1. Results of nutritional analysis of pinyon nutmeats

Sample	% Moisture	% Protein	% Lipid	% Ash	% Carbohydrate	Kcal/100 gm
Clean nutmeat sample						
1	10·5	8·6	56·4	2·4	22·1	630
2	10·1	8·0	57·6	2·4	21·9	638
Mean	10·3	8·3	57·0	2·4	22·0	634
Parched nutmeat sample						
3	7·1	7·6	59·0	2·7	23·6	656

Table 2. Pinyon processing stages and proportion of nutmeats to inedible components

Processing stage	Remaining waste components	Proportion nutmeat by weight	Proportion nutmeat by volume
(i) Collect whole cones	Mostly cones and cone bracts; hulls, some pine needles	0·13	0·03
(ii) Beat cones and separate nuts	Mostly hulls; some needles and a few cone bracts	0·57	0·43
(iii) Clean, parch, hull, and winnow nuts	Few hulls	0·95	0·94
(iv) Clean nutmeats	None	1·00	1·00
(v) Parch nutmeats	None	1·00	1·00

the nuts began dropping. The cones were laid out to dry indoors. After opening, the cones were placed in a cardboard box and beaten with a stick. The nuts were collected from the cone debris and put in a basketry parching tray. The small quantities of pine needles and cone fragments remaining with the nuts were removed, and the nuts were parched using live coals. The nuts were then hulled on a flat milling stone. A loaf-shaped stone was used to break the shells and separate them from the nutmeats. The nutmeats were winnowed to remove remaining hull fragments, further cleaned by hand, and parched with coals in a basketry tray. Following this procedure resulted in five processing stages: (i) collect whole cones; (ii) beat cones to remove nuts; (iii) clean, parch, hull, and winnow nuts; (iv) clean nutmeats; and (v) parch nutmeats.

These collection and processing procedures were timed. Separating the nuts from the cones, Stage (ii), was conducted until Barlow felt she had reached the point of diminishing returns. Careful inspection of the cone debris after the experiments demonstrated that over 96% of the available nuts were recovered during this stage. Nutmeats ‘‘lost’’ during a particular stage of processing (usually less than 10 g) were not used in calculating β for that stage, but were included in the calculation of β for all preceding stages. Two samples of clean nutmeats and one sample of parched nutmeats were sent to the Department of Nutrition and Food Science at Utah State University for nutritional analyses. The clean nutmeat samples averaged 6340 Cal kg^{-1}; the sample of parched nutmeats had a caloric value of 6560 Cal kg^{-1} (Table 1). Previous published estimates of the energetic value of *Pinus monophylla* nutmeats include 4880 (Farris, 1980) and 7335 (Little, 1938) Cal kg^{-1}.

Table 2 presents a brief summary of the field processing procedures, waste products, cost, and various measures of the utility associated with each stage. Table 3 presents the basic data for each of the experiments reported here and the calculated values for x_j and y_j.

Figure 5 illustrates the relationship between time spent field processing at the pinyon grove and the utility of a load of pinyon transported to a residential camp. The utility function ($U(t)$) for pinyon is based on the average collection and processing time (x_j) and utility (y_j) of the samples for each processing stage. The y-axis measures the utility of the resource in Calories per kilogram. Time spent procuring and field processing is scaled on the x-axis to the right of the y-axis, round-trip travel time on the x-axis to the left of the y-axis. Round-trip travel times where each subsequent processing stage is expected to occur prior to transport (z_j) were calculated using Equation (3). These times can also be determined graphically by identifying the x-intercept of a line passing through j and j-1 of the utility function. Round-trip travel time is expressed in terms of L to indicate that this is a relative measure that varies proportionally with expected load size.

Table 4 presents the time and distance expectations for the relationship between minimum round-trip length and the expected field processing stage. Figures are expressed as ranges because they were calculated for loads of 3 kg and 15 kg, the range reported for modern hunter–gatherers transporting vegetal resources. Two points are important. First, for this size range of transported loads, expectations about the

*Table 3. Results of pinyon processing**

Field processing stage	Sample	Time (min)	Weight (kg)	t_j (min)	x_j (min kg^{-1})	Mean x_j (min kg^{-1})	β_j	y_j (Cal kg^{-1})	Mean y_j (Cal kg^{-1})	z (h)
(i) Cone collection	1	10·15	2·2282	10·15	4·56	4·36	0·1026	650·73	800·75	0·00
	2	16·25	2·4136	16·25	6·73		0·1051	666·41		
	3	9·00	2·5088	9·00	3·59		0·1566	993·15		
	4	10·12	3·9366	10·12	2·57		0·1408	892·72		
(ii) Separate nuts from cones	1	12·90	0·4289	23·05	53·74	45·04	0·5164	3274·21	3644·38	0·12
	2	17·18	0·4532	33·43	73·76		0·5410	3430·20		
	3	7·25	0·6100	16·25	26·64		0·6302	3995·24		
	4	12·98	0·8876	23·10	26·03		0·6116	3877·86		
(iii) Clean, parch, hull, and winnow nuts	1	58·28	0·2245	81·33	362·27	286·60	0·9550	6054·77	6028·95	5·40
	2	55·17	0·2487	88·60	356·25		0·9429	5978·01		
	3	69·35	0·4014	85·60	213·25		0·9544	6050·96		
	4	97·97	0·5641	121·07	214·63		0·9514	6032·05		
(iv) Clean nutmeats	1	8·07	0·2144	89·40	416·98	348·98	1·0000	6340·00	6340·00	15·37
	2	12·30	0·2345	100·90	430·28		1·0000	6340·00		
	3	20·63	0·3831	106·23	277·29		1·0000	6340·00		
	4	24·33	0·5358	145·40	271·37		1·0000	6340·00		
(v) Parch nutmeats	1	11·52	0·1846	100·92	546·70	435·74	1·0000	6560·00	6560·00	35·85
	2	10·62	0·2067	111·52	539·53		1·0000	6560·00		
	3	13·70	0·3587	119·93	334·35		1·0000	6560·00		
	4	19·50	0·5115	164·90	322·39		1·0000	6560·00		

*All derived variables (t_j, x_j, mean x_j) were calculated from the original times and weights using a computer spreadsheet that maintains 15 significant figures. Consequently, calculating some values (e.g. mean x_j) from other derived values (e.g. t_j and x_j) as listed in this table may give slightly different results because of rounding error.

Table 4. Results of pinyon processing experiments for 3 and 15 kg loads

Processing stage	Minimum round-trip travel times (h)	Minimum round-trip travel distances (est. 3 km h^{-1})	Time spent procuring & field processing (h)	Maximum net energetic gain/loss (Cal h^{-1})
(i) Cones	0	0	0·22–1·09	10891–10891
(ii) Nuts	0·35–1·77	1·06–5·32	2·25–11·26	4069–4067
(iii) Nutmeats	16·21–81·03	48·62–243·10	14·33–71·65	466–461
(iv) Clean nutmeats	46·12–230·61	138·36–691·82	17·45–87·24	173–165
(v) Parched nutmeats	107·56–537·82	322·69–1613·45	21·79–108·93	26–17

amount of field processing are unambiguous; there is no overlap in the round-trip travel times/distances for the three processing stages that result in the transport and deposition of plant waste in residential sites. For loads of 3 to 15 kg, relatively large quantities of cone debris and hull fragments and a few pine needles are expected in residential sites within approximately 0·5 to 2·5 km (*c.* 1–5 km round-trip) of pinyon groves. Large quantities of hull fragments but few needles and cone fragments are expected in residential sites up to approximately 25–120 km away (*c.* 49–243 km round-trip). Small quantities of pinyon waste are expected in residential sites farther away, and these should consist only of a few hull fragments. Second, the estimated minimum distance for the processing stages that remove all plant waste at the pinyon grove are enormous—for stage (iv), the minimum round-trip distance for 3–15 kg loads are 138 to 692 km between residential base and the pinyon patch, distances at or exceeding the far end of the range noted for ethnographic groups (Rhode, 1990).

Pickleweed

The pickleweed processing experiments were conducted on plants recovered from a large, dense patch near Grantsville, Utah, south of the Great Salt Lake (Figure 1). The plants were collected when the seeds were mature but the plants were still green and succulent. A total of 11·9 kg (51·5 l) of the whole plants were collected in just under 8 min. After the plants had dried indoors for several days, the branches and spikes were stripped by hand, allowing the seeds, pericarps and bracts to fall into a basket. Because the branches are jointed and the plant parts are brittle when dry,

Table 5. Results of nutritional analysis of pickleweed seed

Sample	% Moisture	% Protein	% Lipid	% Ash	% Carbohydrate	Kcal 100 g^{-1}
1	6·18	27·18	10·72	5·87	50·05	405
2	6·18	27·40	9·75	6·18	50·49	399
3	6·21	27·27	9·92	6·02	50·58	401
Mean	6·19	27·28	10·13	6·02	50·37	402

Table 6. Pickleweed processing stages and proportion of seed to inedible components

Processing stage	Remaining waste components	Proportion seed by weight	Proportion seed by volume
(i) Collect green plants	As represented in the plant, including branches, spikes, bracts and pericarps	0·02	0·01
(ii) Strip and remove large branches	Spikes, small spike and branch fragments (most <3 cm), bracts and pericarps	0·23	0·10
(iii) Hand-rub and 1st winnow	Mostly chaff (crushed bracts and pericarps) with very small branch and spike fragments (most <0·5 cm)	0·47	0·31
(iv) 2nd winnow	Mostly chaff and pericarps attached to seeds	0·71	0·58
(v) 3rd winnow	Same as above	0·91	0·85
(vi) 4th winnow	Same as above	0·95	0·92

many branch and spike fragments also fell into the basket. Fortunately, these fragments are very light, and shaking the basket sorts the larger fragments to the top, where they can be quickly retrieved and discarded. At this point, the basket is filled with hundreds of thousands of pickleweed seeds, each encased in a pericarp and bracts, as well as numerous very small branch and spike fragments.

The next processing step consisted of rubbing handfuls of the contents of the basket vigorously between the palms in order to separate the bracts and pericarps from the seeds. Hand-rubbing is an essential step since winnowing is ineffective without it. Samples were then winnowed for 20 min, divided into 5 min intervals. Hand-rubbing was included as part of the first winnowing stage because it does not, by itself, change the proportion of seed to inedible components. Consequently, the experiments were divided into six processing stages: (i) plant collection; (ii) drying, hand-stripping, and removing larger branch fragments; (iii) hand-rubbing for 3 min and winnowing for 5 min; (iv) second winnowing; (v) third winnowing; and (vi) fourth winnowing.

These experiments were timed, and the cost of field processing pickleweed was calculated using Equation (2). Calculating utility for pickleweed required an additional step in the analysis. Measuring the proportional weight of seeds (β) in whole and partially processed pickleweed was problematic because of the extremely small size of seeds. A regression formula was used to transform measures of sample density to estimates of β_j.* The resulting β_j values were then employed to calculate utility using Equation (1).

Three samples of pickleweed seed were sent to the Department of Nutrition and Food Science at Utah State University for nutritional analyses and proved to have an average caloric value of approximately 4020 Cal kg^{-1} (Table 5).

Table 6 presents a brief summary of the field processing procedures, waste products, cost, and various measures of the utility of the resource after each processing stage. Table 7 presents the basic data for each of the pickleweed experiments, and the values for x_j and y_j.

Figure 6 illustrates the relationship between time spent field processing at the pickleweed patch and the utility of a load of pickleweed transported to a residential camp. The utility function ($U(t)$) for pickleweed is

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*Originally we planned to take a sample of the material resulting from each stage of each experiment and manually separate the seed from the inedible components to determine the resulting increase in utility. This procedure was extremely time consuming; each sample required between 10 and 20 h to process. Consequently, it was necessary to find a proximate, simpler measure of changes in β. Increases in the w/v density of the resource with successive processing stages provided such a measure. Nine samples, collected at various points in the processing experiments, were manually separated to directly determine the proportion of seed to inedible parts, and their weight and volume were measured (Table 11). The relationship between β and density is well described by a second order polynomial regression ($\beta = 0{\cdot}15539 – 0{\cdot}59691$ (density)$+ 3{\cdot}8107$ (density)^2: $r^2 = 0{\cdot}92$). Density was measured for each sample of each experiment and coverted to β_j using this regression.

*Table 7. Results of pickleweed processing**

Field processing stage	Sample	Time (min)	Weight (kg)	t_j† (min)	x_j (min kg^{-1})	Mean x_j	Density (w/v)	β_j	y_j	Mean y_j
(i) Fresh plant collection		7·75	11·9	7·75	0·65	0·65	—	—	94·00‡	94·00
(ii) Strip and remove branches (Total for all samples, including those not included in this analysis, is 0·734 kg)	a	30·05	0·200	32·16	160·81	147·07	0·21	0·20	796·32	890·29
	b	27·20	0·231	29·64	128·31		0·22	0·21	838·20	
	c	14·72	0·104	15·82	152·10		0·26	0·26	1036·34	
Subsample for later stages of processing	1(a)	—	0·0537	8·63	—	—				
	2(a)	—	0·0558	8·97	—					
	3(c)	—	0·0589	8·96	—					
(iii) Hand-rub and 1st winnow	1	8·00	0·0251	16·64	662·77	615·73	0·36	0·43	1746·16	1621·22
	2	8·00	0·0260	16·97	652·81		0·37	0·46	1834·00	
	3	8·00	0·0319	16·96	531·61		0·30	0·32	1283·51	
(iv) 2nd winnow	1	5·00	0·0159	21·64	1360·72	1218·98	0·45	0·66	2646·96	2733·09
	2	5·00	0·0173	21·97	1270·12		0·49	0·78	3126·97	
	3	5·00	0·0214	21·96	1026·10		0·43	0·60	2425·33	
(v) 3rd winnow	1	5·00	0·0141	26·64	1889·04	1787·23	0·47	0·72	2880·84	3687·66
	2	5·00	0·0150	26·97	1798·21		0·58	1·09	4386·23	
	3	5·00	0·0161	26·96	1674·44		0·54	0·94	3795·92	
(vi) 4th winnow	1	5·00	0·0127	31·64	2490·98	2397·37	0·51	0·84	3385·36	3803·07
	2	5·00	0·0135	31·97	2368·38		0·56	1·02	4084·95	
	3	5·00	0·0137	31·96	2332·74		0·55	0·98	3938·90	

*All derived variables (t_j, x_j, mean x_j, b_j, y_j, mean y_j) were calculated from the original times, weights and density using a computer spreadsheet that maintains 15 significant figures. Consequently, calculating some values (e.g. mean x_j) from other derived values (e.g. t_j and x_j) as listed in this table may give slightly different results because of rounding error.

†For calculating t_j for Stage (ii), the sample weight was divided by 0·734 kg, the quotion multiplied by 7·75 min (time for total fresh plant collection) to which the sample time to strip and remove branches was added. For calculating t_j for the subsamples, the sample weight was multiplied by the x_j of the sample from which it was recovered, indicated by letter in parentheses.

‡To estimate the utility of whole, wet plants, the y_j for dry plants was calculated using the density of the entire sample of dry plants. The resulting value (Cal kg^{-1} dry plants) was multiplied by the total weight of the dry plants, and divided by the total weight of the wet plants: (Cal kg^{-1} dry plants × kg dry plants) ÷ kg wet plants.

Table 8. Results of pickleweed processing experiments for 3 and 15 kg loads

Processing stage	Minimum round-trip travel times (h)	Minimum round-trip travel distances (est. 3 km h^{-1})	Time spent procuring & field processing (h)	Maximum net energetic gain/loss (Cal h^{-1})
(i)	0	0	0·03–0·16	8535
(ii)	0·83–4·16	2·49–12·47	7·35–36·77	201–200
(iii)	—	—	—	—
(iv)	18·54–92·70	55·62–278·09	60·95–304·74	(− 22)–(− 25)
(v)	20·40–102·00	61·20–306·00	89·36–446·81	(− 25)–(− 27)
(vi)	855·44–4,427·18	2656·31–13,281·55	119·87–599·34	(− 115)–(− 124)

based on the average collection and processing time (x_j) and the average estimated utility (y_j) of the samples for each processing stage. Again, the y-axis measures the utility of the resource in Cal/kg, and time spent procuring and field processing is scaled on the x-axis to the right of the y-axis, round-trip travel time on the x-axis to the left of the y-axis. These values are again expressed in terms of load size (L) to indicate that they vary with the size of the transported load. Round-trip travel times where each subsequent processing stage is expected to occur prior to transport (z_j) were calculated using Equation (3).

Table 8 presents the range of minimum times and distances when each stage of field processing is expected for loads of 3–15 kg of pickleweed. Base camps located within several kilometers of a pickleweed patch would be expected to contain large quantities of plant parts if the plant was exploited by site occupants. For sites located up to relatively large distances from patches, the resource should have been partially winnowed. The major waste component transported to these sites should have been large quantities of chaff. Extensive winnowing at the patch is not expected unless the camp site is hundreds of kilometres away. It is probably not economically profitable to exploit and transport pickleweed these distances, which are well outside the range reported for Great Basin foragers (Rhode, 1990). Round-trip travel times were not calculated for stage (iii) of pickleweed processing because it produces a lower increase in utility than the next 5 min of winnowing. Under these circumstances, the model predicts the forager will transport the resource after Stage (ii), or continue winnowing to remove more chaff.

Drying time and opportunity costs at procurement locations

Although drying both fresh pickleweed plants and sappy pinyon cones was necessary to facilitate processing, we did not include drying time in our calculations of field processing costs because it required no work effort. We initially assumed foragers could spend drying time collecting more pinyon or pickleweed; processing previously collected, dried pinyon or pickleweed; collecting or processing other resources; or in other activities less directly related to subsistence. It is difficult to imagine a forager waiting for a resource to dry. However, field processing behaviours are embedded in a larger set of foraging decisions that likely affect the costs associated with time spent at procurement locations and base camps. These include the range of resources to exploit; the set of patches to utilize; the degree to which collection trips from a base camp or residential moves are employed to collect those resources; and where to locate base camps and auxillary camps and facilities.

The field processing/transport model was developed to predict the behaviour of foragers making collection trips to resource patches from a base camp, and assumes time spent processing at procurement locations is costly because the forager loses opportunities to search for, handle and transport other resources, or engage in activities at a base camp that would benefit the forager or the foragers offspring. On the other hand, time spent at procurement locations may range from relatively costly when foragers employ logistic collection trips from long-term residential base camps, to equal to time spent at home when foragers employ residential moves to resource patches. To illustrate, we imagine several situations in which the costs associated with drying pickleweed and pinyon at procurement locations may vary, and would result in different expectations about the removal and deposition of plant parts than those presented earlier.

(1) *The forager travels from a base camp to a pinyon grove or pickleweed patch, collects enough resource for one load only, waits for it to dry, processes and transports it*. This situation may be most likely when a small group of individuals travels from a residential base to a procurement patch for the collection of a specific resource (*sensu* Binford, 1980: 9). In this case, drying time should be included in the cost of subsequent processing stages. In our experiments (indoors in a dry laboratory) green pine cones required a minimum of approximately 7 days to open and pickleweed plants were dry enough to strip in about 13 days. Including this time in field processing costs results in substantial increases in minimum round-trip travel times before any field processing is expected (approximately 60 km for pinyon and 50 km for pickleweed). However, the estimated caloric return rates for collection trips become so low that we do not expect foragers to employ this type of land use/resource procurement strategy for exploiting resources that require long periods of drying or curing. When drying time cannot be spent in other activities, foragers might be expected to decrease drying costs by varying collection strategies (e.g. collect brown open pinyon cones or nuts from the ground or strip seeds directly from ripe plants) or processing techniques (e.g. roasting the cones or parching plants).

(2) *The forager makes two round-trips from a base camp per load of resource, first to collect the cones or plants and leave them to dry, and second to retrieve the dry resource, field process as appropriate and transport back to camp*. If two trips are made per load, the forager is free to engage in any number of activities during the days or weeks required for drying, but the cost of travel/transport doubles. The forager is expected to maximize caloric return rates over two round-trips to the resource patch. Although some additional time may be required to construct or move resources to a drying facility (e.g. a cache or a cave), the minimum round-trip travel times when processing increases caloric return rates during a trip (Z_j) may be roughly half those predicted in Figures 5 and 6.

(3) *The forager collects and stores multiple loads of pinyon cones or pickleweed plants at one or a series of procurement locations during a single trip from a residential site or seasonal base camp, and later returns to the field process and transport loads*. If the collection of numerous loads of pinyon and pickleweed were ‘‘embedded’’ in one or a sequence of residential moves, drying time would again be free to the forager, and the cost of the extra trip could be amortized over the number of loads collected. The cost of the collection trip likely affects overall foraging efficiency and should influence the foragers decision about whether to employ this type of foraging strategy. However, we still expect the forager to employ field processing strategies that maximize caloric return rates during trips to retrieve, field process and transport loads of pinyon or pickleweed. During these trips, collection is no longer part of handling time at the patch. With a reduction in field processing costs, the minimum travel time when field processing increases caloric return rates (Z_j), would be smaller than predicted in Figures 5 and 6.

Differences are likely to be most dramatic for early to moderate stages of field processing, with less effect on later stages where collection time comprises only a small proportion of overall handling in the field.

(4) *The forager employs residential moves to collect and process resources for consumption and/or transport to the next resource patch*. The field processing/transport model was not developed to address processing strategies employed during residential moves. In this situation, the procurement location is also the base camp. The opportunity costs associated with time spent in the field and at home are equal. If the forager processes resources for consumption at the procurement location/base camp, waste components should be removed and discarded in the same relative proportions in which they occur in the collected resource. If resources are carried to the next resource procurement location/base camp, *when processing costs are equal at both locations* we expect the forager to always process resources into a high utility load before transport. We do not expect the removal and deposition of waste at base camps to be structured by distance from resource patches.

These few hypothetical situations suggest archaeologists should evaluate the strengths and limitations of the field processing/transport model in predicting variation in processing behaviour among modern people employing different foraging strategies. To the extent that these studies yield alternate sets of predictions about spatial patterning in the deposition of material remains, they may provide a useful tool for identifying spatial and temporal variation in the land-use strategies employed by prehistoric foragers.

Field Processing/Transport Strategies and Energetic Efficiency

Once the round-trip travel times were calculated for the various processing stages and load sizes, we investigated how field processing pinyon and pickleweed to various stages would affect net caloric gains per hour associated with exploiting these resources from a base camp.

Calculating net caloric return rates

Equation (4) was used to estimate net caloric return rates for exploiting pinyon and pickleweed at various distances. The net return rates for 3 and 15 kg loads were calculated using the following formula:

$$n = \frac{\alpha\beta L - \left(\frac{1}{2}Te_o + \frac{1}{2}Te_b + te_t\right)}{T + t} \tag{4}$$

where n is the net gain (or loss) in Calories, T is the round trip travel time, t is the time spent procuring and processing the load to be transported, e_o is the rate of energy expenditure traveling to the patch, e_b is the rate of energy expenditure travelling to camp with the load, and e_t is the rate of energy expenditure while in the patch. The utility decay functions developed from these changes in net rate provide insights into the transportability of various resources.

To calculate net energetic return rates, it was necessary to obtain estimates of the energetic costs of travel and processing. Based on the results of experimental studies with human subjects, Pandolf, Givoni & Goldman (1977) provide a nondimensional equation for such estimates:

$$M = 1{\cdot}5W + 2{\cdot}0(W+L)\left(\frac{L}{W}\right)^2 + \eta(W+L)(1{\cdot}5V^2 + 0{\cdot}35VG) \tag{5}$$

where M is the metabolic cost expressed in watts; W is the weight of the forager in kilograms; L is the weight of the transported load, also in kilograms; V is the speed of walking measured in meters per second; G is the grade measured as percent slope; and η is the terrain coefficient. Because we are interested in determining a conservative estimate of the relationship between net return rate and round-trip travel time, in estimating the parameters in Equation (5) we tried to err on the side of making the costs of transport unrealistically low. We assumed the forager weighed 55 kg, walked at a speed of 3 km h^{-1} ($V = 0{\cdot}833$ m s^{-1}), was always on perfectly level terrain ($G = 0$), and travelled along a dirt trail ($\eta = 1{\cdot}1$). With these parameters, the cost of travelling without a load is 125 Cal h^{-1}, with a 3 kg load about 128 Cal h^{-1}, and a 15 kg load costs about 149 Cal h^{-1} (50 Cal km^{-1}).

Using Equation (4) we calculated net caloric return rates for foragers exploiting pinyon and pickleweed from base camps (Tables 4 & 8). While calculating these we noticed several general trends. Larger load sizes increased estimated net caloric return rates at every processing stage, and although caloric return rates decreased rapidly with field processing and transport time, the rate of this decrease varied between resources.

Effects of load size on energetic efficiency

To illustrate the effects of load size on energetic efficiency, Table 9 displays the estimated net energetic return rates for travelling to a grove and collecting, field processing and transporting 3 and 15 kg loads of pinyon. In this example, the expected processing stage, time spent procuring and field processing in the patch, and net return rates were calculated for hypothetical camps located varying distances from the grove. At every distance and processing stage, caloric return rates are highest for 15 kg loads. This difference in return rates increases with travel and transport time. For pinyon groves near base camps, foragers double net

Table 9. Estimated energetic return rates for transporting 3 and 15 kg loads of pinyon

Distance to patch (km)	Time to patch (h)	Expected processing stage	Time spent procuring & field processing (h)	Estimated net energetic gain/loss (Cal h^{-1})
0·5	0·17	(i) Cones	0·22–1·09	4231–8311
5	1·67	(ii) Nuts	2·25–11·26	1831–3618
25	8·33	(ii) Nuts	2·25–11·26	451–1825
50	16·67	(iii) (3 kg)–(ii) (15 kg)	14·33–11·26	253–1092
100	33·33	(iii) Nutmeats	14·33–87·24	97–523

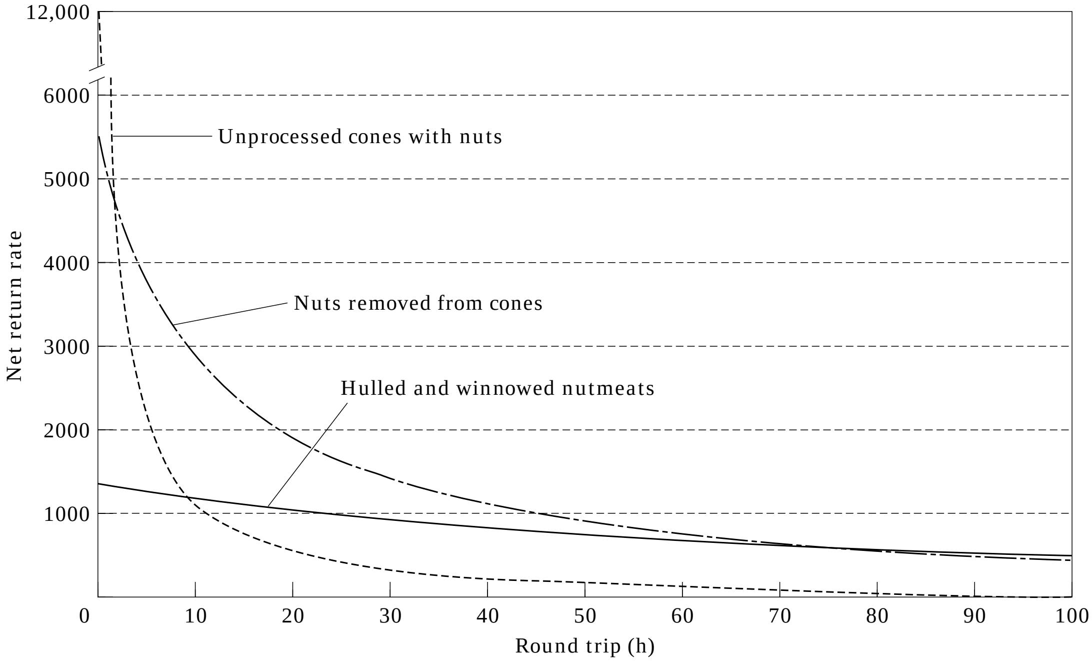

Figure 7. Pinyon transport decay functions. The three decreasing curves show estimated net caloric return rates for collecting, field processing and transporting 15 kg loads of cones, nuts or nutmeats to camps at increasing distances from pinyon groves. Energetic estimates based on Pandolf *et al.* (1977).

caloric return rates during collection trips by carrying 15 kg loads. For pinyon groves 100 km away, transporting a 15 kg load yields a greater than five-fold increase in energetic return rates. The forager will always be more efficient transporting larger, rather than smaller loads.

Transport decay curves

To compare the decreases in energetic efficiency associated with field processing and transporting loads of pinyon and pickleweed, we calculated changes in net caloric return rates associated with transporting loads of each over distances from zero to 100 km. This relationship is modelled as a utility decay function that relates variation in the expected net return rate for the central place forager as a function of (1) the gross caloric value of the transported load, (2) the energetic expenditure of travelling to the patch, procuring and field processing a load of resources, and returning with the added weight of the load, (3) the time required to complete the trip.

The relationship between transport distance and the net rate of energetic return for collecting, field processing and transporting loads of pinyon is illustrated in Figure 7. Three functions are plotted: one for a 15 kg load of cones and nuts, one for the same load of unhulled nuts, and one for nutmeats. Where the functions intersect is the travel time at which increased field processing will increase the net rate of return. For instance, the intersection of the transport decay function for transporting nuts still in their cones and the function for transporting the same size load of just nuts and hulls indicates the distance at which it becomes profitable to cull the cones in the field. This graphic technique also calculates the minimum round-trip travel time when a particular field processing stage increases caloric return rates (z_j), but can include

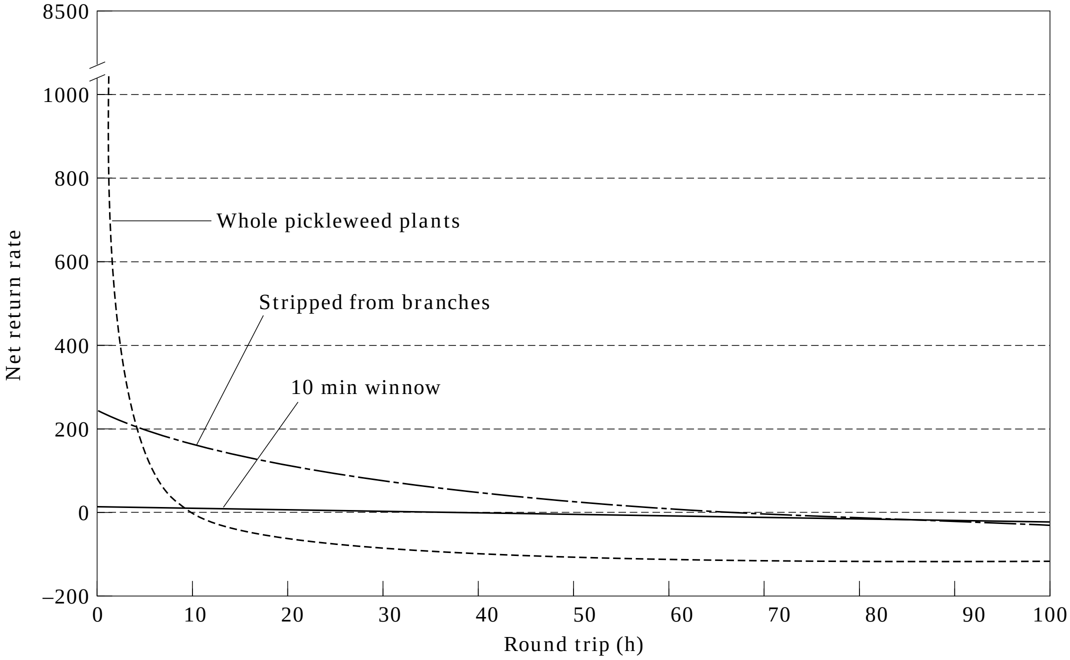

Figure 8. Pickleweed transport decay functions. The three decreasing curves show estimated net caloric return rates for collecting, field processing and transporting 15 kg loads of whole plants, material stripped from plants, or moderately winnowed pickleweed seed to camps at increasing distances from pickleweed patches. Energetic estimates based on Pandolf *et al.* (1977).

different energetic costs associated with time spent travelling, collecting, processing and transporting resources.*

Figure 8 illustrates the net rate of energetic return for transporting 15 kg loads of pickleweed various distances, calculated using Equation (5). Again, where the functions intersect is the round-trip travel time at which increased field processing will increase the net rate of return. In this example, the loads consist of whole plants, threshed pickleweed, and partially winnowed seed. The net energetic return rates for transporting pickleweed decrease even more rapidly with distance from the patch than those associated with transporting pinyon.

The transport decay curves clarify three relationships between field processing/transport strategies and overall foraging efficiency. First, it is always more efficient to move the consumer to the resource patch than it is to move the resource to the consumer. Even relatively short transport times dramatically lower the net return rate for exploiting pinyon and pickleweed. The procurement of either of these plants from a base camp outside the resource patch is only expected when the choice of the camp location is a tradeoff between other competing demands, such as access to water, fuel, other foods, or perhaps previously stored foods. Second, when the forager stages collection trips from a base camp, the transport decay curves illustrate large differences in caloric return rates associated with transporting pinyon or pickleweed at different field processing stages. Foragers can increase net energetic efficiency substantially if they vary field processing strategies with transport distance. For example, at 20 h round-trip travel time, a forager gains approximately 500 Cal h^{-1} transporting unprocessed pine cones, nearly 2000 Cal h^{-1} transporting pine nuts, or about 1000 Cal h^{-1} transporting hulled nutmeats. Finally, our estimated net caloric return rates indicate that pinyon may be efficiently collected, field processed and transported while operating from a base camp, but return rates associated with trips to pickleweed patches drop rapidly with increases in travel/transport time. This suggests intertaxonomic differences in processing characteristics should structure variation in which resources are likely to be exploited through logistic collection trips, and which through residential moves. In general, when both types of resources are taken simultaneously, the spatial distribution of resources with processing characteristics like pickleweed should strongly affect where foragers locate base camps or residential sites.

Pickleweed return rates

Several researchers have noted that the estimated caloric return rates associated with the exploitation of

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*The graphic technique illustrated in Figures 5 and 6 are only precise when the costs associated with (a) travelling to the patch, (b) transporting the load home, and (c) procurement and field processing are equal. It also requires that further processing for consumption at the central place has no cost. The graphic technique illustrated in Figures 7 and 8 provides estimates when those costs vary, although we have not attempted to include variable costs for processing at home.

Table 10. Results of pickleweed processing experiments recalculated for samples winnowed in 2 l batches

Processing stage	Minimum round-trip travel times (h)	Minimum round-trip travel distances (est. 3 km h^{-1})	Time spent procuring & field processing (h)	Maximum net energetic gain/loss (Cal hr^{-1})
(i)	0	0	0·03–0·16	8552–8552
(ii)	0·83–4·16	2·49–12·47	7·35–36·77	201–200
(iii)	—	—	—	—
(iv)	—	—	—	—
(v)	1·42–7·08	4·25–21·25	34·91–174·55	179–179
(vi)	186·98–934·90	560·94–2804·69	41·85–209·27	(− 77)–(− 85)

Table 11. Values relating β to density for pickleweed samples

β	Density (g ml^{-1})
0·34	0·23
0·27	0·23
0·31	0·33
0·24	0·31
0·33	0·34
0·64	0·45
0·76	0·44
0·11	0·04
1·00	0·56

pickleweed are extremely low, both absolutely and relative to other Great Basin resources (Simms, 1987; Jones & Madsen, 1989). This observation has been enigmatic to Great Basin archaeologists, mostly because large quantities of remains in archaeological sites indicate it was a food resource for prehistoric inhabitants. Some archaeologists have discounted the utility of experimental estimates, arguing that modern investigators are not likely to achieve aboriginal levels of efficiency in plant processing, and variation in the way resources were collected and processed results in substantial variation in return rates (Bettinger, 1993; Bettinger & Baumhoff, 1983). Our calculations also suggest that the caloric return rates associated with exploiting pickleweed are low, and large amounts of time are required to collect and process loads of pickleweed even to intermediate processing stages. Consequently, we attempted to identify aspects of the processing experiments that likely influenced our estimated energetic return rates, and may limit energetic efficiency during the processing of small seed resources in general.

Loss of pickleweed seed during each stage of the processing experiments may have lowered our estimated return rates. The most significant loss occurred during the stripping/threshing of whole plants, at which point an estimated 47% of the seed occurring in whole plants was lost. The maximum seed loss occurring during any other procedure was approximately 6%. Because of their small size, it is likely that pickleweed seeds were also lost by aboriginal foragers threshing, crushing or winnowing this resource (cf. Sikkink, 1989, threshing quinoa seeds). If they lost significantly less, however, their caloric returns rates may have been nearly twice those estimated for processing stages (ii) through (vi).

Our energetic return rates for pickleweed processing were also constrained by the amount of resource winnowed during the experiments. A standard sample size of 0·25 l was used for each winnowing batch; partly to facilitate monitoring increases in efficiency during winnowing, and also because we used a small winnowing tray. We did not anticipate the potential effects of batch size on calculating changes in the utility of pickleweed with winnowing time. However, the small batch size resulted in large estimates of the time required to collect and process a kilogram of pickleweed at each processing stage (x_j) that included winnowing (Table 7). To assess the effect of batch size on our estimated caloric return rates we recalculated our estimates of the costs and benefits associated with field processing pickleweed using a winnowing batch size of 2 l.*

The results of these changes are shown in Table 10. Increasing the amount of resource winnowed in each batch substantially decreased the minimum round-trip distance to camp before moderate amounts of time spent winnowing at the pickleweed patch would be

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*The reported sizes of winnowing trays in several ethnographic collections suggest women often winnowed large batches of small seed resources. Generally, trays used to winnow seeds were shallow, closely woven circular or fan-shaped baskets measuring approximately 35 to 50 cm across by 8 to 12 cm deep (Bowers Museum, 1977; Cahodas, 1979; Fowler & Matley, 1979; Bedford, 1980; Fowler, 1989). Two tightly woven Paiute winnowing trays were located in the Utah Museum of Natural History collections. These were fan-shaped and measured 41 × 38 × 7 cm, and 51 × 48·5 × 11·5 cm. The volumes were approximately 4 and 9·5 l, respectively, calculated by filling them to the rim with Styrofoam ‘‘peanuts’’ and measuring the volume of the ‘‘peanuts’’. Even the smaller tray would allow a forager to winnow more than the 0·25 l samples we employed in the experiments. To assess how an increase in the size of winnowing samples would affect estimated return rates, we recalculated these values using half the volume of the smallest tray measured (2 l). The weight of each 0·25 l subsample and the time required to collect and process it (Table 7) were multiplied by 8. The weights of samples at subsequent winnowing intervals were also multiplied by 8. These changes increased the sample weights (w_j) and times (t_j) for each winnowing stage. We made the assumption that the volume increase would not decrease processing efficiency, and did not change the w/v density or utility (y_j) of samples.

expected. The estimated time in patch for collecting and processing 3 and 15 kg loads of winnowed pickleweed is less than half that calculated for smaller batches, and the estimated net energetic return rates associated with collecting, processing and transporting pickleweed increased dramatically. Even so, our estimated net caloric return rates for threshed and winnowed pickleweed are at the low end of caloric return rates estimated for plant foods, and similar to the post-encounter return rates calculated for other small seed resources (O'Connell & Hawkes, 1981; Simms, 1987; Cane, 1989; Wright, 1994).

Implications for Great Basin plant macrofossil assemblages

As noted earlier, the analyses and interpretation of plant macrofossils from Danger and Hogup Caves have structured interpretations of Archaic subsistence in the Great Basin. Both sites are located within a kilometer of pickleweed communities today, and cultural deposits are reported to have been dominated by ''organic chaff'' and ''stems and twigs'' (Jennings, 1957; Aikens, 1970). Although we were not able to determine the relative quantities of the different parts of pickleweed plants recovered from these sites, these descriptions are not inconsistent with the kinds of waste that would be expected at base camps or processing locations adjacent to pickleweed communities.

Our results do not support inferences about the relative importance of pickleweed in past diets based solely on large quantities of chaff and plant parts in sites near procurement locations. The processing experiments indicate that 98% of wet pickleweed plants brought to a site would consist of chaff and inedible plant parts (Table 6). Less than half a kilogram of each 15 kg load consists of edible seed, so large quantities of chaff and plant parts may not indicate a large dietary contribution. Even if pickleweed was only stripped from plants at the sites for transport elsewhere, waste would accumulate rapidly. Each 15 kg load transported away from the site would include more than 11 kg of chaff and small branch fragments, but approximately seven 15 kg loads of whole plants are needed for one 15 kg load of pickleweed at this processing stage. Again, the deposition of large quantities of pickleweed waste (in this case *c.* 350 l per 3·5 kg of transported pickleweed seed) may not be associated with large quantities of the resource in the diet of the forager. If pickleweed was also winnowed at the site, even greater quantities of waste would have been deposited relative to the amount of seed field processed or consumed at the site.

In contrast, pinyon remains were relatively rare in these sites. Early reports indicate that Danger and Hogup Caves yielded ''a few seed coats'' to ''one or two pine cones and a few hulls'' (Jennings, 1957; Aikens, 1970). However, the recent meticulous removal and laboratory excavation of a 2 by 2 m column of deposits from Danger Cave suggests that pinyon remains may have been more common than previously thought. Pinyon remains were recovered in varying quantities from 27 levels radiocarbon dated to between 7900 and 330 years BP. Fourteen of the strata yielded 0 to 15 pinyon hull fragments, while greater quantities of pinyon remains were recovered from 13 levels, ranging from 20 to 130 hull and cone fragments (Madsen & Rhode, 1990).

Today, the nearest pinyon groves are located in the Toana, Pilot and Grouse Creek Mountain Ranges, approximately 20–40 km from the caves (Figure 1). Our experiments suggest that if prehistoric foragers staged collection trips from these sites to pinyon groves located between approximately 3 and 120 km away, they should have transported 15 kg loads of nuts still in hulls (Table 4). The waste remaining with our experimental samples in this field processing stage consisted mainly of hulls, with some needles and a few fragments of cone bracts (Table 2). The remains from several levels are not inconsistent with our expectations about waste components returned to base camps. No pine needles were recovered, but five of nine cultural levels dating from approximately 7400 to 6000 years BP yielded relatively large numbers of hull fragments, and three of these also contained a few cone fragments. Higher in the stratigraphic profile, two levels dating to approximately 5300 and 5000 years BP, and one level deposited before 880 years BP, yielded similar assemblages of pinyon remains. Conversely, our predictions about the deposition of large quantities of pinyon hulls appear to be falsified for at least half of the occupational units if foragers were staging collection trips to pinyon groves during these times.

It is interesting to note that a sharp decrease in the frequency of cultural levels with large quantities of pinyon remains at approximately 6000 years BP appears to coincide with proposed ecological changes and increases in the frequency of sites located in upland environments in the region (Aikens & Madsen, 1986). Although the period from approximately 7500 to 4500 years ago is generally thought to have been a time of increased aridity throughout the Great Basin (Antevs, 1948; O'Connell, 1975; Mehringer, 1986; Grayson, 1993), some local paleoenvironmental records from the central and eastern Basin suggest that most post-Pleistocene changes in vegetation communities occurred prior to approximately 6000 years ago. Plant and macrofossil and pollen records indicate rapid elevational and latitudinal changes in the distribution of plant species between approximately 7000 and 6000 years BP, possibly associated with intense aridity or a shift towards summer dominated precipitation. With the exception of two species (Ephedra and Rocky Mountain Juniper), plant communities appear to have been essentially modern in the range and relative proportions of species by or shortly after 6000 BP in the eastern Great Basin (Mehringer, 1986; Thompson, 1990). Around 6000 BP a trend towards increased precipitation is suggested by pollen records from a number of Great Basin locations, including the Great Salt Lake area (Madsen & Currey, 1979; Currey & James, 1982; Grayson, 1993).

If the stratigraphic distribution of pinyon remains in the Danger Cave sediment column accurately reflects temporal variation in processing activities, this may indicate differences in the use of Danger Cave within the larger, regional strategy of land use employed by prehistoric foragers. Estimates of length of occupation range from several weeks (Aikens, 1970) to the hypothesis that Danger Cave was a winter base camp where inhabitants stored local resources and foods collected during trips to other resource patches in the area (e.g. Madsen, 1982: 214–215; Hall, 1988). It may be that when the site was used as a base camp foragers returned relatively large quantities of hulls to the site during trips to nearby pinyon groves, while at other times it was occupied primarily for the collection and processing of local resources such as pickleweed (e.g. Jennings, 1957; Aikens, 1970; Fry, 1976). If so, we might also expect temporal variation in the types and quantities of plant components representing other local and transported plant foods. An analysis of the relative proportions of pickleweed components from the Danger Cave column, and pinyon and pickleweed remains recently recovered from nearby Floating Island rockshelter site (K. Jones, D. Madsen, personal communication) may provide a preliminary assessment of these predictions. A more informative test requires the analyses of macrofossil asemblages from habitation sites located varying distances from both pickleweed and pinyon patches.

Discussion

Plant resources in the Great Basin are distributed in widely scattered, environmentally segregated patches. Given this situation, the costs associated with plant procurement and processing strategies have important implications for expecting differential field processing, and subsequent patterning in the deposition of plant waste in archaeological sites. If prehistoric collectors varied field processing strategies as a consequence of differences in the costs and benefits of transporting plant foods, the results of these experiments suggest that reconstructions of dietary importance based on relative quantities of remains are suspect. The importance of plant foods represented by waste that can be quickly removed for large increases in utility may be underestimated, while the contribution of plants that require extensive field processing for similar gains in utility may be exaggerated.

In addition to making potentially testable predictions about field processing behaviour and its material consequences, identifying the costs and benefits of field processing may contribute to our understanding of resource exploitation systems. Field processing decisions are embedded in a larger resource procurement strategy which includes resource choice, patch choice and settlement pattern decisions. In this paper transport distance, or the distance between the resource patch and the residential camp, was not modelled as a decision variable. From the perspective of the ethnographer or archaeologist who monitors field processing behaviour, transport distance has already been determined by the location of the residential camp. Within the larger framework of logistic organization, however, field processing resources for transport (especially those with predictable locations) occurs near the end of the exploitation continuum. It is possible that the processing characteristics of important resources in the diet influence settlement patterns in general, and specifically the locations of base camps or residential sites.

The estimated net energetic return rates associated with collecting, field processing and transporting loads of pinyon and pickleweed to base camps strongly suggest that foragers would always increase their energetic efficiency by carrying larger loads of these resources and locating camps close to collection patches. If transporting resources is generally characterized by rapid decreases in energetic return rates (Figures 7 & 8), such strategies should only be employed when the locations of other critical resources [e.g. water, firewood or other collected foods, sensu Binford (1980)] require a forager to consider the costs and benefits of transporting several resources to the same place. Given an array of resources in the diet, the processing characteristics of each may influence which resources are most effectively exploited through strategies of logistic procurement and long distance transport, and which are more likely to affect the locations of residential camps.

The transport decay functions calculated for pinyon and pickleweed illustrate how differences in processing characteristics might affect camp location. A forager's expected return rate is high for a camp located at either patch. But if camp is located 15 km away (a round-trip distance of 10 h or 30 km), the estimated net return rates for collecting, field processing and transporting loads of pinyon and pickleweed are approximately 3000 and 190 Cal h^{-1}, respectively (Figures 7 & 8). A resource like pinyon, considered a ‘‘high-ranked’’ plant resource, yields relatively high caloric returns, even with extensive field processing and transport time. Alteratively, small seed resources and possibly many ‘‘low-ranked’’ resources, may not be very attractive for transportation (Jones & Madsen, 1989). By reducing the transport time of this kind of resource when it becomes an important component of the diet, the expected costs of field processing and transporting it could be minimized, and may increase the caloric return rate for the entire set of resources exploited.

Studies which detail the field processing and transport of plant resources among modern hunter–

gatherer populations are needed to test this model. A number of ethnographic and actualistic studies have already employed the methodology needed to document these relationships. Researchers collected cost/benefit data, recorded procurement and processing times and calculated the caloric benefits of resources after processing (e.g. O'Connell & Hawkes, 1981; Hawkes *et al*., 1982, 1989; Simms, 1987; Bleige Bird *et al*., 1995; Jones & Madsen, 1991). If resources were also weighed and sampled at timed intervals during processing to document changes in utility, expectations about variation in field processing strategies could easily be developed. Ethnographic situations that also include observations of foragers or farmers travelling to resource patches and transporting loads of resources back to camp would provide the opportunity to test those expectations (e.g. Hawkes *et al*., 1989; O'Connell & Hawkes, 1981; Sikkink, 1989).

One research project has recently been undertaken that includes calculating the costs and benefits of field processing several kinds of shellfish for transport among the Meriam of the Eastern Torres Strait Islands, Australia (Bird & Bird, in press). This study will determine if some individuals vary field processing strategies as expected with different transport distances and processing characteristics. Initial observations indicate that Meriam children are efficient foragers, and routinely vary the locations where shellfish are processed with differences in the size of shells and the relative ease or difficulty of removing them (Bleige Bird *et al*., 1995). More studies of this kind, documenting relationships between field processing and transport in a variety of environments and foraging contexts, would provide insights about the types of resources most likely to be processed prior to transport and the situations in which archaeologists should expect field processing behaviour to strongly influence assemblage composition.

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