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Brodiaea Return Rates and Their Ethnographic and Archaeological Implications for Occupation of the Northwestern Mojave Desert of North America

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Brodiaeas—*with the inclusion of blue dicks (*Dichelostemma captitatum*)—are among the most widespread geophytes found in the state of California. They are also among the geophytes most widely consumed ethnographically, with reports of their use by the majority of native groups within the state. A notable exception involves the desert region of southeastern California, particularly the northwestern Mojave Desert.*

Although their use and nutritional value are widely documented, little is known about the costs associated with Brodiaea *procurement. Here we present data on* Brodiaea *energetic return rates by combining published nutritional information with timed collection experiments from Pilot Knob Valley, California. We show that the plants produce very low energetic returns (50–239 Kcal/hr.) owing to their small corm size, low caloric content, and the substantial time required to extract them. These low returns mirror data from a small number of previously unpublished experiments and fall at or below rates typically reported for small seeds. Such low values indicate that the plants may have been a marginal resource under many circumstances. We suggest that the absence of these plants in ethnographic accounts may stem from their low returns, as well as their intermittent availability tied to variations in local rainfall. To the extent that these estimates characterize potential returns elsewhere, they have implications for* Brodiaea *consumption in other contexts as well.*

Geophytes are perennial plants that go through part of their annual life cycle as a dormant, fleshy, underground structure. These structures—bulbs, tubers, corms, or rhizomes—represent an important food resource with a deep history, and they have been exploited by hunter-gatherers and agriculturalists world-wide. Their consumption is ethnographically well documented throughout western North America, including also the use of camas (*Camassia* sp.) and wapato (*Sagittaria* spp.) in the Pacific Northwest (Deur and Turner 2005:156); biscuitroot (*Lomatium* spp.), bitterroot (*Lewisia rediviva*), camas (*Camassia quamsh*), and yampah (*Perideridia* spp.) in the Great Basin (Fowler 1986), and various members of the Themidacea in California and Oregon (Anderson 1997, 2005; Gill 2013, 2014; Hammett 1991; Keator 1968; Prouty 1995; Reddy and Erlandson 2012). Geophytes are thought to have been an important component of early hominid diets, and their consumption may have played a key role in hominid evolution as well (Hawkes 2003; Hawkes et al. 1997; Laden and Wrangham 2005; O'Connell et al. 1999; Wrangham et al. 1999).

Our focus here is on members of the *Brodiaea*, sensu lato (s.l.; Gill 2014:639), particularly the blue dicks (*Dichelostemma capitatum*). As summarized by Gill (2014), *Brodiaea* s.l. are three closely related genera of corm-producing plants in the family Themidaceae (*Brodiaea* spp., *Dichelostemma* spp., and *Triteleia* spp. [Pires and Sytsma 2002]; hereafter simply referred to as "*Brodiaea*").These plants have a complicated taxonomic

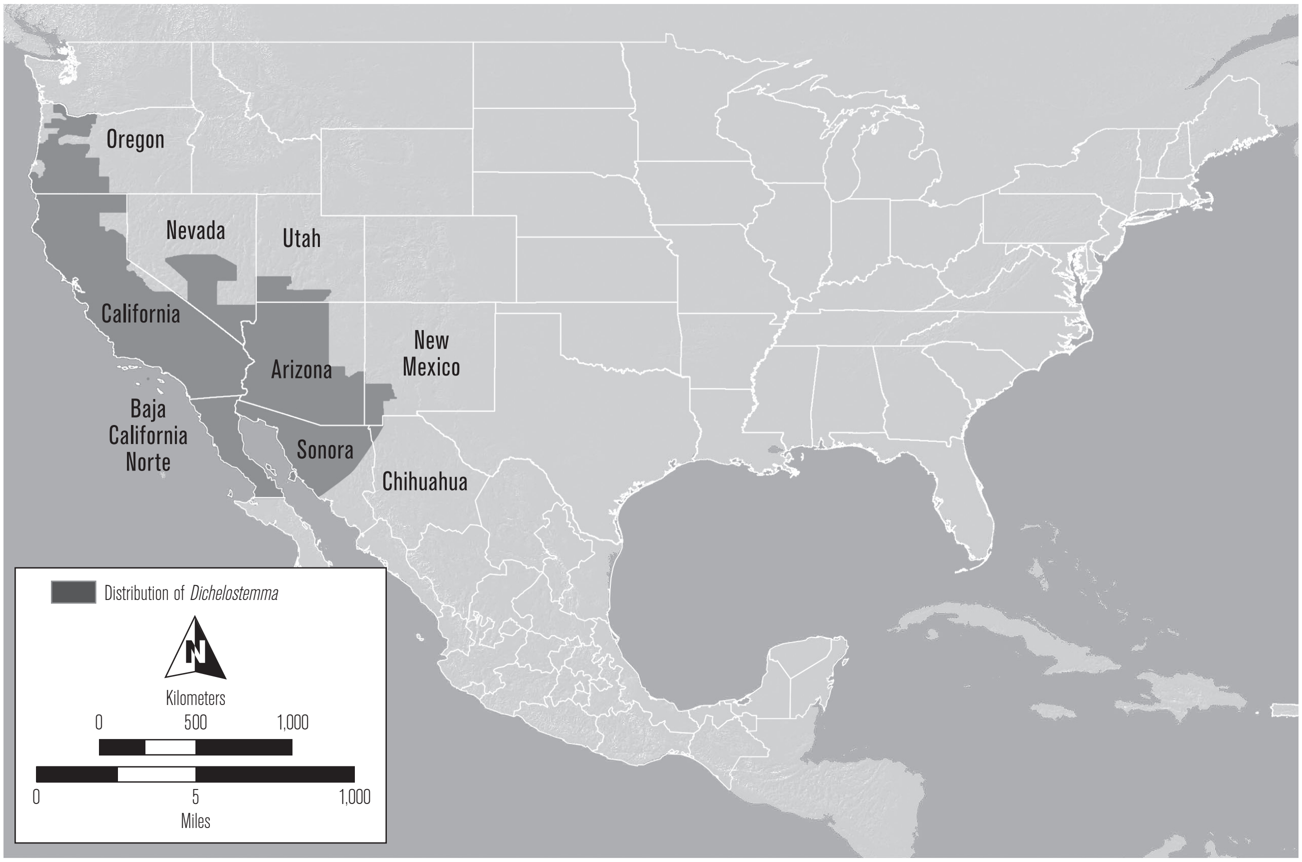

Figure 1. Geographic distribution of blue dicks (*Dichelostemma capitatum*).

history and exhibit a "kaleidoscopic" range of floral diversity (Pires and Sytsma 2002:1342), with substantial variation in flower position, color, and architecture (Keator 1968, 1989; Moore 1953; Niehaus 1971, 1980). All, however, are morphologically similar perennial herbs with jointed pedicels, fibrous-coated corms, a tubular perianth with distinct filaments, and all lack an alliaceous (onion-like) odor (Fay and Chase 1996; Hoover 1939). The various genera also have overlapping biogeographic ranges, with blue dicks (*Dichelostemma capitatum*) exhibiting the broadest distribution. Blue dicks occur from sea level to 2,100 m. (Keator 1993) and can be found in a diverse array of plant communities, including coastal strand, chaparral, evergreen and coniferous forest, oak woodland, valley grassland, and desert scrub, among others (Keator 1992). They occur throughout the west coast from Oregon to central Baja California, extending south and east into Nevada, Utah, Arizona, New Mexico, and Sonora, Mexico (Fig. 1; Junak et al. 1995:278; Keator 1968, 1989; Schlising and Chamberlain 2006).

Anderson and Rowney (1999:233) state that the corms of *Dicholestemmma* were consumed by approximately one-third of California Indian tribes (citing Bean and Saubel 1972; Heffner 1984; Hudson 1900; Timbrook 1993), and given the plant's wide distribution, prolific nature, and agreeable taste, that they may have been consumed by as many as three-quarters of them. If we include other *Brodiaeas*, this three-quarters estimate only becomes more likely, as various ethnographic and archaeological studies have highlighted the productivity of *Brodiaeas* and other geophytes and their importance to native California Indians (Anderson 1997:156, 2005; Anderson and Rowney 1999; Barrett and Gifford 1933; Gill 2013, 2014; Latta 1977:45; Martin and Popper 2001; Reddy and Erlandson 2012; Timbrook 2007).

The ethnographic or prehistoric use of *Brodiaeas* in the Mojave Desert region of southeastern California is our particular focus here. Speaking of *Dichelostemma* in particular, Anderson (1997: Fig. 8) notes that the tribes of the Mojave Desert were among the few that did not consume blue dicks, even though the plants occur throughout California and adjacent areas and even though the use of other *Brodiaeas* has been recorded ethnographically among the nearby Owens Valley Paiute (Lawton et al. 1976; Steward 1933:245). Furthermore, other geophytes such as the mariposa lily (*Calochortus* spp.) were consumed (e.g., Zigmond 1981).

The discrepancy between the apparently frequent consumption of *Brodiaeas* in other parts of California and its absence in the Mojave became more striking given our own recent survey in the Pilot Knob Valley, Naval Air Weapons Station (NAWS) China Lake, California during the late winter and early spring of 2015 (Fig. 2). At that time, blue dicks formed dense patches on several of the alluvial fans in or near our survey area (Fig. 3), reminiscent of descriptions of geophyte densities elsewhere in California (e.g., Anderson 2005:296–297). Yet the archaeological record of *Brodiaea* consumption at NAWS China Lake mirrors the ethnographic picture from the Mojave generally, with no evidence of their use in over 700 survey and testing reports spread across 4,500 km.[2] of the Indian Wells, Searles, Panamint, Pilot Knob, and Superior valleys and surrounding areas. The question becomes, why not? In the case of the archaeological evidence, poor preservation and limited attention to archaeobotanical analysis may certainly play a role. But should we expect *Brodiaeas* to have been collected, either ethnographically or prehistorically? In addition, how important might they have been?

Here we contribute to the latter two questions by providing new experimental data on the energetic return rates for blue dicks taken in the northwestern Mojave Desert. In the sections that follow, we lay out the rational for using return rates to assess the value of these plants, describe the project area in which the experiments took place, and summarize the results. We conclude with a discussion of those results and their importance for understanding the local archaeological and ethnographic record and the implications of those results for the use of geophytes in California more generally.

DEVELOPING EXPECTATIONS

Should we expect prehistoric or ethnographic peoples to have exploited *Brodiaeas* if and when they were available? There is a temptation to read ethnographic and historical accounts describing the apparent abundance and extensive use of certain geophytes (see Anderson 2005:296–297 for an excellent summary) and to infer that they were everywhere lucrative and important. However, these things are independent of one another. Foods that provide critical nutrition in times of starvation, for example, are clearly important when they are needed, yet they are costly given the minimal nutrition they provide. It is this high cost which leads foragers to avoid them under most circumstances, despite the fact that they are sometimes quite abundant. Conversely, high-value, high-return foods may also be important. Spring geophytes in the Pacific Northwest, northern Great Basin, and Columbia Plateau formed the basis of stored reserves used to last through the winter. These could be collected at rates of up to 3,800 Kcal/hr. (Couture et al. 1986:158, Table 3), and estimates of their dietary contribution suggest they supplied as much as 52 percent of annual caloric intake (Hunn 1990:177, Table 15; Prouty 1995). A good harvest could be the difference between surviving the winter or not, and they, too, were significant. Finally, the value of a food resource can have little to do with its nutritional content, and its importance may even be negatively correlated with its ease of procurement (Bliege Bird et al. 2001; Hawkes 1991; Hawkes and Bliege Bird 2002; Hildebrandt and McGuire 2003). Other examples might fall anywhere in between. The point here is that the "importance" of a particular food is variable, and may be separate from its nutritional value, abundance, or the cost of acquiring it.

Whether a resource is worth taking may also have nothing to do with its abundance. This observation has been one of the key insights gleaned from the application of microeconomic models to studies of human and nonhuman foraging behavior (Davies et al. 2012:52–82; Hawkes and O'Connell 1992; Kaplan and Hill 1992; Kelly 2013; O'Connell and Hawkes 1981; Simms 1987; Stephens and Krebs 1986). Following the logic of these models, resources can be ranked on the basis of their energetic value relative to the time required to pursue and process them once found. The highest ranked resource should always be taken on encounter, and successively lower ranked items should be added as long as their returns on encounter are greater than the returns obtained by searching for, pursuing, and processing any of the higher ranked items. The set of resources that follow this prey

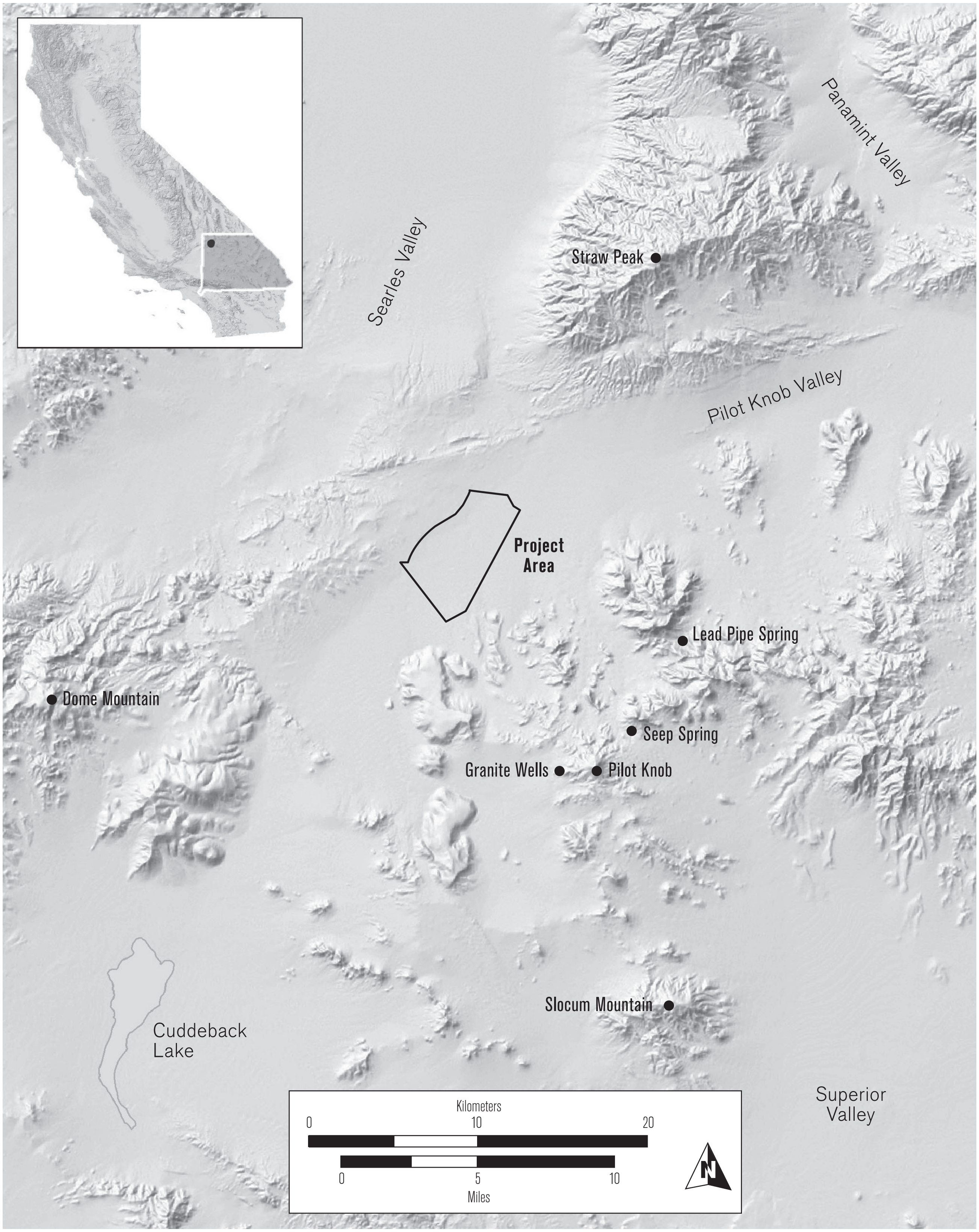

Figure 2. Project Location. Experiments took place on the alluvial fans in the project area, which falls in the western Pilot Knob Valley, San Bernardino County, California.

Figure 3. A dense patch of blue dicks (low, curly leaves) growing in an ephemeral wash, western Pilot Knob Valley, California.

choice rule represents the optimal diet, and by taking those resources, a forager maximizes total energy gained relative to the time spent searching for *and* processing them. Somewhat paradoxically, a forager would actually do worse by stopping and collecting a lower-ranked resource (one outside the optimal set), even when it occurs at high frequencies.[1]

This same prey choice/optimal diet logic provides a basis for quantifying the value of a resource such as *Brodiaea*. By combining ethnographic or experimental work on processing times with nutritional analyses of a particular plant taxon, one can calculate its rank (energetic value relative to the time required to collect and process it) and compare this to other common components of the diet. Doing so produces a clearer picture of the relative value of the different resources in the diet and allows for a more nuanced understanding of how regularly they should have been consumed. More importantly, one can examine how variations in search and handling times affect ranking and diet breadth, and derive expectations regarding resource use under differing circumstances.

This approach has a long history of use in the Great Basin, where return rates have been calculated for a wide variety of seeds, nuts, and geophytes (Barlow and Metcalfe 1996; Couture et al. 1986; Jones and Madsen 1991; Prouty 1995; Simms 1987). However, with the exception of limited work on acorns (Barlow and Heck 2002: Table 11.3; Basgall 1987; Bettinger, et al. 1997; Bettinger and Wohlgemuth 2006), no such data are available for ethnographically important foods in California. Lacking them, California archaeologists have had to be content with extrapolating returns for California plant foods using Great Basin analogues (e.g., Gill 2013; Rosenthal and Fitzgerald 2012; Wohlgemuth 2010). While they are better than no estimates at all, such extrapolations are not without peril. As Wohlgemuth (2010:60–61) points out, the nearest analogues for California plants often come from different species, and sometimes completely different genera. California also has a longer growing season, and (west of the Sierra Nevada Mountains) greater rainfall and increasing grass seed yields, potentially resulting in higher associated return rates. Finally, Wohglemuth (2010) notes that root crops in the Columbia plateau are often larger than their California counterparts, and that their return rates may differ as well. There is thus a clear benefit to having resource-specific return rate estimates for California taxa and—as Gill (2015:285) has pointed out—such estimates are still needed for *Brodiaea*. To help address this problem, we took advantage of the seasonal appearance of blue dicks in the Pilot Knob Valley of southeastern California to conduct a series of collection experiments and estimate associated return rates.

PROJECT AREA

The Pilot Knob Valley is located in the northwest portion of the Mojave Desert on what is now the Naval Air Weapons Station (NAWS), China Lake South Range (Fig. 2). The South Range is characterized by typical western Mojave Desert topography, including granitic and volcanic mountain ranges with alluvial plains and basin floors. The South Range straddles all or parts of four block-faulted valleys (United States Dept. of the Navy 1989). These include the Panamint and Searles valleys to the north, Superior Valley to the south, and the Pilot Knob Valley in the center. The Pilot Knob Valley bisects the South Range from east to west and is bordered by the Slate and Quail mountains on the north, the Granite Mountains, Robbers Mountain, Eagle Crags, and Black Hills to the south, and the Lava Mountains to the west. Elevations range from 2,200 to 5,600 feet (670–1,700 meters) amsl (Naval Air Weapons Station China Lake and Bureau of Land Management 2004).

The local climate is extremely arid, with monthly average high temperatures ranging from 15°C in December and January to 41°C in July. Monthly average lows range from 1°C to 23°C in the same months. Unsurprisingly, snowfall is almost non-existent, with trace amounts (7 mm.) occasionally reported in January. Precipitation averages approximately 93 mm. per year (historical data based on reporting from the Trona weather station, 1920–2015; Western Regional Climate Center 2015). Half of this precipitation falls in the winter months, with a long-term winter average (Dec.–Feb.) of 56 ± 41 mm./year. Amounts are also highly variable, with some years receiving little or no winter rainfall (Fig. 4). At the time crews were in the field, rainfall totaled 83 mm., or almost 50 percent greater than normal.

The whole area is relatively undisturbed, owing to its remote location and restricted access. The Navy took

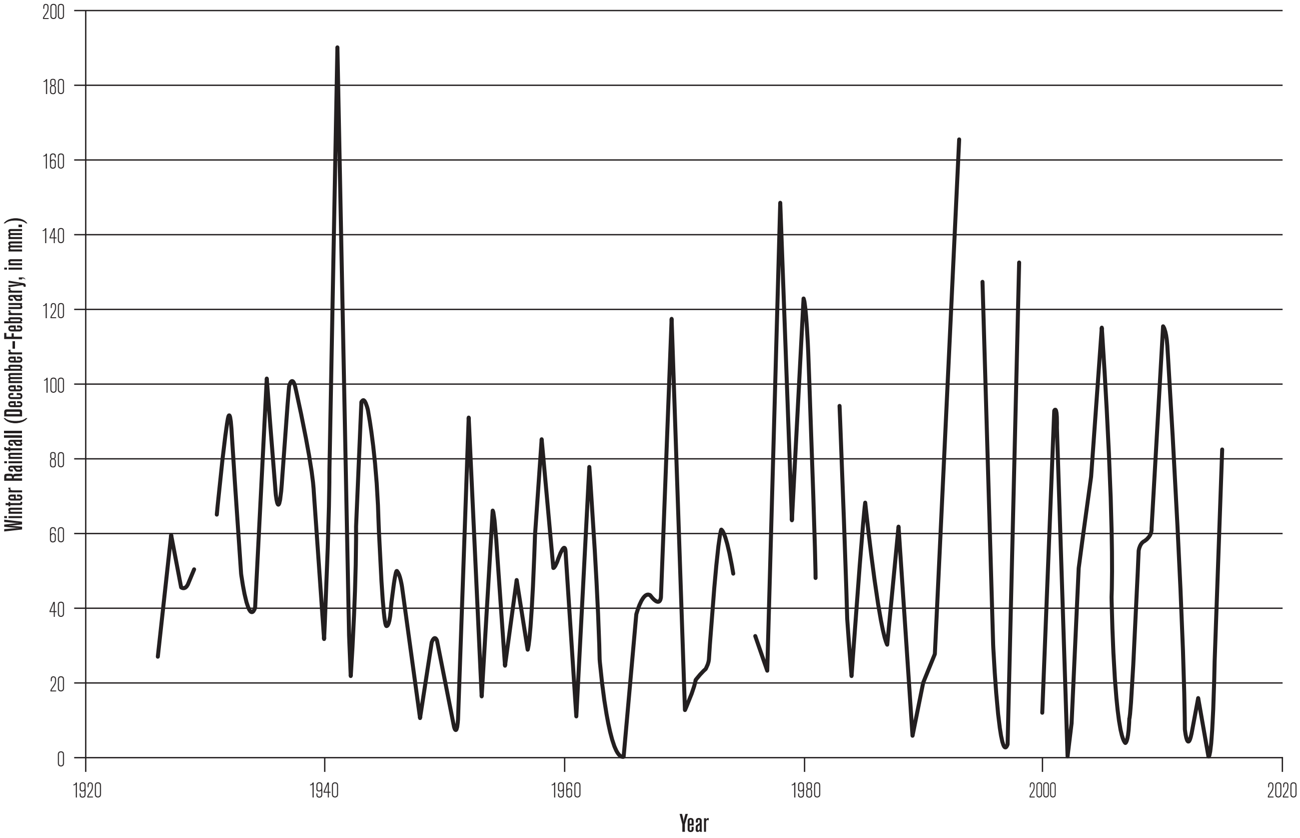

Figure 4. Variation in winter rainfall for the period of record, Trona station, Searles Valley, California. Gaps (n = 8) represent years missing one or more months of winter precipitation data.

control of part of the South Range during World War II, and expanded it in the years immediately after the war to meet the need for additional munitions testing and pilot training. While there are ordnance test targets in the Pilot Knob Valley, they are discrete and located in the valley floor in the central and eastern half. Most of the valley, particularly the western area around the headquarters buildings, is currently dedicated to pilot training and electronic warfare, which has a small terrestrial footprint that is mostly confined to specific roads and facilities.

There is also little record of land use prior to the Navy, probably owing to the valley's remote location and lack of water. There is no perennial water in the valley, nor has there been since the terminal Pleistocene. Other sources of water such as Granite Wells, Seep Springs, and Lead Pipe Springs all lie 11–12 km. to the south and east of the project area, on the other side of the mountains. Unlike Superior Valley, 30 km. further south, there are no land patent claims or evidence of homesteading in the valley, though several roads connecting coastal California to desert mining and farming communities did pass through the area. These include parts of the San Bernardino-Panamint/20 Mule Team Road and Nadeau's Death Valley Road. However, even as late as the 1870s, major transportation routes in the area continued to circumvent rather than cross through NAWS China Lake. The earliest maps showing routes through NAWS China Lake date to 1871 and 1877, and were drafted by Lt. George Wheeler (Kellawan et al. 2013).

Between January and March of 2015, crews working for Far Western Anthropological Research Group conducted a survey of several thousand acres within this valley. Roughly half of the survey took place in the central part of the valley south of the Quail Mountains. The rest took place on the alluvial fans emanating from the north edge of the Black Hills, east of the Lava Mountains and south of the Randsburg Wash Headquarters Building. It is in this latter area that dense stands of *Dichelostemma* were seen and where a series of collection experiments took place. These fans are a mix

Figure 5. Green vegetation and abundant wildflowers visible after a period of heavy winter rains. Pilot Knob Valley, California, March 2015.

of granitic and basalt sands and gravels, crossed by a few larger drainages and various small, ephemeral drainages and rills. The vegetation consists of an open and sparse creosote bush scrub community (*Larrea tridentata* and affiliates), with an abundance of exposed soil between plants and occasional patches of barren desert pavement. These areas of exposed soil actually harbor a plethora of desert ephemerals. These plants, which are dormant and largely invisible much of the year, produced an amazing display of wildflowers during the short time crews were working in the area (Fig. 5). This included blue dicks.

METHODS AND RESULTS

The experimental work took two forms. First, a record was made of encounters with patches of blue dicks on

Figure 6. Collecting blue dicks using a wooden digging stick.

Feb. 23, 2015. This was done by the senior author, who logged a waypoint on a handheld Garmin GPS receiver each time a patch of *Dichelostemma* was seen. To qualify as a patch, a cursory visual examination had to identify a number of visible plants. A specific count was not made, but single plants or thin patches with fewer than 10 or so plants were ignored. The patch was logged when first identified, and survey then continued. Subsequent plants were considered to be part of the same patch until their density dropped back down to the encounter threshold just mentioned. Each transect was spaced 120 m. apart. In this manner, 31 patches were identified over the course of four hours, for an encounter rate of approximately eight patches per hour or roughly one patch every eight minutes. Some of these patches covered less than 100 m.^{2} and others easily covered over 1,000 m.^{2}, some were less dense and others more so, but the bottom line is that opportunities to collect blue dicks were numerous.

The second set of experiments involved a series of seven collecting activities carried out on February 26, March 18, and March 22. This time, crew members carried wooden digging sticks and stopped several times during survey or site recording to collect plants (Fig. 6). In late February most of the patches were identified based on the unique shape of the plant stems, which were single, dark green structures visually similar to a small, thin green onion (Fig. 7). No other plants in the area had such stems, nor were any other geophytes seen. By mid-March, specimens of blue dicks had begun to flower as well. Because their stems were so distinctive, however, flowering did not make plants or patches substantially easier to spot. By late March, these stems had begun to dry up and wither away. Once desiccated, stems would blend into the background and often break off or disappear completely, rendering the plants invisible (cf. Gill 2014:648). Several of the patches identified on

Figure 7. Close-up image of blue dicks (*Dichelostemma capitatum*) after being collected. The plant was not flowering.

Feb. 23 were revisited on Mar. 22, only to find surface evidence of those patches gone.

During each experiment someone with a stopwatch kept time. Individuals who were digging plants were allowed to select any spot that suited them, and to move around within a patch at will. Soils in all patches were broadly similar, with loose, sandy surface sediments covering a more compact subsurface layer in which most of the blue dicks were anchored. All plants were collected whole (roots, stems, corms/cormlets, etc.), but there were no limits on how plants were exhumed. Most participants would identify a plant stem and begin by digging adjacent to it, working their way in toward the stem and down toward the corm. Where the ground was soft and plants dense and not too deeply rooted, some participants had success loosening larger areas of soil and sieving through it with their fingers for whole plants and occasional separated corms or cormlets. Root depths varied and were not measured directly, but were on the order of 15–30 cm.

While surface sediments were almost always loose, subsurface sediments were typically compact, which when dry made digging difficult. If plants occurred sufficiently close to one another, holes were expanded from one plant toward the next. If not, those digging would shift to the next plant and a new hole would be started. Stems were also fragile, and breaking one off below ground made it difficult if not impossible to locate the corm. Depending on their perceived likelihood of success, individuals would sometimes continue to pursue the corm when this occurred. More often, individuals would leave off digging, abandon the stem, and move to a new plant.

All plants collected during a bout were placed in a labeled bag (Fig. 7) and kept refrigerated until returned to the lab. There the plants were washed and weighed. Corms and cormlets were separated from the stems and weighed separately. The various specimens recovered included plants with corms, plants with corms and cormlets, and plants with contractile roots, all of which

Table 1

TIME AND PRODUCTION VALUES FOR 20 *BRODIAEA* COLLECTION BOUTS

Experiment Bout	Patch	Time (min.)	Fresh Whole Weight (g.)	Fresh Corm[a] Weight (g.)	Date Collected	Rate (g. corn/hr.)
1	1	17.5	37.0	18.0	2/26/15	63.1
2	1	17.5	43.0	23.0	2/26/15	77.5
3	2	5.0	18.0	12.0	2/26/15	139.2
4	2	20.0	53.0	31.0	2/26/15	92.1
5	2	20.0	34.0	17.0	2/26/15	52.2
6	3	20.0	47.0	21.0	2/26/15	61.5
7	3	20.0	22.0	13.0	2/26/15	39.3
8	4	30.0	77.0	48.0	3/18/15	95.8
9	4	30.0	84.0	59.0	3/18/15	118.6
10	4	30.0	21.0	13.0	3/18/15	26.6
11	4	30.0	130.0	68.0	3/18/15	136.4
12	5	20.0	93.0	49.0	3/18/15	146.1
13	5	20.0	84.0	55.0	3/18/15	165.3
14	6	20.0	44.0	29.0	3/22/15	86.1
15	6	20.0	55.0	27.0	3/22/15	79.8
16	6	20.0	24.0	16.0	3/22/15	48.0
17	6	20.0	25.0	18.0	3/22/15	55.2
18	7	20.0	58.0	22.0	3/22/15	67.2
19	7	20.0	49.0	32.0	3/22/15	96.3
20	7	20.0	63.0	40.0	3/22/15	120.3
Total		**420.0**	**1,061.5**	**611.1**	**Mean**	**88.3**

[a] Includes weight of attached cormlets, if any.

Table 2

NUTRITIONAL COMPOSITION OF BRODIAEA, PER 100 G. (FROM GILLILAND 1985:TABLE 4-7)

Species	Water	Protein	Fat	Carbohydrate	Kcal
Brodiaea hyacintha	64.1	1.0	0.5	30.0	129
Brodiaea laxa	62.9	1.0	1.4	31.0	140
Brodiaea multiflora	62.6	0.6	0.4	34.8	145
Brodiaea pulchella (*Dichelostemma capitatum*)	62.8	1.8	1.4	31.4	145
Mean	**63.1**	**1.1**	**0.9**	**31.8**	**140**

are known to occur in the winter-spring period (Gill 2014). No plants appeared to have adventitious roots or root-scars, which in the Channel Island area form in the fall (Gill 2014:648).

There were a total of 24 experimental bouts recorded, half conducted by adult women, half by adult men. Each bout represents one individual digging in one of seven unique patches. With a single exception, each bout lasted between 17.5 and 30 minutes (Table 1). That exception was a single five-minute bout, which some may consider too short a time to be a reliable marker of average productivity. The associated returns were within the range of other experiments, however, and so were retained. Twenty of these bouts form the basis of the present analysis. The remaining four bouts produced between just one and seven grams of corms over a 20-minute period. These samples came from three different individuals in three different patches and were the result of the diggers continuing to extract roots in difficult contexts rather than quickly shifting to another area within the patch. These values were anomalously low and were excluded.

Despite omitting the four anomalous (lowest-return) cases and retaining the five-minute sample, which had higher than average returns, overall productivity was very low. The average rate of corm collection was 88.3 g./hr. (76.0 g./hr. if the four dropped samples are included). Given previously published data on *Brodiaea* nutritional values (Table 2), these yields can be converted from grams to kilocalories per hour, the standard metric when ranking foods in foraging models. Using the lowest, highest, and average values from Tables 1 and 2, we find that on-encounter energetic return rates vary from 50–239 Kcal/hr., with an average of 123 Kcal/hr.

DISCUSSION

A return rate of 50–239 Kcal/hr. is exceptionally low by any standard, placing *Brodiaeas* well below most estimates for geophytes and among the dregs of small-seeded plant resources (seed returns: range 90–1,360 Kcal/hr., median 460 Kcal/hr., lower quartile 230 Kcal/hr.; Gremillion 2004:Table 4; Kelly 2013:Table 3-4; Simms 1987:Table 5). If these estimates accurately reflect return rates for *Brodiaeas*, they immediately draw into question the proposition that they were among the highest ranked plant resources exploited by California Indians (cf. Gill 2013, 2015; Wohlgemuth 2010). They also bring into question their role as a dietary staple, given the substantial costs associated with their acquisition. However, the question of accuracy is critical, and several observations are in order.

First, the present data provide a resource-specific starting point for estimating *Brodiaea* returns, but numerous factors can influence such rates. One of the most frequently mentioned is experience. There is a learning curve associated with taking any resource, and blue dicks are no exception. The four trials that were omitted from our calculated returns are a clear example. Locating a plant for extraction was never a problem, but it did take time to appreciate how fragile stems could be, how difficult corms were to locate in the absence of the stem, and how variation in soil characteristics affected the ease with which plants could be extracted. Additional practice would almost certainly improve returns to some degree.

Another source of potential variation is the size of the plant. While the nutrient composition of *Brodiaeas* is relatively homogenous (Table 2), there may be differences in the size of the plants and associated corms. While examining the corms recovered during these experiments, for example, archaeobotanist Eric Wohlgemuth (personal communication 2015) observed that they looked somewhat smaller than samples he had seen from other parts of California and the Channel Islands. Assuming larger plants take no more time to dig than smaller ones, bigger plants will produce higher returns in proportion to the difference in size.

While size may matter, density did not, being high enough in all cases that shifting from one plant to the next required a negligible amount of time. Very low densities might reduce these returns further. Higher densities might improve returns, but only if they reached a point where the cost of digging became distributed over multiple plants. This might occur when hoeing and sieving a section of ground or where digging up one plant made the next easier to access, such as might occur if one was peeling back the face of an existing hole rather than starting a new one. How much of a difference it might make is difficult to say without more experimental work.

Technology can also be a factor. All the experiments here used simple digging sticks, although these included unsharpened 20 mm. dowels, sharpened 28 mm. dowels (sections of a polished broom/mop handle), and impromptu digging sticks made from locally available creosote branches. We did not track type of digging stick across experiments and cannot speak quantitatively about any differences, but our sense is that differences were small over the course of a 20-minute bout. However, the 28 mm. sticks were preferred for their comfort (smoother surface) and greater weight, and would be the clear choice for long stretches of digging. We also did not try to use digging stick weights. While reportedly not used in the desert region of California (Driver 1937; Drucker 1937), these round, perforated, donut-shaped stones were used by Native Americans taking *Brodiaea* in the Channel Islands and along the Central California coast (Sutton 2014). Such weights might improve return rates when digging in harder ground, although the time invested in producing such weights would represent an additional cost (Bright et al. 2002; Ugan et al. 2003).

Finally, soils and geologic context also matter. Here again our experience is anecdotal, but everyone felt it was easier to take corms during the first set of experiments, when recent rains had made the soils softer and looser. By the middle of March, the ground had dried substantially, indurating the soils and making it harder to extract the corms. There was also variation in soil compactness with depth and topographic context. Some of the densest patches of blue dicks occurred within shallow channels (Fig. 3). While surface sediments in the channels were loose, those sediments extended just a few centimeters below ground before becoming very compact. Corms within the channels were almost always buried in the compact soil horizon and were very hard to extract efficiently, leading people to shift from the channel to the softer margins despite their lower plant densities. There was also some discussion about whether larger plants tended to be more deeply rooted, increasing collection times and negating the benefits from their greater caloric content.

Even though these factors might have combined to produce our low estimated returns, two additional points bear mentioning. First, these low returns are not unique. Similar returns are seen in other parts of California. In an experiment with *Brodiaea coronaria* in the Upper Klamath region, Gleason (2001:921) acquired 48.9 g. of corms in 20 minutes (147 g./hr.). Using her estimate of 100 Kcal/100 g. for *B. coronaria*, this amounts to 147 Kcal/hr. Using our estimate of 140 Kcal/100 g. for *Brodiaea s.l.*, it translates to 205 Kcal/hr. Both of these estimates are well within the range of the data presented here. Similar returns have been reported by Todt and Hannon for *B. coronoria* in the same area (<250 Kcal/hr.; Todt and Hannon 1998:Table 1), although these do not appear to be experimentally derived. Two unreported experiments by Wohlgemuth (personal communication 2015) in the Cuyama Valley and the foothills of the Coast Range near Winters, California were also quite low, producing 75–105 g. of *Dichelostemma* corms/hr., or 117–164 Kcal/hr. Finally, ethnographic data on return rates for other geophytes can also be quite low. For example Couture et al. (1986:Table 3) report that Northern Paiute women collecting Canby's lomatium (*Lomatium canbyi*) and Gairdner's yampah (*Perideridia gairdneri*) using metal-tipped digging sticks achieved return rates of just 143 Kcal/hr. and 172 Kcal/hr., again well within the range of returns that we report.

The second point worth mentioning is that even if the low return rates reported here are in fact a product of inexperience, local *Brodiaea* morphology, technological choices, etc., changing these factors may not have any qualitative impact on rates. If an experienced forager could double our production values, for example, and if corms in other areas were double the size, the net effect would be to quadruple return rates. But even though a 400% improvement in return seems huge (and it is), the end result is still only ~500 Kcal/hr. *Brodiaeas* would still produce some of the lowest energetic returns reported for plant resources taken prehistorically, rather than some of the highest.

Broader Implications for Brodiaea *Studies*

These last two points have clear implications for studies of *Brodiaea* use more generally. While no one should take the results summarized here as the last word on *Brodiaea* returns, they are currently the only word. They show that *Brodiaeas* are very costly to acquire and likely among the least preferred resources—less preferred than even small seeds. This differs from previous estimates, which place them among the highest ranking resources (Gill 2013, 2015; Wohlgemuth 2010).

Given that our results from the Mojave are mirrored by experiments in different parts of the Central Valley and Northern California, they also cannot be characterized *a priori* as a purely local phenomenon. This, then, raises interesting questions about the apparently heavy reliance on *Brodiaeas* by groups elsewhere in California (Anderson 1997, 2005:Chapter 10, and references therein; Timbrook 1993). Historical descriptions of geophyte distribution and use are often qualitative and focus on yields rather than their associated costs or the means by which they were acquired (e.g., Chesnut 1902:327–329; Latta 1977:45 fn.; Powers 1856:189), and discussions of their use tend to characterize them as a lucrative, valuable resource and a major source of calories and nutrition. The results here, in contrast, focus attention on alternative interpretations of *Brodiaea* use. Examples would include consuming *Brodiaea* as part of a highly marginalized (low return rate) subsistence base, with all that that implies for morbidity and mortality; using it as an emergency or fallback food; or accepting low returns in order to meet nutrient (carbohydrate) needs (as posited by Gill 2013 for the Channel Islands). None of this is to deny the possibility that return rates might actually be higher in other parts of California, whether as a result of greater natural corm densities than were seen here, deliberate tillage and burning (Anderson 2005:299–302), or the use of technologies other than simple digging sticks, but that case now needs to be more clearly made. Additional experimental work will obviously help clarify this issue.

Implications for Local Archaeology and Ethnography

There are no local ethnographic descriptions of Native Americans taking blue dicks or other *Brodiaeas* in the area around Pilot Knob Valley, and the experimental data and observations presented here lead to several hypotheses as to why that might be. First, given the very low apparent returns that these plants provide, it is possible that *Brodiaea* were never used. Unlike other areas of California, the northwestern Mojave may simply not have provided plants that were large enough, or stands that were dense enough, to serve as a viable resource. In this area, they may have simply always been absent from the diet.

Another possibility is that the plants were used only intermittently, such as in times of extreme nutritional stress or scarcity. That is, they may have served largely as a survival food, as described earlier, and were taken intermittently. Even if *Brodiaeas* were a regular component of the diet, they may still have only been taken intermittently if they remained dormant during years of low rainfall. Geophytes are well adapted to avoiding drought conditions (Walter and Breckle 1985:154–155), and the bulbs of blue dicks can remain buried for up to 10 years until stimulated by soaking rains (Hanson 2015:73; Spellenberg 2003:102). The winter rainfall in 2014–2015 was roughly 50 percent higher than normal, and substantially higher than it had been in prior years. The previous three winters had produced just 6, 17, and 1 mm. of rainfall respectively, and nothing like the array of flowers and vegetation seen in 2015. If dry winters force these plants to remain dormant, it would effectively render them unavailable by substantially increasing the costs of extracting them. Our experimental return rates, which are already low, depended upon the ability of the diggers to use stems to identify the approximate location of a plant. Lacking this cue, a forager would be left to dig indiscriminately within the patch in the hopes of finding corms, dropping those returns further and almost certainly making *Brodiaeas* uneconomical to acquire. In either case, *Brodiaeas* may have been used, but so intermittently that they did not register ethnographically. This does not mean that they were not important at certain periods in the past, however, when conditions were moist enough to sustain more regular production.

In this regard, the experimental work presented here provides an important context for interpreting the local archaeological record. Archaeological residues in the western Pilot Knob Valley are exceedingly thin. Our survey of 4,500 acres of land in the same area where the *Brodiaea* experiments took place found just 21 prehistoric sites on the surface of a Pleistocene-age alluvial fan. Seventeen of them (80%) were simple segregated reduction locations—areas just a few meters in diameter where one or a few white cryptocrystalline silicate (CCS) cobbles had been tested or reduced—and two were small lithic scatters of the same material.

The remaining two sites included a short-term camp and a milling station. The former contained small amounts of debitage, two battered cobbles, 16 pieces of ground stone, and a small rock concentration possibly representing the remains of a cooking feature. The latter consisted of one portable milling stone and four milling slicks on small boulders overlooking a nearby dry drainage. Neither of these sites was remarkable, with tiny surface assemblages and few prospects for subsurface deposits. Both were marginal locations for a campsite, given that the nearest perennial water lies over 10 km. away, and while something was being ground or processed at each, little further can be said. Prior to our research, the obvious candidates would have been such locally important small seeds as ricegrass (*Achnatherum hymenoides*), blazing star (*Mentzelia* sp.) and chia (*Salvia* sp.) (Coleville 1892; Steward 1938).

The realization that underground corms are abundant in the area, are seasonally limited to mid- to late winter, and are costly to acquire, changes this. Whether or not blue dicks were being gathered is now an interesting and important question. While we do not currently know the answer to that question, the sites become a potential source of relevant data. This obviously influences both whether and in what way these sites and others like them are managed, excavated, or protected. If subsequent testing should show that *Brodiaea* was exploited at these sites, then our field observations and experimental work suggest the following potentially important corollaries.

(1) If one presumes the grinding stones are subsistence related, current ethnographic data would suggest a late-spring or summer use of the site, since this is when known seed resources such as ricegrass, chia, and blazing star were available. *Brodiaea*, on the other hand, would suggest a late winter occupation. *Brodiaeas* also do not require grinding to render them edible; however, since these plants are well adapted to surviving dry conditions, they may not store well without it (Gill 2014:649). Grinding may thus be an important part of, and indicator for, storage preparation rather than immediate consumption. This hypothesis can be readily tested experimentally by looking at rates of corm spoilage for ground and unground samples.

(2) Grinding also implies additional work and lower returns than consuming the plants immediately. Transportation costs would reduce those returns even further, and together these two factors severely constrain the distances that one might be expected to travel (Grimstead 2010; Jones and Madsen 1991; Metcalfe and Barlow 1992; Whitaker and Carpenter 2012; Zeanah 2004). The implication is that associated residential sites are likely to be located quite close by. Similar though much less severe constraints likely structured the ethnographic exploitation of geophytes elsewhere. Prouty, for example, notes that root patches exploited by Basin and Plateau groups were also within a few day's walk of winter residences in order to limit transport costs and decrease the amount of labor involved (Prouty 1995:45).

(3) If these two sites are shown to be *Brodiaea* processing localities, or even areas of immediate consumption, they also almost assuredly represent short-term seasonal camps. The lack of locally available water and the (currently) limited growing season of *Brodiaea* would both limit the possibility of longer-term occupation. The small surface assemblages and lack of obvious pit depressions or architecture are certainly consistent with this, though excavation might always change the picture. Again, ethnographic constraints for geophytes taken elsewhere may have been similar, with people leaving winter camps and traveling to the uplands, where they are described as setting up temporary wind-break structures at dry-root processing camps (Prouty 1995:48).

Our goal in laying out these possibilities is not to make definitive statements about how or why these sites were used. Rather, we wish to highlight how a simple piece of experimental work can change the nature and focus of archaeological inquiry and open up new avenues of research. While our emphasis is on the northwestern Mojave Desert, we would suggest that similar opportunities exist elsewhere.

CONCLUSIONS

While only visible intermittently, *Brodiaeas* can be found in large numbers in parts of the Mojave Desert and may have served as a prehistoric food resource. However, work reported here and elsewhere indicates that their associated return rates are as low or lower than those reported elsewhere for small seeds. Such low returns and their intermittent visibility represent two good reasons why ethnographic evidence for *Brodiaea* consumption is absent from much of California's desert region. Evidence of their consumption would suggest that better subsistence options were lacking and conditions were marginal, perhaps to the point that *Brodiaeas* served only as a fallback food or a key late winter or early spring resource, when alternatives were scarce or unavailable. If such low return rates characterize *Brodiaeas* taken in other parts of California, their regular consumption would imply marginal subsistence opportunities in those locations as well, potentially altering our view of the role these geophytes played both ethnographically and prehistorically.

Other possibilities also exist, but to explore any of them requires a clearer understanding of the costs and benefits associated with *Brodiaea* exploitation. The return rates presented here provide a starting point, but one experiment in one part of California can only begin to scratch the surface of any underlying variability. Additional experiments are clearly needed. Fortunately, such experiments are hardly complicated, and as we have demonstrated, are easily integrated into a broader field program—even in the context of simple cultural resource management archaeology. Hopefully, the results reported here will spark the interest and participation of others.

NOTES

1 We recognize that factors such as storability, risk sensitivity, and others may affect the attractiveness or perceived benefit of a resource. One can also parse the general diet breadth model much more finely that we do here, discussing, for example, the role of density in structuring handling times and on-encounter returns for resources that are not randomly encountered (e.g., denser versus thinner patches of plants, when the patch is the unit being handled). We omit these discussions here for the sake of brevity.

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