Why foragers choose acorns before salmon: Storage, mobility, and risk in aboriginal California

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ABSTRACT

Despite the enormous potential of anadromous fish, foragers do not mass extract and store salmonids until very late in the archaeological record of California. Acorns, by contrast, were intensively used quite early in the record. Salmon are traditionally viewed as a low cost, high ranking resource, and acorns as a high cost, low ranking resource. The question thus arises: why were salmon not used and stored en masse much earlier? We offer a solution using a simple foraging model that distinguishes resources on their storage as well as overall cost, making it possible to calculate the risk of resource caching, which appears to have delayed intensive salmon procurement in California.

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Introduction

Over the past 30 years, an increasing number of archaeologists have employed foraging theory to understand the subsistence behaviors of prehistoric hunter–gatherers. A basic foraging theory tenet is that humans are rational and make decisions based on calculations of costs and benefits. Diet breadth (contingency) models, for example, assume that resources enter the diet according to their rank as measured by calories per unit of handling time (MacArthur and Pianka, 1966).

The diet breadth model is attractive because it is simple, but this simplicity necessarily ignores complicating circumstances that may have influenced foraging decisions. In particular, it overlooks the risks and benefits of storage—elements that are critical in understanding intensive use of resources acquired en masse.

The front–back loaded model considers the risks and benefits associated with stored resources, modeling forager decisions between resources that vary with respect to ease of procurement, storage, and processing time (Bettinger, 1999a,b, 2009). The model divides resources on this basis into those defined as “front-loaded,” easy to procure and store, costly to prepare for consumption, and “back-loaded,” easy to procure and store, costly to prepare for consumption. The model contrasts two resources set in specific relationship to one another: a back-loaded resource (higher overall handling time) and a front-loaded resource (lower storage time). While overall handling time is higher for back-loaded resources, front-loaded resources are riskier for mobile foragers because there is a higher probability that their stored caches—and the labor involved in laying up these caches—will go unused. Back-loaded resources entail less risk for mobile foragers because the cost of their procurement and storage is lower, and therefore less is lost if the cache is never used.

In this paper we employ the front–back loaded model to understand why California hunter–gatherers chose to intensify acorns, a resource that is widely viewed as a high-cost, low-rank food, over salmon, widely viewed as a low-cost, high-rank food. In the diet breadth model, salmon is clearly higher ranking because of its higher overall return rate. The archaeological data, however, are at odds with the prediction that they should enter the diet before acorns; intensive procurement and storage of acorns predates intensive procurement and storage of salmon. We argue that despite the enormous potential of their anadromous fishery, northern California hunter–gatherers chose to intensify acorn use first because they are a back-loaded resource whose storage permitted greater settlement flexibility than front-loaded salmon.
Hunter–gatherer storage

Food storage, often conceived as a means for groups to manage abundant, yet temporally or spatially incongruous resources (e.g. Suttles, 1968), has long been recognized as critical to understanding the behavior and cultural evolution of hunter–gatherers, particularly those living in mid- to high latitudes (e.g., Binford, 1990; Cannon and Yang, 2006; Rowley-Conwy and Zvelebil, 1989; Soffer, 1989; Testart, 1982; Woodburn, 1980). Among the best-known food storing hunter–gatherers are the native peoples of the Pacific Northwest Coast and California, the Jomon of Japan, and pre-agricultural Natufians of the ancient Near East. Storage has been linked to sedentism and high population densities (e.g. Testart, 1982; Rowley-Conwy and Zvelebil, 1989), sociopolitical complexity (Price and Brown, 1985), the emergence of social inequality (Testart, 1982), and the development of agriculture in many parts of the world (Testart, 1982). However, the nature and universality of these relationships is debated (e.g. Ingold, 1982, 1983).

Influential archaeological models often divide hunter–gatherers into two groups: for example, storing versus non-storing economies (e.g. Testart, 1982), foragers versus collectors (Binford, 1980), and delayed versus immediate return economies (Woodburn, 1980). In recent years, however, a growing number of scholars have pointed out that there was in fact a great deal variability in hunter–gatherer storage (Kuijt, 2009; Morgan, 2012; Sakaguchi, 2009). Furthermore, while food storage is often a key component of evolutionary theory, and a variety of evolutionary models imply the importance of storage (e.g., central place foraging, risk aversion), few models address or operationalize it explicitly (Morgan, 2012; Sakaguchi, 2009). This is particularly true for more mobile foragers or “emergent storers”, groups experimenting with small-scale caching and likely concerned with the risks of storage. Low intensity/low investment forms of storage or caching are particularly difficult to identify archaeologically; without large storage facilities, small-scale storage or caching is often inferred from proxy measures (e.g., the presence of intensive processing tools such as mortars and pestles or large amounts of processed, mass harvested food remains).

As Ingold (1982, 1983) pointed out (contra Testart, 1982), the correlation between storage and low mobility is not universal. Indeed, there appears to be a spectrum of storage strategies and different scales of storage even within groups. For example, Morgan (2012) distinguished between caching (low intensity, dispersed storage) and central place foraging (more intensive, tethered bulk storage at a central home base), which were both employed by the same groups in southeastern California. This is an important distinction because it recognizes variability in hunter–gatherer mobility and storage strategies. An issue that has been left largely unexplored, however, is how foragers decided which resources to store, particularly when groups began experimenting with storage while settlement flexibility and mobility remained important strategies. In this study we employ the front–back loaded model to explain why, despite expectations, a resource widely assumed to be high cost/low rank (acorns) may have been intensified before one that is low cost/high rank (salmon).

Predictive frameworks

Salmon figures prominently in the ethnographic literature as the economic foundation for many north Pacific hunter–gatherer social institutions (Goddard, 1945; Hewes, 1938; Kroeber, 1925; Kroeber and Barrett, 1960). Likewise, many archaeologists have stressed reliance on, and control over, anadromous fish as critical to understanding the development of foraging societies in the north Pacific Rim (cf. Hayden, 1992; Hewes, 1938; Maschner, 1998; Matsui, 1996; Schalk, 1977). Salmon can be harvested in great numbers, provision large populations with a substantial supply of protein, and arrive in predictable runs. It has been assumed for these reasons that salmon is a relatively low-cost, high-ranking resource that would always have been as prominent in the diet as its numbers would allow.

Over the past 30 years, a growing number of scholars has challenged this view, which Monks (1987:119) calls “salmonopia” or “the inability to see all the food resources because of salmon.” Indeed, research incorporating the systematic analysis of dietary remains (of fish bone in particular) and stable isotope analyses of human bones have given archaeologists a much greater appreciation of the diversity of hunter–gatherer diets. Regional syntheses throughout the Pacific Northwest Coast and northern California demonstrate that the timing and trajectory of salmon intensification was not uniform; diets were often quite diverse, and while salmon was undeniably a staple, its importance varied significantly (e.g. Ames, 1991:941, 1994, 1998; Butler and Campbell, 2004; Coupland et al., 2010; Gobalet et al., 2004; Monks, 1987; Moss, 1993, 2012; Moss and Cannon, 2011a; Thornton et al., 2010; Tushingham and Benze, 2013; Tveskov and Erlandson, 2003; see also papers in Moss and Cannon, 2011b). Furthermore, there is a growing appreciation of the fact that salmon runs are not as predictable as previously portrayed, with tremendous variability in species behavior, and inter-annual cycles of abundance (e.g. August, 2003; Cannon et al., 2011; Moss, 2012; Rogers et al., 2013; Schalk, 1977). Mounting evidence has led many to question whether salmon ranked as highly as the ethnographic records suggest, and if it did, why hunter–gatherers did not intensify salmon exploitation earlier and uniformly through time and space.

As Schalk (1977) observed, extended salmonid runs imposed fewer scheduling demands in California than in the northern and central Pacific Northwest Coast. He argued that this flexibility was more important than run size in determining the onset of intensive salmonid use. That is, salmonid intensification did not hinge on the available quantity of salmon, but on the timing of runs and the scheduling constraints they imposed, which varied by latitude. In southern latitudes, including all of California, there were more salmon species, and their runs were extended relative to points farther north on the coast. Though their numbers fluctuated, salmon were available practically year-round in larger rivers. Given this, Schalk predicts that, at southern latitudes, one should “find evidence of the earliest dependence upon anadromous fish without the need to store or make a heavy investment in the technology for capturing and processing large quantities of fish in a short period of time.” In this scheme, human population growth is more or less continuous, and did not involve significant investment in salmon storage or specialized technology to exploit salmon. In short, archaeological sites in California regions with anadromous fish should show evidence of salmon exploitation (e.g. abundant salmon bone, human bone with isotopic signatures reflecting the dietary contribution of salmon) virtually from the very start of human occupation, continuing to the historic period.

Heavy ethnographic reliance on acorns in California persuaded scholars that they, too, were a high quality resource (Baumhoff, 1963; Gifford, 1936; Mayer, 1976), but Basgall (1987) showed that they were extremely labor-intensive—easy to collect but costly to process—and argued that this delayed intensification of the resource in northern California. In this view, acorns are a high-cost, low-ranking resource that would have entered into the diet only when people were forced to expand their diet breadth.

Cohen (1981) and Basgall (1987) argued that acorns became a key food source only after population pressure forced aboriginal groups in California to focus on high-cost foods. Historically, mortars and pestles have been associated with labor intensive processing methods including flour making and leaching, while
millingslabs and handstones have been associated with processing small seeds and nuts (Fredrickson, 1973; Moratto, 1984:264; Baggall, 1987). This chronology places widespread intensification of acorns at 2500 BP, when mortars and pestles widely replace millingslabs and handstones. If true, evidence of significant exploitation of acorns (abundant acorn nutshell, appearance of mortar and pestle technology, isotopic signatures on human bone reflecting the contribution of acorn) should be relatively abrupt (once acorns are in the diet, their abundance would make them a staple) and late in the archaeological record.

**Ethnographically documented use of acorns and salmon**

Here we focus on three areas in California where both salmon and acorns were documented as key ethnographic staples: the Central Valley—including the northern Sacramento River basin and southern San Joaquin River basin—the San Francisco Bay area, and northwestern California (Fig. 1). According to Gifford (1936:87), acorns were a key resource “…from Lower California northward through the Pacific states practically wherever oaks grew. The northern limit of abundant oaks was the Umpqua divide in Oregon. Beyond that they were relatively rare and played a correspondingly small part in the native dietary.” There is substantial evidence that historic native Californians managed oak groves by burning undergrowth to improve acorn crop productivity at minimal cost (e.g. Anderson, 2005; Blackburn and Anderson, 1993; Lightfoot et al., 2013; Lightfoot and Parrish, 2009:94–122; McCarthy, 1993a); the antiquity of this practice, however, is unclear (Lightfoot et al., 2013; Lightfoot and Parrish, 2009:113, 122).

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Fig. 1. Major salmon streams in California, with archaeological regions mentioned in the text. Base map redrawn from Moratto (1984); salmon stream data from CalFish (n.d.) and Yoshiyama et al. (1998, 2000, 2001).
Acorns were the main dietary staple of most contact period groups in California, but were thought to rank second to salmon in the northwest (Baumhoff, 1963; Gifford, 1936; Kroeber, 1925). The acorns of several species of oak (*Quercus* and *Lithocarpus* spp.) were harvested in the fall by small household groups who simply collected the nuts after they had fallen to the ground or after having been knocked down from the trees (Barrett and Gifford, 1933; Chestnut, 1902; DuBois, 1935). Acorns were transported back to home base villages in burden baskets and were typically stored in above-ground granaries or (in northwestern California) in large baskets within plank houses (Barrett and Gifford 1933; Driver, 1939; Gould, 1966). Acorns were processed for consumption by women “as-needed”; preparation typically involved an elaborate three-step process to remove bitter tannic acids (Fig. 2), which involved shelling the nuts, pounding them into a flour with a mortar and pestle, and then leaching the flour by carefully and repeatedly pouring water over it in a sand basin which was sometimes lined with grass or in an openwork basket lined with sand (Barrett and Gifford, 1933; Driver, 1939, 1953; Gifford, 1936). The leached flour was boiled in baskets, stone bowls and wooden or bark boxes heated with hot stones, and eaten as a mush or soup. Acorn flour was also made into bread, baked on stone or wooden or bark boxes heated with hot stones, and eaten as a mush or soup. Acorn flour was also made into bread, baked on stone or wooden or bark boxes heated with hot stones, and eaten as a mush or soup.

Salmon was a key resource throughout northern California, but is argued to be the primary staple only in the northwest (Baumhoff, 1963). Important mass-harvested species include Chinook or king salmon (*Oncorhynchus tshawytscha*) and steelhead (*O. kisutch*), chum salmon (*O. keta*) and pink salmon (*O. gorbuscha*). Chinook salmon runs were also historically present in the San Francisco Bay and Central Valley; Spring Chinook once extended to both rivers (Sacramento, San Joaquin) of the Sacramento River drainage and its tributaries, while runs were winter-only in the McCloud, Pit, and Upper Sacramento Rivers (Moyle, 2002:253; Yoshiyama et al., 1998, 2000, 2001). Chum, pink, silver, and sockeye salmon were also present on the upper Sacramento River in the late summer to fall but their numbers were far fewer than Chinook (Hallock and Fry, 1967). Ethnographers detailed the elaborate fishing technology that was used to take anadromous species including Chinook salmon, silver salmon, steelhead, lamprey and sturgeon. A wide range of facilities and implements were used, from communal weirs (Fig. 3) to simple fish spears and poisons (e.g. Hewes, 1938; Kroeber and Barrett, 1960).

**The antiquity of salmon and acorn intensification**

Direct and indirect evidence used to determine the age of initial salmon and acorn intensification in California includes: (1) plant processing gear (e.g. mortars and pestles) and specialized salmon fishing equipment (e.g. salmon harpoon tips in northwestern California), (2) culturally deposited salmon bone and charred acorn nutshell, and (3) stable isotopes in human bones.

Basgall (1987) summarized archaeological data supporting his position that acorn intensification began approximately 2500 years ago throughout northern California. He relied primarily on tracing the appearance of the mortar and pestle, formal tools traditionally associated with intensive methods of balanophagy (the practice of eating acorns). These tools generally replace or overtake the frequency of handstones/millingslabs (better suited for seeds than nuts) in deposits dated to the last 2500 years.

Here we summarize additional data from well-dated archaeological contexts at northern California sites excavated in the 25 years since Basgall’s (1987) study, and draw on the numerous specialized studies, including fine grained analyses of fish bone (e.g., Gobalet et al., 2004) and macrobotanical remains (e.g. Wohlgemuth, 1996, 2004, 2010, 2012). Also relevant are recent isotopic analyses of human bone, which provide a powerful and direct means of reconstructing general trends in hunter–gatherer diets (e.g. Bartelink, 2006, 2009; Beasley, 2008; Beasley et al., 2013). Although contact era native Californians widely practiced low-cost fire management strategies to improve productivity (e.g. Anderson, 2005; Blackburn and Anderson, 1993; Lightfoot et al., 2013; Lightfoot and Parrish, 2009:94–122; McCarthy, 1993a), distinguishing between natural and anthropogenic fire regimes in the past is challenging: archaeologically we have not learned anything conclusive about the chronological development of oak tree
management techniques (Lightfoot et al., 2013; Lightfoot and Parrish, 2009:113, 122).

Plant macrofossil studies have provided evidence that acorns were an important food in parts of northern California by the early-middle Holocene. However, we follow Basgall (1987) in associating the mortar and pestle with the time consuming and labor intensive methods of acorn intensification. That is, we interpret early sites that contain abundant acorn nutshell but primarily (or only) handstones and millingslabs, as places where acorn processing (and, thus, use) was probably less intensive than at sites where the presence of mortar and pestle technology indicate time-consuming flour making and leaching (i.e., more intensive use; White et al., 2002; Wohlgemuth, 2004).

Due to the preponderance of cultural historical frameworks and different reporting standards between and within the three regions considered below—the Central Valley, San Francisco Bay area, and Northwestern California—in the following discussion we report in calibrated years before present (cal BP) unless otherwise noted. For site-specific data we direct the reader to regional summaries cited below (e.g., Basgall, 1987; Hildebrandt, 2007; Milliken et al., 2007; Rosenthal et al., 2007; Wohlgemuth, 1996, 2004, 2010, 2012).

Central Valley

Mortar and pestle technology is common at well-dated contexts at some Central Valley sites as early as 7500–5000 cal BP. Key sites (summarized in Whitaker and Rosenthal, 2010:167) include Blossom Mound, CA-SJO-68 (Ragir, 1972; Schultz, 1981), Laguna Oaks, CA-ALA-483 (Bard et al., 1992; Wiberg, 1996), Marsh House, CA-CCO-548 (Wiberg and Clark, 2004), and Skyrocket, CA-CAL-629/630 (Lajeunese and Pryor, 1996).

Intensive acorn processing methods become widespread by about 4000 years ago; mortars and pestles dominate groundstone assemblages after that time at sites throughout the delta, Sacramento River and San Joaquin River Valleys (Basgall, 1987:91; Johnson, 1984:445–447; Rosenthal et al., 2007:156). Evidence supporting this trend is provided by Wohlgemuth (1996, 2004, 2010) in his study of 387 plant macrofossil assemblages from well-dated contexts (5500 BP-historic period) at sites in interior central California. An increase in the abundance of acorns and in the acorn-to-small-seed ratio suggests a pattern of acorn intensification beginning by about 4000 years ago (Wohlgemuth, 2010:70).

In contrast to acorns, evidence of the intensive use of salmon is sparse. Fishing may have become more important between 7500 and 2500 BP as evidenced by new forms technology (e.g., composite and gorge hooks, and spears); large numbers of fish bones occur at some lowland sites during this period and later at residential sites dating to between 1000 BP and the historic period (Rosenthal et al., 2007:155, 159). However, salmonids account for a surprisingly low number of identified fish bone. For example, Broughton (1994a: Table 2) found that salmonids accounted for 3.7% of 9894 identified fish bones from 9 sites in the Sacramento Valley. Gobalet et al.’s (2004) regional survey of fish bone from northern California middens showed a similar trend: In a sample of 41 sites in the Sacramento River drainage, salmonids (including Chinook, steelhead or cutthroat trout) account for only 9.2% of the 20,056 identified fish bone elements (Gobalet et al., 2004: Table 3); Chinook salmon accounted for only 0.04% of the fish bone (n = 9169) identified at 33 sites in the San Joaquin Valley (Gobalet et al., 2004: Table 4).

Bartelink’s (2006) stable isotope study of human bone indicates that terrestrial foods (including acorns) were a focus of the Central Valley diet for most of the mid- to late Holocene, while marine fish (such as salmon) was not. His sample included 56 individuals from six Central Valley sites dating to contexts spanning in age between 4500 and 200 BP. Bartelink found a remarkable degree of stability over this period, with isotopic signatures from bone collagen associated with a mixed diet dominated by C3 terrestrial resources. Locally available resources include terrestrial herbivores and carnivores, C3 plants (acorns and seeds), and freshwater fish. Notably, none of the individuals in the study had an isotopic signature consistent with a diet centered on 13C-enriched aquatic resources such as anadromous fish.

San Francisco Bay area

The earliest mortars in the San Francisco Bay area date to as early as 6000–5000 cal BP (Rosenthal and Meyer, 2004:34–35; Whitaker and Rosenthal, 2010:167). Pestles used with wooden mortars date to this time at Los Vaqueros, CA-CCO-637 (Meyer and Rosenthal, 1998). Early mortars and pestles are also documented at the West Berkeley site, CA-ALA-307 (Wallace and Lathrap, 1975) in deposits dating to between 5000 and 3195 cal BP, and at Stone Valley, CA-CCO-308 (Friedrickson, 1986) in components dating to between 6000 and 3000 cal BP.

Mortar and pestle technology becomes widespread by 3000–2500 BP at Bay Area sites (Basgall, 1987; Friedrickson, 1973; Hildebrandt, 1985; Milliken et al., 2007:115–116). A pattern of resource intensification and widened diet breadth after 2500 BP is supported by studies of faunal remains from the Emeryville Shellmound, CA-ALA-309 (Broughton, 1994b, 1997, 1999), where lower-ranked fauna (e.g. shellfish, small fish, acorns and small seeds) are more frequent after this time.

Macrobotanical data from 195 flotation samples from East Bay archaeological sites support the hypothesis that acorns were a key food source at some sites during the Middle Period (2500–1000 BP), a time when great shell mounds dominated the Bay Area landscape (Wohlgemuth, 2010, 2012). In some areas, settled mound occupation seems to have declined along with the use of acorns in these sites (e.g., the Richmond locality of the north Bay), possibly due a shift in settlement patterns, from near-shore mounds to inland locations where more productive acorn groves were located (Lightfoot and Luby, 2002:276–277). Milliken et al. (2007:107), however, suggest this shift occurred slightly earlier in the North Bay and question the concept of a pan-Bay Area decline in near-shore occupation. In other words, Bay Area settlement patterns differ by location, with data pointing variously to occupational stability, expansion, and decline after 1000 BP. Similarly, the macrobotanical record in the Bay Area is quite variable over time and space. As described by Wohlgemuth (2012), much of this variability can be explained by variation in the abundance and availability of nut crops. Simply put, hunter-gatherers relied heavily on acorns wherever productive plant patches were located within a reasonable foraging radius, even at sites in productive littoral zones. Wohlgemuth notes that this contradicts the ethnoarchaeological pattern described by Keeley (1999), in which hunter-gatherers relied less on plant foods where aquatic faunal resources were abundant.

Salmon fishing was evidently more important in the San Francisco Bay area than in the Central Valley but, again, fish bone assemblages are not dominated by anadromous fish. Salmonid bone (including Chinook, Coho, and steelhead trout) account for 13.6% of the fish bone (n = 10,556) at 49 sites on San Francisco Bay, with the highest frequencies of salmon present at sites on the East Bay and adjacent drainages (Gobalet et al., 2004: Table 2). Angel Island, CA-MRN-44/H, a residential village site excavated after the publication of the Gobalet et al. (2004) survey, does not fit this trend, however. Still, while salmon was clearly an important food at Angel Island (64.4% of the fish bone assemblage; DeGroegey, 2007; Simons and Carpenter, 2009), the site dates to between 1500 and 500 cal BP, well after acorns are intensified throughout the Bay Area.
Isotopic studies of human remains (50 individuals) from four Bay Area sites (Bartelink, 2006, 2009) reflect a significant shift from a diet based on high trophic level marine fauna to one based more heavily on terrestrial foods. Early Period (circa 4500–2500 BP) individuals have dietary signatures indicative of frequent consumption of high-trophic level 13C-enriched marine proteins (e.g., marine and anadromous fish, and sea mammals), while C3 terrestrial resources likely contributed little to the diet. In contrast, Middle Period (2500–1300 BP) individuals seem to have consumed more low-trophic level marine foods (e.g. shellfish) and terrestrial resources, including land mammals and C3 plants. In the Late Period (1300–200 BP) isotopic signatures are similar to those of Middle Period individuals, although marine resources such as shellfish may have been slightly more important. Additional evidence of increased dietary breadth after 2500 BP is supported by an isotopic study of human bone from 68 burials at Ellis Landing (CA-CDO-295), a Middle- to Late Period shell mound located on the eastern shore of the San Francisco Bay (Beasley, 2008; Beasley et al., 2013).

Northwestern California

Despite the expectation that salmon would have been an important resource in northwestern California by 3000 years ago (Hildebrandt and Hayes, 1983, 1993), evidence for the intensive use and storage of the resource is lacking until quite late in the record, and then only in the extreme north-western corner of California. Acorns were probably an important food source in northwestern California as early as 9000–3500 BP as evidenced by the presence of milling gear at many sites in the interior uplands dating to this period (Hildebrandt, 2007; Hildebrandt and Hayes, 1983, 1993). Intensive acorn processing after 3500 BP is indicated by the presence of mortars and pestles at several lowland riverine sites (Hayes, 1985; Hildebrandt and Hayes, 1993:116–117; Tushingham, 2009) including McKee Flat on the Mattole River (CA-HUM-405; Hildebrandt and Lovenholt, 1997) and Redwood Creek (CA-HUM-452; Hayes, 1985) in Humboldt County. Examples from north central California include CA-SHA-192 (Johnson, 1976), CA-SHA-543 (Jenson, 1977) and CA-SHA-177 (Johnson and Skjeldtad, 1974). As summarized by Hildebrandt and Hayes (1993:103–104), these sites provide “evidence for acorn use and some degree of occupational stability” (dark midden soils, diverse assemblages, including mortar bowls and pestles, but no “direct evidence for the exploitation of salmon or the extensive use of storage facilities.”

Ethnographic groups who lived around and north of Humboldt Bay were distinct from other California groups. They shared many traits in common with Pacific Northwest Coast groups (e.g. permanent plank house dwellings, developed woodworking technology, emphasis on salmon in the diet), but other key cultural elements including the focus on acorns, small size of houses and household units, and extreme autonomy of socio-political units made them distinctive among Pacific Northwest Coast groups as well.

Despite the ethnographic primacy of anadromous fish in the region, even here acorns appear to have been intensified before salmon. Evidence supporting this hypothesis comes from the Mattole River and Redwood Creek examples cited above, and, more recently, from Tushingham's (2009) study of sites on the Smith River including Red Elderberry (CA-DNO-26) and CA-DNO-333. Tushingham's work, designed to clarify the timing and trajectory of intensive use and storage of salmon and acorns in the region, shows that mass extraction and storage of salmon did not occur until after the emergence of semi-subterranean plank house villages ca. 1250 BP. Increased residential stability and evidence of intensive plant processing (mortars and pestles), however, was documented at these sites beginning about 2000 years earlier.

Summary of regional trends

The evidence presented here aligns with Basgall's (1987) study, although recent data suggests acorn intensification probably began earlier than 2500 BP in many parts of California. Acorn intensification occurs in the Central Valley at many sites by 7500–5000 BP, and is widespread between 4000 and 3000 BP. In the San Francisco Bay area, acorns are intensified in many places as early as 6000–5000 years ago and the practice is widespread by 3000–2500 BP. Finally, acorns are intensified at some sites in the north Coast Ranges between 7000 and 5000 years ago, and at most sites in northwestern California by about 3500 BP.

Contrary to Schalk's (1977) prediction that salmon would enter the California diet early in time, followed by a gradual increase in population and eventual reliance on salmon, there is relatively little evidence for salmon intensification anywhere in California. In the Central Valley, for example, salmon may not have been a key food until historic times. Salmon were probably more important in the San Francisco Bay area; stable isotope signatures of human bone suggest a dietary focus on marine protein between 4500 and 2500 BP. However, it remains unclear whether this reflects a large amount of salmon in the diet, as opposed to other marine foods (seals, fish) with similar marine signatures. Indeed, that salmon bone is so sparse compared to that of marine mammals and non-anadromous sea fish in San Francisco Bay area sites suggests little use, and certainly not intensification. In northwestern California, intensive salmon use occurs much later than intensive acorn use and begins only with the development of plank house villages in the far north at about 1250 years ago.

The timing is variable, but the northern California sequence everywhere is the same, with acorns intensified before salmon. The question is why?

The front–back loaded model

The front–back loaded model addresses situations where foragers decide between storing resources that vary in ease of procurement, storage time, and processing time (Bettinger, 1999a,b, 2009). As described above, the model requires a distinction between “front-loaded” (costly to procure and store, easy to prepare for consumption, and cheaper overall) and “back-loaded” (easy to procure and store, costly to prepare for consumption, and more costly overall) resources. This distinction is relative, however; the model deals with pairs of resources that stand in specific relationship to one another, one defined as back-loaded when it has a lower storage time relative to the other, which has a higher overall handling time (see Bettinger, 2009:49–50). Furthermore, while many resources can be procured at low cost (e.g. spearing salmon, passive leaching of acorns) for immediate consumption, the model specifically addresses intensification and storage.

Back-loaded resources (e.g. acorns and piñon nuts), are cheap to procure and store, but are costly to process for consumption. Time spent shelling and grinding acorns is poorly documented in the ethnography, although Goldschmidt (1974:52–53) reports that the total processing time for about six pounds of shelled acorns was about 7.5 h for the Hupa (for ethnographic handling time estimates see Basgall, 1987:89–90; Bettinger et al. 1997, 893–894; Jackson, 1994:173–174). In any case, it is clear that leaching makes acorns back-loaded in the extreme, storage time constituting just 6% of its total handling time (McCarthy, 1993b: Table 5-2).

Front-loaded resources (fish, game and most roots), are expensive to procure, process, and store on the “front end” but, once stored, do not take a lot of time to prepare. Mass harvested, stored and dried salmon are extremely front-loaded: costly to catch, dry, and lay away, but thereafter easy to prepare. Salmon are further
front-loaded in that their mass harvest typically involves nets and other complex technologies that take a great deal of time to make and maintain. Weirs also entail high upfront costs, including construction and coordination. Storage of expensive technologies (e.g., nets) and of processed fish would have been very risky for foragers where the potential for loss of labor and capital would have been high without permanent storage facilities.

Quantitative estimates of handling time for salmon can vary significantly by technology, species, etc. (Lindström, 1996; Moss and Cannon, 2011a:5), and ethnographic accounts from California are few, although Gifford (n.d., cited in Kroeber and Barrett, 1960:99) recorded the “old way” of Karuk salmon curing: over the course of 11–13 days, salmon were prepared for storage through complex butchery, an initial drying and curing period of about 3 days, and a final period during which prepared slabs of salmon were dried in houses taking about 8–10 days. This process is not only lengthy; it is complex. One reviewer of this paper, Madonna Moss, drove home the point and with her permission is quoted here:

“In general, people don’t realize how difficult it is to store salmon… If you’ve ever tried to save even cooked fish without refrigeration (even at 60 degrees outside, let alone warmer), you know it will rot in less than a day. If you’ve ever caught salmon that are just a little too spawned-out and tried to dry or smoke them, you also end up with a mess. Fish can be spoiled easily at various stages in the drying and smoking process. (I know this from unhappy experience). It takes skill, technology, experience, and knowledge. Perhaps storing salmon in the warmer California climates was even harder than on the Northwest Coast. I would like to see more exploration (and appreciation) of the skill and logistics involved in preserving fish.”

Indeed, when mass-harvested, stored and dried, it can be reasonably argued that salmon were as front-loaded as acorns were back-loaded.

Risk and caching

When groups were still quite mobile, food storage likely involved “caching,” a strategy involving stowing relatively small amounts of food in a broad range of places throughout a group’s foraging radius (cf. Morgan, 2012). Caching affords mobile foragers substantial flexibility: they are not tethered to particular resource patches and can take full advantage of seasonal resources as they become available. Mobile groups first experimenting with caching would have been particularly sensitive to the risk of wasting time and energy on stores that go unused. Overall handling time may be higher for back-loaded resources than front-loaded resources, but front-loaded resources are clearly riskier because the chance they will go unused is relatively high. Note that “unused stores” does not include normal losses due to insects or pests, spoilage or deterioration. These factors are accounted for in the return rate equation, just as inadvertent losses during processing (e.g., spills during acorn winnowing or pounding) are simply treated as part of the “cost of doing business” and likewise built into the return rate equation. Risk does include the possibility that others will rob caches, which mobile foragers are not positioned to protect. In summary, there is more of a chance that mobile groups will not return to or abandon caches than will groups who are less so; back-loaded resources afford more settlement flexibility in that less is lost if the stores go used.

In the diet breadth model (MacArthur and Pianka, 1966), the highest ranked resources are those with the lowest per-kcal handling times—the total amount of time expended in procuring and processing a resource, including constructing the cache and later preparing the resource for consumption. The risk of not using cached resources must be factored into foraging decisions and the front–back loaded model divides this handling time into two components:

a. Storage time (the time required to acquire and process a resource for storage)

b. Culinary time (the time needed to prepare the stored resource for final consumption)

The purpose of this division is to isolate the key point that resource caching involves acquisition and storage, but not processing unless the cache is actually used. Thus foragers may select resources with low storage times (i.e., back-loaded resources) for caching over those with high storage times (i.e., front-loaded resources), even though the low storage time, back-loaded resource is more costly overall (Fig. 4).

The solution

The front–back loaded model explains why salmon intensification was delayed by human groups in prehistoric California: So long as groups remained mobile, the risk that caches would be abandoned remained too high to warrant heavy investment in salmon; anadromous fish intensification involved too many costs and was simply too risky until very late in time. Foragers intensified acorns instead because they were back-loaded and less risky. Inter-annual variation in these resources may have also played a role in the risk associated with their intensification, although much remains to be learned about these dynamics.1

Despite longer salmon runs and fewer scheduling constraints, salmon intensification in California does not follow the pattern predicted by Schalk (1977). There is no evidence for dependence on salmon in the Central Valley, and very little in the San Francisco Bay area. It is only in northwestern California around and north of Humboldt Bay where there is good evidence that salmon was a staple, but not until after 1250 years ago. Even there the trajectory of development was akin to the pattern Schalk predicted for the north, not for California: salmon appear late (not early) and suddenly (not gradually) in the archaeological record with the rapid emergence of plank house villages. Plank houses are a key development, because they function as large, permanent food storage facilities (cf. Ames, 1986; Ames et al., 1992, 2008; Tushingham, 2009). Salmon intensification required a similar qualitative jump that was taken in the central and northern Pacific Northwest Coast by 3000–3000 BP, but because foragers chose to intensify a back-loaded re-

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1 While salmon in California are assumed to have been much more abundant in the past (Yoshitama et al., 1998; 2000; 2001), we know little about variability of the fishery over the long term historic record, and while research in the northern Pacific Rim suggests salmon were subject to centennial scale fluctuations (Rogers et al., 2013), similar studies in southern areas are non-existent and it remains unclear whether variation in the resource would have been enough to effect human populations. In contrast, we know more about variation in acorn abundance in many parts of California through pollen studies taken from offshore and lake cores which have offered sophisticated reconstructions of past climatic and vegetation histories. During the mid-Holocene in northwestern California, for example, oak forests were generally more expansive, being found at higher elevations than today (West, 1993; West et al., 2007). Although inter-annual acorn production is highly variable, annual variation in masting patterns is correlated within species, but independent between species (Koenig et al., 1991, 1994). Thus while acorns of one species may not produce a crop in 1 year, they are likely to be available among other oak species. Furthermore, because of these asynchronous masting patterns, in areas where there are more species of oak, there is less variation in acorn yield size and risk of crop failure (Bock and Bock, 1974; Koenig and Haydock, 1999). Indeed, post-contact hunter-gatherers of California used various kinds of oak, gathering acorns from less favored species when preferred ones were unavailable (Baumhoff 1963:Table 2; Baumhoff, 1978:16), a practice that buffered the risk of relying on a single species.
1976, 1978; Kroeber, 1925, 1962), and we think that the emphasis were small and highly autonomous political units (e.g. Bean, implications. Despite high populations, California social groups become less risky. It seems likely that in this way, acorn intensifi-
sition. In contrast, acorns could be intensified more gradually. Acorns can be cached almost casually, small stores of food put
sition. As population densities increased and plant re-
source use intensified, we suggest economic demand for women’s labor increased. For those providing the bulk of the labor (women), the efficiency of acorns likely remained attractive since reliance on the resource did not require spending time working for people out-
side of one’s immediate family. Moreover, “top down” labor de-
mands were virtually non-existent. In sum, the procurement system that developed in California was small-scale, but highly efficient, particularly for those performing most of the labor.

Conclusions

Despite growing recognition of the importance of food storage among hunter–gatherer societies (cf. Ingold, 1983; Kuij t, 2009; Morgan, 2012; Sakaguchi, 2009), “archaeologists have only mini-

mally assessed in quantitative ways the causes and effects of food storage variability and how these might play out in evolutionary-ecological context” (Morgan, 2012:715). Our study provides in-
sight into the diversity of hunter–gatherer food storage strategies and associated behaviors. We employ the front–back loaded mod-
el, which addresses the risks and benefits associated with stored resources, and provides a means of understanding how foragers made decisions about which resources to store, particularly when settlement flexibility and mobility remained important strategies.

The front–back loaded model could be applied to other regions of the world where variables affecting the intensification of mass-
harvested plants and fish in hunter–gatherer economies is debated, as among the Jomon in northern Japan (see Habu, 2004:60 for a summary of the “salmon hypothesis” and “plant cultivation hypothesis” debate) and during the Archaic period of northeastern North America (see Carlson, 1988; and also Sassaman, 2010:159–162 on the expected evidence of salmon intensification and possible misuse of Northwest Coast analogs in the eastern Archaic). However, it is important to point out that the model may also be applied to a range of situations where foragers decide between any two resources that vary in ease of procurement, storage, and processing time, not just salmon and acorns.

In the current case, the front–back loaded model explains why, despite the enormous potential and apparent caloric superiority of higher ranked anadromous fish, it was not until very late in prehis-
tory that evidence for the mass extraction and storage of salmonids appears in the archaeological record of northern California. Lower ranked acorns became an important staple much earlier because caching them was less risky. The downstream effect of this was to center the economy on plants, which favored the development of relatively small social units—supported mainly by women’s la-
bor—and privatization of the back-loaded plants on which it centered.

The ethnographers were not guilty of “salmonopia”: they correctly captured the importance of salmon to California historic groups. The idea that what they observed ethnographically applied uniformly to the past, however, was wrong. The situation thus is different than in the Northwest Coast where salmon intensification is early but is argued to become a contact era specialization,
possibly the result of dramatic population declines in the historic period (Butler, 2000; Campbell, 1989). In California, by contrast, salmon intensification is late and becomes even more intensive in the wake of Euro-American contact. As farmers, miners, lumberers, and ranchers encroached on their lands, native peoples were increasingly excluded from access to rangelands (Burcham, 1981). With free access to traditional terrestrial resources so constrained, there was little choice but to intensify salmon.

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