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Authors

Eerkens, Jelmer W
Schwitalla, Al W
Spero, Howard J
et al.

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STAPLE, FEASTING, OR FALLBACK FOOD? MUSSEL HARVESTING AMONG HUNTER-GATHERERS IN INTERIOR CENTRAL CALIFORNIA

Jelmer W. Eerkens^{1*}, Al W. Schwitalla², Howard J. Spero³, and Ryan Nesbit¹

*Shells are a visible component of archaeological middens in Central California. While coastal and bay shore sites are often dominated by shells, these food items were sometimes hauled many kilometers from their collection points and are found in appreciable numbers in inland sites as well. Using oxygen and carbon stable isotope data from 44 *Mytilus* sp. (mussel) shells, we reconstruct shellfish seasonality harvesting at one inland site dating to the Middle Period (ca. 2500–1000 cal yrs BP), CA-SOL-364. Data show that shells were collected from nearby Suisun Marsh and were harvested almost exclusively during winter, a pattern that contrasts with coastal and bay shore sites. Such a harvesting signature is unlike that expected for a food staple or a feasting resource. We suggest mussels were harvested as a fallback food, as a source of protein or micronutrient to complement carbohydrate-rich foods that were stored and consumed during winter, or perhaps were only exploited as opportunity costs relaxed during winter, making sessile mussels an attractive subsistence pursuit.*

Keywords: shellfishing, seasonality estimation, stable isotope analysis, fallback food, California prehistory

Introduction

Despite low caloric return rates, shellfish were an important part of hunter-gatherer diets in pre-contact Central California. Given the high productivity of shellfish in coastal and estuarine environments, this result is not surprising. Indeed, San Francisco Bay is famous in archaeological circles for its large shellmounds, some over 12 m high, that dominated the pre-contact landscape (Bickel 1981; Leventhal 1993; Lightfoot et al. 2011; Luby 2004; Luby et al. 2006; Nelson 1909; Uhle 1906; Wallace and Lathrap 1975). Few of these mounds remain today (though see Schneider 2009), but in a survey around San Francisco Bay in the early 1900s, Nelson (1909) recorded over 400 shellmounds and “shell heaps” along the bay shore. As Gifford (1916) showed, shell is a dominant constituent within bay shore shellmound sites, comprising between 50% and 65%, by weight, of all material. Archaeological analysis of shellfish from bay shore and coastal sites has been an important line of inquiry into a range of pre-contact human behaviors, including diet (Culleton et al. 2009; Jones et al. 2008; Kennedy 2004; Lightfoot and Luby 2002; Schweikhardt et al. 2011; Whitaker 2008), and paleoenvironmental conditions (Ingram 1998). In this respect, shellfish are an

¹Department of Anthropology, University of California at Davis, One Shields Ave, Davis, CA 95616-8522.

²Millennia Molding and Casting.

³Department of Earth and Planetary Sciences, University of California at Davis.

*Corresponding author (jweerkens@ucdavis.edu)

important complement to other paleodietary analyses (e.g., Bartelink 2009; Broughton 1994a, 1997; Broughton et al. 2007; Simons 1992).

More surprising is the presence of significant amounts of bay and coastal shell at inland sites and earthen mounds in Central California. Although found in lower quantities, shell is nevertheless quite visible in many sites. For example, shellfish comprises between 0.06% and 1.1% in a range of sediment samples, by weight, in the site discussed below (CA-SOL-364). Despite their visibility, analysis of shell remains in these inland sites has not been an important part of archaeological inquiry. Instead, analyses of faunal and paleobotanical remains have received the majority of analytical attention (Broughton 1994b; Gobalet 1992; Wohlgemuth 1996) and shells are typically mentioned in passing only.

As a result, we know little about the role of shellfish in the diets and foraging efforts of inland populations. For example, it is unclear if shellfish was a major staple of the diet and was collected and transported inland throughout the year or if shellfish was a fallback food only consumed in times of need. Fallback foods are sometimes referred to as “starvation foods,” though we interpret fallback as a more general term that includes a range of items eaten when preferred foods were unavailable or in short supply, whereas starvation foods are typically a last resort to avoid starvation. Alternatively, it is possible that shellfish was a novelty item in inland settings, only eaten as part of feasting events (Hildebrandt et al. 2009) or was an important source of protein during particular seasons when protein was otherwise in short supply. It is also possible that shellfish provided important micronutrients, such as sodium or iodine that were otherwise difficult to obtain in inland locations. Although these are important questions, to date, they have not played an important role in structuring archaeological research in Central California.

This study seeks to answer two basic questions regarding shellfish use at one inland location, CA-SOL-364, in Central California (see Figure 1). First, we ask where the shellfish at this site were originally collected. Two locations are likely candidates and are nearly equidistant from the site: Suisun Marsh, located some 10–15 km to the south, and San Pablo Bay, approximately 15–20 km to the southeast. However, a coastal location 75 km to the east is also possible. Because stable oxygen isotope signatures vary with salinity levels, and these three locations differ greatly in their average and maximum salinities, stable isotope data should be able to differentiate between these locations. Second, we wish to determine the season in which the shells at CA-SOL-364 were collected. Previous isotopic studies at other bay shore sites suggest that shellfish harvesting of clams and mussels tended to occur in two seasons, early winter and early summer, though some shellfish gathering occurred during all seasons (Culleton et al. 2009; Eerkens et al. 2013a, 2014). Together, these two lines of evidence reveal important information about the role of shellfish in local diets at CA-SOL-364, and, by extension, landscape use and seasonal-specific foraging patterns, and are used to formulate hypotheses for future research on shellfish use in Central California.

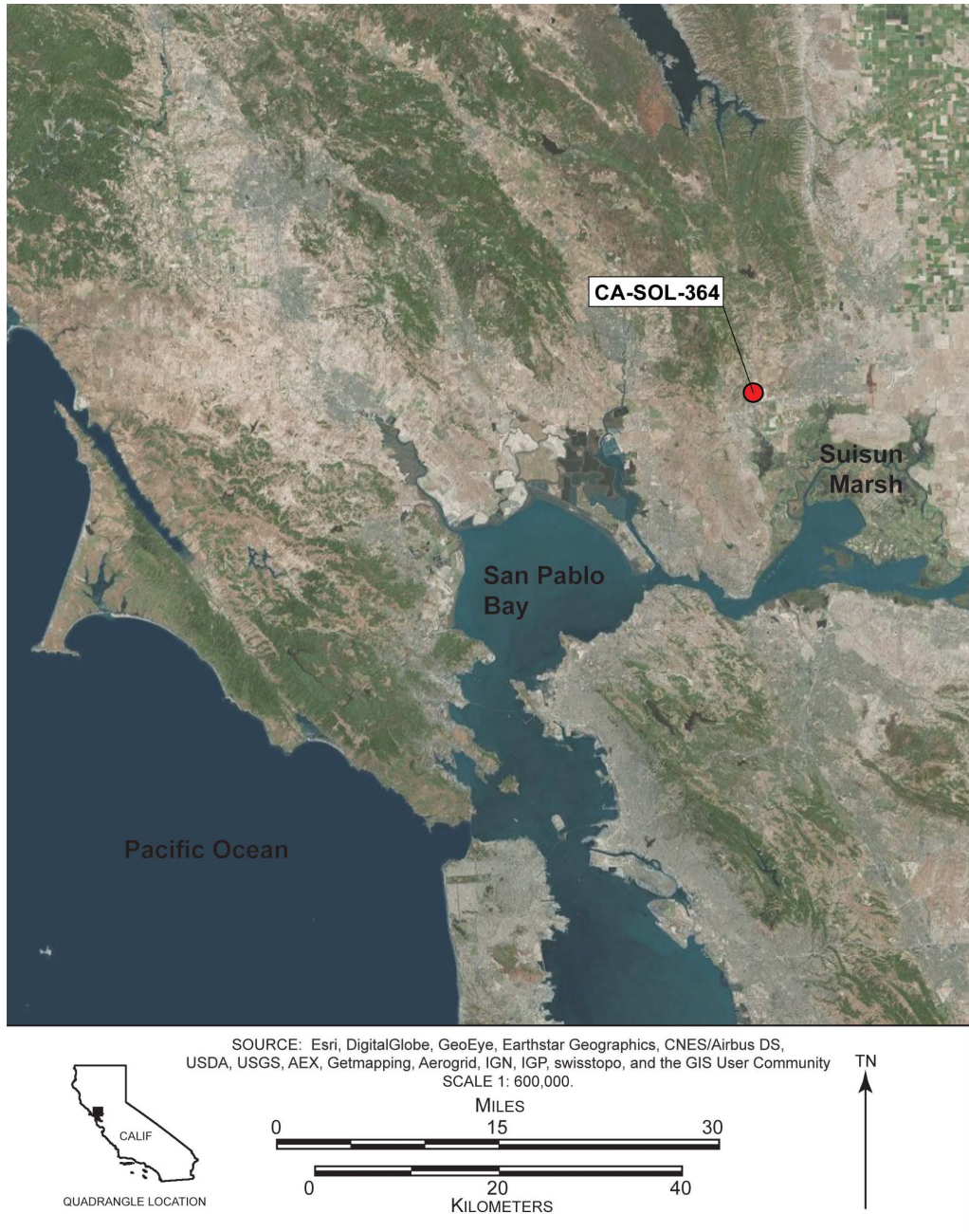


Figure 1. Map of Central California showing San Pablo Bay and Suisun Marsh relative to CA-SOL-364.

CA-SOL-364

CA-SOL-364 is located in present-day Fairfield, California (Figure 1). The site was excavated by Solano Archaeological Services between 2007 and 2010 as part of a cultural resource management project to mitigate impacts from construction

Table 1. Radiocarbon dates from CA-SOL-364.

Context	Material	Bead type	$\delta^{13}\text{C}$	^{14}C Age BP	Median cal yrs BP	Lab #
Burial 148	Shell bead	F2b	0.90	2740 \pm 25	2097	OS- 79479
Burial 132	Shell bead	G4	0.70	2690 \pm 30	2058	OS- 79469
Burial 179	Shell bead	G3a	0.99	2660 \pm 30	2021	OS- 79470
Burial 62/65	Shell bead	G2a	0.40	2660 \pm 25	2021	OS- 79480
Burial 198	Shell bead	C2	0.74	2590 \pm 25	1938	OS- 79478
Burial 87	Shell bead	C3	1.40	2440 \pm 40	1760	OS- 79472
Burial 288	Shell bead	G3b	1.27	2380 \pm 30	1691	OS- 79471
Burial 264	Shell bead	F3b1	1.18	2220 \pm 25	1500	OS- 79483
Burial 264	Shell bead	F3b2	1.09	2060 \pm 25	1338	OS- 79482
Burial 264	Shell bead	F3a	1.15	2040 \pm 30	1320	OS- 79481

Note: Dates calibrated using a marine reservoir (ΔR) of 260 ± 35 (Groza et al. 2011).

of a gas station (Coleman et. al. 2014). Fieldwork revealed a dense midden containing a range of domestic features, artifact caches, and tool production debris, with nearly 50,000 artifacts (including ground and flaked stone tools, shell beads and pendants, charmstones, and bone tools), 335 human interments, and a rich assemblage of faunal and paleobotanical remains. A range of seasonality indicators (e.g., charred seeds, waterfowl, anadromous fish) suggest year-round occupation of the site, a finding that is consistent with the presence of domestic features (hearths, pits, and an extensive cemetery population). A series of radiocarbon dates on burial-associated *Olivella biplicata* beads indicate the site was occupied mainly between 2100 and 1300 cal yrs BP (Table 1). Likewise, 23 obsidian hydration measurements on artifacts taken from burial contexts yield an average estimated age of 1710 cal yrs BP, and 16 obsidian samples from feature contexts yield an average estimated age of 1450 cal yrs BP. Together with temporally diagnostic artifacts, the site seems to date primarily to the Middle Period, ca. 2300–1200 cal yrs BP (Coleman et al. 2014).

Subsistence remains include over 8000 bones and bone fragments representing a wide range of animal species, over half displaying some degree of burning or cutting. Mammalian bones dominate the assemblage, accounting for over 60% by count. Of these, large game, mostly deer (*Odocoileus* sp.) and elk (*Cervus* sp.), comprise the majority of bones identified to the genus or species level. Smaller-bodied taxa such as leporids, canids, and reptiles are also present, but represented by smaller numbers of bones (e.g., pond turtles [*Actinemys* sp.] = 0.2%). Fish are also common (6% of the assemblage by count), and include sturgeon (*Acipenser* sp.) and salmon (*Oncorhynchus* sp.), species that would have been available in nearby brackish-water estuaries. Avifauna comprise just over 2% of the assemblage and are dominated by waterfowl, including ducks (*Anas* sp.) and geese (*Chen* sp.). Together, the animal remains indicate that local foragers had access to both interior lands and marsh locations to access prey.

Paleobotanical remains recovered from flotation analyses are dominated by nutshells, berry pits, and lesser numbers of small seeds. Acorn (*Quercus* sp.) and manzanita (*Arctostaphylos* sp.) are most common, though smaller numbers of charred seeds from other species, especially goosefoot (*Chenopodium* sp.) and

Table 2. Distribution of shellfish species at CA-SOL-364, by total count (NISP), weight, and hinge fragments (MNI) in a sample of 20 carefully controlled excavation contexts.

Species	Common name	NISP (fragments)		Weight		MNI (hinges)	
		#	%	grams	%	#	%
<i>Mytilus</i> sp.	Mussel	1672	97.4	560	98.2	545	97.5
<i>Haliotis</i> sp.	Abalone	33	1.9	7.8	1.3	7	1.3
<i>Ostrea lurida</i>	Oyster	4	0.2	1.7	0.3	2	0.4
Other species		7	0.4	0.9	0.2	5	0.9

Note: the thinness of the mussel shells and overall shape suggests *Mytilus trossulus* (bay mussel).

hairgrass (*Deschampsia* sp.), were also recovered. Thus, in contrast to the animal remains, plant remains are dominated by terrestrial species and do not include significant numbers of marshland species.

In addition to the items mentioned above, a variety of shellfish debris was also recovered from the site (Table 2). Careful tabulation from a small number of controlled contexts (n = 20 control unit and feature contexts) reveals that the shellfish assemblage is dominated by mussels (*Mytilus* sp.). As measured by either the number of identified specimens (NISP; total fragments), the minimum number of individuals (MNI; hinge fragments), or the total weight, mussel accounts for over 97% of the shell assemblage. Small numbers of abalone (*Haliotis* sp.), oyster (*Ostrea lurida*), and assorted clams were also present, though some of these shell fragments, especially abalone, may have been refuse from bead or pendant manufacturing rather than dietary refuse. Mussel would have been available only in nearby brackish water marshlands and along the Pacific Coast. Thus, like some of the fish, waterfowl, and possibly pond turtles, mussels must have been collected in these environments and hauled back to CA-SOL-364.

An Isotopic Model

Oxygen isotope ratios, $^{18}\text{O}/^{16}\text{O}$, are expressed in standard delta (δ) notation, where $\delta^{18}\text{O} = (R_{\text{sample}}/R_{\text{standard}} - 1) \times 1000$, and R_{sample} and R_{standard} are the oxygen isotopic ratios ($^{18}\text{O}/^{16}\text{O}$) of the sample and Vienna Pee Dee Belemnite (VPDB) international standard, respectively, in ‰ or “per mil” units (parts per thousand ‰). $\delta^{18}\text{O}$ of biogenic carbonates, such as calcite and aragonite, deposited by shellfish organisms depends strongly on water temperature and which varies directly with salinity (Bemis et al. 2002; Kim and O’Neil 1997). Along the open Pacific Coast of California, salinity is relatively constant and it is water temperature that mainly affects changes in $\delta^{18}\text{O}$ in shell carbonate. Because water temperatures fluctuate seasonally in a predictable manner (warm summer-fall, cold winter-spring) it is possible to estimate the season in which an organism deposited the final layer of carbonate prior to death (harvest, in the case of human-caused death).

In estuaries that receive significant freshwater input, such as San Francisco Bay, changes in salinity have a stronger influence on shell $\delta^{18}\text{O}$ than temperature (see Culleton et al. 2009; Eerkens et al. 2013a, 2014). If such runoff has a predictable

seasonal pattern, season of harvest of individual shells can, again, be estimated. Further, because lower salinity causes shell $\delta^{18}\text{O}$ values to decrease, and different estuarine systems vary in terms of their minimum and maximum salinities, different ranges in shell $\delta^{18}\text{O}$ can be distinctive within particular estuaries.

Kim and O'Neil (1997; see also Bemis et al. 2002) provide a relationship that relates temperature, the $\delta^{18}\text{O}$ of water ($\delta^{18}\text{O}_w$), and the $\delta^{18}\text{O}$ in calcite ($\delta^{18}\text{O}_{\text{calcite}}$). This is given in equation 1: $T = 16.1 - 4.64 (\delta^{18}\text{O}_{\text{calcite}} - [\delta^{18}\text{O}_w - 0.27]) + 0.09 (\delta^{18}\text{O}_{\text{calcite}} - [\delta^{18}\text{O}_w - 0.27])^2$, where T is the temperature measured in degrees C. An offset correction of -0.27‰ is included in equation 1 to compensate for the difference between water on the Vienna Standard Mean Ocean Water (VSMOW) scale and calcite on the (VPDB) scale (Bemis et al. 2002). If we can measure $\delta^{18}\text{O}_w$ and T, we can rearrange the terms in equation 1 to predict $\delta^{18}\text{O}_{\text{calcite}}$ in *Mytilus* shells.

Unfortunately, $\delta^{18}\text{O}_w$ is not often recorded in modern water studies, particularly at multiple points throughout the year and across multiple years. However, Ingram et al. (1996a, 1996b) have shown that salinity and $\delta^{18}\text{O}_w$ are related in San Francisco Bay by the relationship in equation 2: $\delta^{18}\text{O}_w = 0.34S - 11.6$, where S is water salinity measured in practical salinity units (PSU) and $\delta^{18}\text{O}_w$ is in ‰ units relative to the VSMOW standard. Because salinity is typically measured with temperature in modern studies, we can use salinity and equation 2 as measures of $\delta^{18}\text{O}_w$ and substitute them back into equation 1. We use modern surface water temperature and salinity data collected and published online (USGS 2012) for Suisun Marsh (Stations 5, 6, and 7) and San Pablo Bay (Station 17). We also use water data for Bodega Bay to estimate $\delta^{18}\text{O}$ fluctuations throughout the year along the Pacific Coast (data from SCCOOS 2010).

Figure 2 plots a polynomial spline, along with one standard deviation, of predicted $\delta^{18}\text{O}_{\text{calcite}}$ throughout an annual cycle for Suisun Marsh, San Pablo Bay, and Bodega Bay. In Suisun Marsh and San Pablo Bay, annual variation in predicted $\delta^{18}\text{O}_{\text{calcite}}$ is driven mainly by water salinity changes, causing predicted $\delta^{18}\text{O}_{\text{calcite}}$ to be highest in fall and early winter (when salinity is highest), and lowest in spring and early summer (when salinity is lowest). There is a slight offset in the timing of the annual maxima and minima between these latter two locations, with annual maxima and minima occurring slightly earlier (ca. 1–2 months) in San Pablo Bay. This is a result of a waning in the strength of freshwater runoff from the Sacramento River in summer, allowing salty waters from the Pacific Ocean to push into San Pablo Bay first (typically beginning in early summer), and eventually reaching Suisun Marsh later in the year. As salinity is fairly constant in the Pacific Ocean, predicted $\delta^{18}\text{O}_{\text{calcite}}$ in Bodega Bay is mainly driven by changes in water temperature. This causes predicted $\delta^{18}\text{O}_{\text{calcite}}$ to follow a different seasonal curve, with annual maxima in the winter and minima in the summer.

Most striking from Figure 2 is the difference in the absolute values of predicted $\delta^{18}\text{O}_{\text{calcite}}$ in these three locations, again driven mainly by differences in salinity. In particular, predicted $\delta^{18}\text{O}_{\text{calcite}}$ in Bodega Bay is typically around 0.0‰ , varying between -0.8‰ and 0.5‰ (one standard deviation). In San Pablo Bay and Suisun Marsh, predicted $\delta^{18}\text{O}_{\text{calcite}}$ is nearly always negative, generally ranging between -7.0‰ and -3.0‰ in the former, and between -12.5‰ and -7.0‰ in the latter (one standard deviation). This results because Suisun Marsh

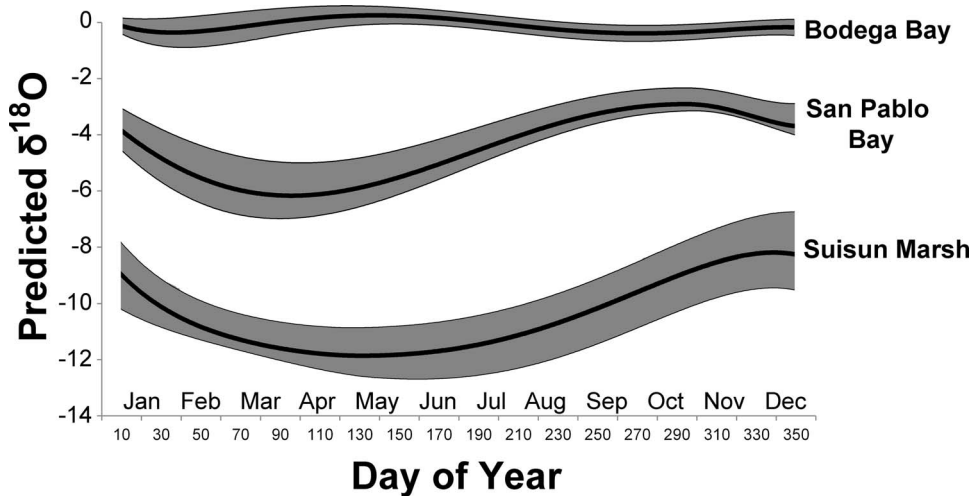


Figure 2. Predicted $\delta^{18}\text{O}$ in calcite using modern temperature and salinity in Suisun Marsh, San Pablo Bay, and Bodega Bay, with estimated one standard deviation around polynomial regression.

rarely exceeds 20 PSU, even in fall, and is close to 0 PSU in spring and early summer at maximum freshwater runoff. By contrast, San Pablo Bay reaches fully saline conditions (32 PSU) in fall, and rarely is below 10 PSU, even in springtime. Significant for the research below, these differences in the maxima and minima allow us to estimate the location of harvest for shells found in interior locations.

Once a location of harvest has been determined, the predicted $\delta^{18}\text{O}_{\text{calcite}}$ models in Figure 2 can be used to estimate season of harvest. To do this, shell $\delta^{18}\text{O}$ values from four serial samples (see below) were compared to the appropriate curve to identify the location of the seasonal trend that best matches the model, with a final estimate of the month of harvest derived from the final collection value. Given year-to-year variation in the timing of annual maxima and minima, we estimate that each month-of-harvest estimate has an error of ± 1.5 months (Eerkens et al. 2014). As well, empirical data from other San Francisco Bay area sites (Eerkens et al. 2013a, 2014) show that $\delta^{18}\text{O}$ values in ancient shells are typically enriched relative to predicted $\delta^{18}\text{O}$ from modern water conditions. This is partly due to differences in the spatial location of water buoys, which are in the center of marshes and bays, versus where shells grow, on the margins of marshes and bays. Historic changes in water flow due to upstream diversions behind dams and for agriculture may also contribute to this difference. As a result, we add 2.0‰ to our San Pablo Bay and Suisun Marsh curves in Figure 2, when plotting archaeological shells.

Methods

Forty-four mussel (*Mytilus* sp.) shells or shell fragments with an intact ventral growing margin were selected from a range of contexts at CA-SOL-364.

Twenty-four of these shells were recovered from fill associated with burials, while the remaining 20 were recovered from general midden fill within formal excavation units or associated with domestic features (hearths and ash dumps). The shells and shell fragments were first cleaned by gently scrubbing with a toothbrush followed by sonicating in deionized water. After drying, four serial samples, labeled A through D, were removed from each shell. Sample A came from the intact growing edge, with samples B, C, and D removed in parallel grooves (approximately 0.3 mm deep) at 1 mm intervals from the edge. Thus, sample B represents growth at 1 mm from the edge, sample C at 2 mm from the edge, and sample D at 3 mm from the edge. Shell was removed using a 0.5 mm diameter drill bit attached to a hand-held drill. Powdered carbonate samples ranged from 85 to 120 μg in weight.

Carbonate samples for isotopic analysis were processed in the Stable Isotope Laboratory in the Department of Earth and Planetary Sciences at the University of California at Davis (UC Davis) on a Micromass Optima isotope ratio mass spectrometer (IRMS). Prior to isotopic analysis, powdered calcite samples were gently heated at 75 °C *in vacuo* for 30 minutes to remove adsorbed water and subsequently reacted in 105% orthophosphoric acid at 90 °C using an automated common acid bath system. The resulting CO_2 was then purified through a series of cryotrap and introduced into the IRMS through a dual inlet system. Both oxygen and carbon isotopes are measured and reported, though only oxygen is used in the interpretation of shell season of harvest. $^{13}\text{C}/^{12}\text{C}$ of the sample, or $\delta^{13}\text{C}$, is also systematically measured and reported, though it does not play an important role in seasonality estimation. External precision for $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ values is ± 0.07 and ± 0.04 (1σ), respectively, based on multiple ($N = 177$) analyses of the calcite standards NBS-19 or UCD-SM92.

Results

Isotopic results for the 44 shells are given in Table 3. Data show that the CA-SOL-364 shells are depleted in ^{18}O (i.e., negative $\delta^{18}\text{O}$ values), suggesting growth in an environment with either high water temperatures or low salinity levels. The shells also show high intra-shell variation in $\delta^{18}\text{O}$, with an average of 2.0‰ difference between the maximum and minimum values (the greatest difference is 5.6‰). To achieve such high intra-shell variation, water temperatures would have to fluctuate, on average, nearly 10 °C on an annual basis (and over 20 °C to produce the maximum intra-shell difference). Such water conditions are unknown along the Pacific Coast, suggesting that the shells were collected in an estuarine environment with fluctuating salinity instead.

Data further suggest that terminal growth bands display significantly less variation in isotopic composition than interior samples. Figure 3 plots $\delta^{18}\text{O}$ vs. $\delta^{13}\text{C}$ values for sample A (terminal growth) vs. samples C and D (earlier growth). Because we cannot control for the rate of growth in shells, which varies with water conditions and age of the organism, samples C and D represent an uncontrolled amount of time prior to shell death, that is, a nearly random point in

Table 3. $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ on serial samples from 44 shells from CA-SOL-364.

Cat	Context	Len (cm)	Wid (cm)	$\delta^{18}\text{O}$ (‰)				$\delta^{13}\text{C}$ (‰)				Month of death
				A	B	C	D	A	B	C	D	
125A	Burial 160	46.3	24.4	-3.8	-4.3	-3.6	-3.8	-3.1	-3.1	-2.2	-2.3	Jan
125B	Burial 160			-3.8	-4.6	-7.1	-7.7	-2.6	-2.3	-3.4	-4.2	Dec
125C	Burial 160	33.8	17.9	-4.6	-4.2	-4.7	-4.9	-2.6	-1.8	-2.1	-2.2	Feb
125D	Burial 160	38.0	16.5	-3.8	-4.8	-4.6	-4.8	-2.7	-4.2	-2.3	-2.4	Dec
125E	Burial 160			-3.7	-4.4	-6.2	-9.3	-2.4	-2.0	-2.9	-4.5	Dec
125G	Burial 160			-3.1	-4.7	-3.4	-4.1	-2.4	-2.7	-3.6	-2.8	Dec
556A	Burial 14			-3.3	-3.9	-4.5	-7.0	-3.3	-3.2	-3.2	-4.2	Dec
556B	Burial 14			-3.6	-3.6	-4.0		-2.9	-1.9	-1.7		Dec
556C	Burial 14			-3.8	-3.7	-4.6	-4.8	-2.4	-1.3	-1.7	-2.1	Jan
567A	Burial 28			-4.5	-4.8	-4.8	-5.1	-3.3	-2.5	-1.9	-2.8	Nov
653A	Burial 38	33.8	18.5	-3.9	-3.6	-3.4	-3.9	-3.2	-2.1	-1.4	-1.7	Jan
682A	Burial 27			-3.7	-4.1	-3.8	-3.4	-3.4	-3.2	-2.9	-2.3	Jan
728A	Burial 18			-5.2	-5.8	-4.8	-5.4	-6.0	-5.4	-2.9	-3.6	Oct
743A	Burial 21/34/36			-3.7	-3.3	-3.0	-3.4	-4.1	-3.0	-2.4	-2.6	Jan
743B	Burial 21/34/36			-2.6	-3.7	-7.5		-2.7	-2.8	-3.0		Dec
1016A	Burial 48	19.1	11	-2.6	-2.6	-3.2	-3.5	-2.0	-1.2	-1.3	-1.5	Dec
1016B	Burial 48		23.4	-3.1	-3.6	-5.0	-5.6	-2.4	-1.9	-2.2	-3.1	Dec
1016C	Burial 48	44.4	21.91	-3.2	-3.1	-3.7	-4.1	-2.1	-1.1	-1.4	-1.6	Jan
1016D	Burial 48			-3.5	-6.3	-5.3	-5.6	-1.6	-2.8	-3.0	-3.1	Dec
1717	Unit 1	39.3	16.6	-3.9	-6.1	-5.0	-3.1	-2.6	-2.6	-2.8	-1.9	Dec
1726A	Unit 2	35.8	16.6	-6.5	-5.2	-3.8	-1.9	-5.0	-3.1	-2.4	-1.6	Apr
1726B	Unit 2	43.2	21.5	-2.8	-3.5	-4.0	-4.4	-2.5	-2.1	-2.2	-2.5	Dec
1777A	Unit 4	18.3	10	-4.3	-2.7	-2.2	-3.5	-5.1	-3.1	-2.5	-2.8	Jan
1777B	Unit 4			-3.3	-3.7	-4.7	-5.0	-4.1	-2.7	-2.9	-2.9	Dec
1777C	Unit 4			-6.2	-5.8	-5.7	-5.6	-6.7	-3.1	-3.0	-3.0	Mar
1777D	Unit 4			-4.3	-3.8	-4.5	-4.6	-3.8	-2.0	-2.2	-2.3	Jan
1793A	Unit 4			-3.5	-5.3	-8.0	-8.3	-2.4	-2.2	-3.6	-4.1	Dec
1793B	Unit 4	36.7	17.7	-4.6	-5.3	-5.3	-5.8	-3.2	-3.8	-2.6	-2.6	Nov
2063A	Burial 158		18.8	-5.2	-4.1	-4.4	-4.2	-5.5	-2.5	-2.9	-2.5	Feb
2063B	Burial 158	22.6		-4.7	-4.1	-4.5	-4.9	-4.1	-3.2	-2.8	-3.1	Feb
2063C	Burial 158		20.6	-4.3	-8.8	-8.3	-6.3	-3.0	-3.8	-4.1	-6.4	Nov
2063D	Burial 158			-3.8	-2.7	-5.6	-5.5	-3.4	-0.9	-2.1	-2.4	Jan
2063E	Burial 158			-2.7	-4.4	-6.3	-8.2	-3.0	-2.5	-3.7	-4.2	Dec
2063F	Burial 158			-6.1	-8.6	-9.1	-7.6	-7.3	-3.9	-4.4	-4.5	Sep
2907C	Unit-Salvage			-3.6	-4.3	-4.3	-5.5	-3.5	-2.3	-1.8	-2.7	Dec
2907E	Unit-Salvage			-4.5	-4.0	-4.2	-4.7	-5.2	-1.8	-1.7	-2.1	Feb
2907F	Unit-Salvage			-2.2	-2.8	-3.1	-3.3	-1.2	-1.0	-1.3	-1.8	Dec
2907G	Unit-Salvage			-3.9	-4.2	-3.8	-4.7	-3.2	-2.1	-2.0	-2.4	Jan
3273A	Monitor Salvage			-4.1	-4.1	-4.5	-4.8	-3.7	-2.4	-2.1	-2.3	Nov
3273B	Monitor Salvage			-5.3	-8.6	-8.5	-6.6	-2.2	-3.6	-4.1	-3.3	Oct
3273C	Monitor Salvage			-3.5	-5.4	-4.6	-3.3	-2.5	-2.8	-3.0	-2.4	Dec
3273D	Monitor Salvage			-3.8	-3.8	-4.1	-4.4	-3.3	-2.1	-2.1	-2.1	Dec
6368A	Burial 198	38.5	17.6	-3.9	-3.8	-3.9		-3.9	-2.1	-1.9		Jan
6368B	Burial 198	40.5	18.9	-4.1	-4.1		-6.9	-3.2	-2.1		-3.8	Jan

the year before harvest. As seen in Figure 3, terminal growth tends to cluster on the higher end of the range observed in $\delta^{18}\text{O}$, generally varying between -5.5‰ and -2.5‰ (barring a few outliers) and a standard deviation of 1.0‰ , while interior values generally vary between -9.0‰ and -3.5‰ , with a standard

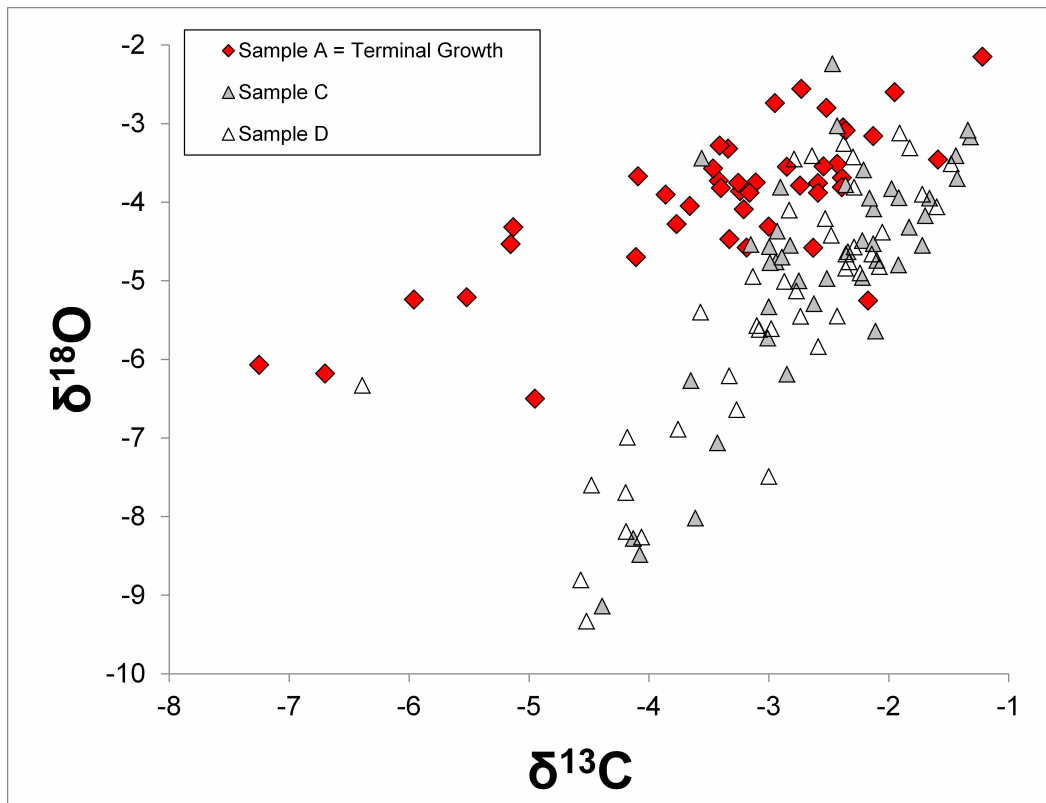


Figure 3. $\delta^{18}\text{O}$ vs. $\delta^{13}\text{C}$ for terminal growth vs. interior growth for 44 shells from CA-SOL-364.

deviation of 1.6‰. This suggests a more limited range of water conditions during harvest than at other times of the year. In other words, shell harvesting was targeted during a particular time of the year.

Figure 4 presents a histogram showing the reconstructed month of harvest for the 44 shells from the site. The figure shows a unimodal distribution, with over 70% of the shells falling within a strong peak centered on December and January. No shells appear to have been harvested from May through August (late spring through summer). A unimodal distribution for shellfish harvesting is distinctly unlike patterns documented previously at bay shore sites where bimodal distributions are present (Culleton et al. 2009; Eerkens et al. 2013a, 2014; Schweikhardt et al. 2011).

There is slightly greater seasonal diversity among shells drawn from general midden contexts than shells included in burial fill matrix. Indeed, three out of the four burial contexts where we have sampled three or more shells (Burials 14, 48, and 160) are either homogenous or show very little variation in the month of harvest estimates. It is possible that our month of harvest estimates for these shells date, or just pre-date, the month in which the individual died. The shells were not obviously stacked or arranged around the burial to indicate intentional burial, but it is possible shells were symbolically placed with the individual for consumption in the afterlife. Alternatively, interment pit fill may have included recently discarded shells from meals or feasting events. In either case, that

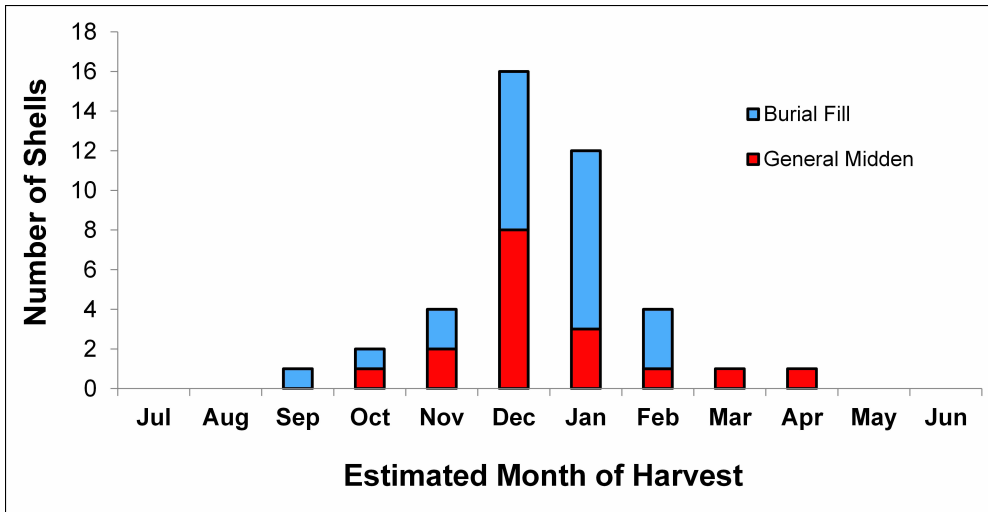


Figure 4. Histogram of month of harvest estimates for 44 shells from CA-SOL-364, showing samples from burial fill vs. general midden contexts.

seasonality profiles in burial pits are less diverse than from general midden is consistent with the notion that burial fill typically represents a shorter temporal window than general midden.

The one exception to this pattern is Burial 158, where our estimates for the month of harvest for six shells from the pit fill span a wide temporal window, September through February, similar to the range of months observed in shells drawn from general midden. For this burial, it is possible that the interment fill was taken from midden that had been discarded at much earlier dates. Paired human bone collagen and shell radiocarbon dates would have helped address this issue, but was not undertaken.

Finally, we were unable to document any size changes in the width or length of shells associated with the month of harvest estimates. Thus, shells harvested earlier in the season (November) seem to be the same size as those from peak harvesting season (December and January) and later in the year (February to April). This suggests that mussel stripping or plucking activities (see Jones and Richman 1995) throughout the harvesting season did not have a deleterious effect on shell size.

Discussion

Results of the isotopic analyses demonstrate two patterns regarding the location and timing of shellfish harvesting at CA-SOL-364. Regarding the location of mussel collection, the range of $\delta^{18}\text{O}$ values observed both within individual shells and among all the shells together suggests growth in an environment where salinity levels reached quite low levels, near 0 PSU at some points of the year. This could not have been along the open coast of California and are very unlikely from San Pablo Bay. Instead, the absolute $\delta^{18}\text{O}$ values overlap best with

values predicted for Suisun Marsh and we argue all the shells from the site were harvested in that location. That the shells were collected in Suisun Marsh is not surprising, given the proximity to CA-SOL-364. Significantly, this result suggests that the shells are not from an exotic location, but came from the nearest brackish-water estuary to the site, minimizing the travel and transport costs of moving the shells from the bay to the site.

The second significant result concerns the temporal context of shellfish harvesting (not to be confused with the season[s] of site occupation, which was likely year-round in the case of CA-SOL-364). Previous season of harvest studies in San Francisco Bay demonstrate that shells were typically collected year-round at bay shore sites, though often with distinct harvesting peaks in summer and winter (Culleton et al. 2009; Eerkens et al. 2013a, 2014; though see Schweikhardt et al. 2011, who document peaks in spring and fall at CA-CCO-295 using a different method). In this regard, CA-SOL-364 shows a different pattern, with just a single peak centered on winter. This result was determined for shells in burial contexts as well as midden, suggesting it is a pattern that holds for the site in general.

Such a pattern suggests that shellfish were not always “in” the diet, as would be expected of a staple food item. Instead, shellfish were only exploited during particular windows of time, in this case, winter. In Central California, winters are cold and rainy and most plants are dormant. In general, there is less food available to hunt and gather. The ethnographic pattern suggests that winter subsistence was focused on stored foods that were overharvested during the fall, especially small seeds and acorn (Kroeber 1925). In this respect, sessile shellfish such as mussels may have been one of the few foods that were still easily accessible in wintertime.

The results also suggest that shellfish was not a feasting food at CA-SOL-364, unlike what has been reported at sites to the north (Hildebrandt et al. 2009). Unlike fall, winter was generally not a time of feasting in Central California. Moreover, while feasting foods are typically exotic in nature, the shells at CA-SOL-364 do not appear to have been carried over very long distances, such as from the Pacific Coast. Furthermore, other marshland resources, such as fish, waterfowl, and charred seeds of marshland plants, are present in the midden, suggesting regular access to Suisun Marsh, even during summer and fall when shellfish were not apparently collected. Similarly, stable isotope analyses of human bone collagen show that some individuals at contemporaneous and nearby sites consistently accessed marshland resources (Eerkens et al. 2013b).

In this respect, shellfish appear to be a low-ranked food resource that was only exploited when the availability of other higher-ranked food items waned during winter. This result is in line with experimental results showing that caloric yields from shellfish gathering are low when compared to other foods, including small game and even many plants (Kennedy 2004; Simms 1985). Hauling shellfish 10–15 km into inland locations would have reduced their caloric yields even further (Bird and Bliege-Bird 1997; Bird et al. 2002). Such a result also conforms to predictions from foraging theory where food items come into and exit the diet breadth depending on the availability and density of other items. As

well, colder temperatures during winter act to refrigerate mussels and would have extended the edible window relative to other seasons.

Winter-only harvesting from Suisun Marsh presents three main options regarding the role of shellfish in the diets of the CA-SOL-364 population. We note that these three options are not exhaustive but seem most plausible to us. We also note that they are not necessarily mutually exclusive in their ability to explain the winter-only pattern documented. Additional research will be necessary to test the plausibility of each of the three options.

First, it is possible that shellfish comprised a fallback food (see Marshall et al. 2009) when other higher-ranking foods were in short supply. In this respect, shellfish could have provided an important source of calories when plants were no longer producing edible products during winter and many animal species were either dormant or had migrated to other locations. Within this scenario, shellfish could have been regularly exploited during winter by most or all of the population, or could have been used by just a small segment of the population as a staple fallback or starvation food during periods of extreme need, such as when fall failed to provide enough storable food to last throughout the winter. In both scenarios, shellfish would have been an important source of basic calories during winter.

Second, shellfish could have provided a particular macro- or micro-nutrient that was in short supply during wintertime. Humans require more than 50 essential nutrients for normal growth and cell maintenance. These nutrients cannot be synthesized in the human body through digestion and reassembling of biomolecules in the diet, but must come directly from foods ingested (e.g., Hockett and Haws 2003). In Central California, many of the foods that were overharvested in the summer and fall, and were stored and eaten in winter and spring, are carbohydrate-rich but protein-poor. This includes acorns and small seeds that can be amassed in bulk and are easily stored, and require significant processing time. An over-reliance on these foods in winter and spring may have created a protein deficiency in local populations. In this respect, California mussels are protein-rich (Erlandson 1988), are easily located and collected, and may have complemented carbohydrate-rich stored resources during winter. At other times of the year, fish and/or large game (e.g., deer, elk) or small game (e.g., rabbits, rodents) may have been more plentiful, especially in inland locations, and hence, higher-ranked sources of protein. Alternatively, shellfish could have provided an essential micro-nutrient, such as iodine or sodium, that was deficient in stored plant foods during winter. In either case, inhabitants of the site could have been encouraged to seek out shellfish during wintertime when other sources of this macro- or micro-nutrient were difficult to obtain.

Third, it is possible that neither use as fallback food nor source of protein or other micro-nutrient was the primary reason behind winter-only harvesting of shellfish at CA-SOL-364. Instead, it is possible that opportunity foraging costs for women, or perhaps men (Whelan et al. 2013), made mussels only attractive during wintertime. For example, demands on women to process and prepare foods for storage during summer and fall, and the need to gather newly ripening foods for consumption during spring, may have precluded mussel harvesting at

other times of the year. During winter, however, these other tasks were not performed as much, making shellfish an attractive option to supplement the diet.

Testing these three scenarios would require significant additional research, but would comprise an important contribution towards understanding the shifting emphases of hunting and gathering efforts throughout the year in Central California. To begin addressing these issues, it would be informative to know if mussels were consumed by the entire population, or only certain individuals or families. Examining the distribution of mussel shells horizontally across the site, and/or its association with certain contexts (e.g., present in some houses or hearths, but not others), might help in this regard. Unfortunately, not enough domestic features were excavated to make such comparisons statistically meaningful, and the site was not systematically excavated and screened to allow fine-scaled analysis of the horizontal distribution of shell. An alternative approach would be to examine stable isotope signatures within the burials. Because brackish-water mussels carry an enriched carbon isotopic signature relative to terrestrial foods (Eerkens et al. 2013b), examining inter-individual variation in carbon isotopes could help delineate whether everyone or just a small subset of people were consistently eating brackish-water foods, including mussels. Unfortunately, this line of inquiry is no longer possible as the human remains from the site have been reburied. Future research at similar sites in the region could follow such a program.

Conclusion

Stable oxygen and carbon isotope analysis of 44 shells deposited at CA-SOL-364 between 2100 and 1300 cal yrs BP suggest that mussels were harvested in Suisun Marsh and hauled 10–15 km inland before being consumed and that this activity occurred nearly exclusively during the winter. Of course, sessile mussels are available and easily accessible at all times of the year. Winter-only harvesting, then, suggests a special foraging context for this food resource and does not support their exploitation as a staple component of the ancient diet. Likewise, feasting during the lean time of the year with a low-return food that was accessed from a nearby source, also seems unlikely.

In light of the stable isotope data, we offered three main hypotheses to explain the presence of mussels at CA-SOL-364. First, mussels could have served as a fallback food in wintertime, either consistently from year to year to make up for resource shortfall, or perhaps only occasionally as a true starvation food when all other fallback resources had failed in a particular year. Second, mussels could have served as a source of protein or micronutrient in wintertime to complement the consumption of carbohydrate-rich stored foods, and were attractive for their nutrient composition rather than as a source of calories. Finally, opportunity costs associated with harvesting and storage shells versus other foods may have made the latter more attractive during spring, summer, and fall, but made mussels a valuable resource only during winter. Additional targeted research at other regional sites will be needed to test these hypotheses.

In sum, stable isotope analysis is an effective method for determining season of death for shells, especially in estuarine environments with seasonal fluctuations in salinity. Such analyses can help determine the role that shellfish played in local diets, whether as a staple, feasting food, or fallback subsistence resource. Our research also suggests that shellfish seasonality data from burial contexts may correspond to the season of death for the individual interred in the associated grave pit. However additional testing is necessary to establish this as a reliable method for determining season of death for humans.

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