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# Sea Mammal Hunting and Site Seasonality on Western San Miguel Island, California

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*Point Bennett, on western San Miguel Island, California, was an important location for sea mammal hunting through time. We use stable oxygen isotopic ($\delta^{18}O$) measurements from California mussel (*Mytilus californianus*) shells to reconstruct a seasonal pattern of mussel harvesting by the human occupants of Point Bennett during three time intervals dated to the middle (~7,550–3,600 cal B.P.; CA-SMI-528, Stratum 3) and late (after ~3,600 cal B.P.; CA-SMI-528, Stratum 1; CA-SMI-602) Holocene. During both periods of occupation at CA-SMI-528, mussel harvesting was primarily during the spring, coincident with onshore sea mammal breeding. This suggests a seasonal pattern of site occupation. At CA-SMI-602, mussel harvesting primarily occurred during the summer and fall. This is opposite when sea mammals are present in highest densities, suggesting year-round occupation. This shows how seasonality of mussel harvesting can be used alongside other indicators like seasonal availability of sea mammals to understand broader patterns of human mobility.*

Among hunter-gatherers, seasonal mobility can allow access to a diverse range of resources distributed across the landscape, provide protection or comfort during periods of poor weather, and facilitate social, political, or ceremonial interactions. Therefore, many archaeologists have focused on reconstructing site seasonality using a variety of methods (e.g., Bernstein 1990, 1993; Erlandson 1994, 2001; Kennett 1998, 2005; Kerber 1984; Leveillee et al. 2006; Waller and Leveillee 2002). Sites that are occupied for only part of the year make up part of a larger settlement system and may have different or more limited roles than those occupied year-round. Furthermore, seasonally occupied sites should have more limited artifact and faunal assemblages. On California's northern Channel Islands, there is evidence for seasonal movement of human populations throughout the Holocene. Site seasonality is therefore an important aspect of understanding human settlement and mobility through time (e.g., Glassow 1993, 2013; Glassow et al. 2012; Jazwa 2015; Jazwa et al. 2015a, 2015b; Jew et al. 2013a, 2013b; Kennett 1998, 2005; Perry 2003; Thakar 2014). On San Miguel Island, the westernmost

of the Channel Islands, hunter-gatherer-fishers exploited the local high-ranked marine resources for at least 12,000 years (Erlandson et al. 1996, 2005, 2011; Kennett et al. 2008). By looking at seasonal movements of these populations, it is possible to better understand changes over time in settlement patterns and resource use.

Point Bennett, at the western end of the island, is one of the most productive sea mammal rookeries in southern California (Fig. 1; Braje 2007, 2010; Delong and Melin 2002; Kennett 1998, 2005; Melin and Delong 2002; Stewart et al. 1993). There is evidence of human occupation of this part of the island as early as the early Holocene (~11,500–7,550 cal B.P.) at CA-SMI-693, which dates to 8,800 years ago (Jew et al. 2015). There are also deposits dating to the middle (~7,550–3,600 cal B.P.) and late Holocene (after ~3,600 cal B.P.; Kennett 1998; Walker et al. 2002). Sea mammal makes up the dominant component of the late Holocene strata of CA-SMI-528 and is second to fish at CA-SMI-602 (Walker et al. 2002). This demonstrates the importance of sea mammal hunting for the occupants of these sites. Other studies of faunal material from Late Holocene sites on western
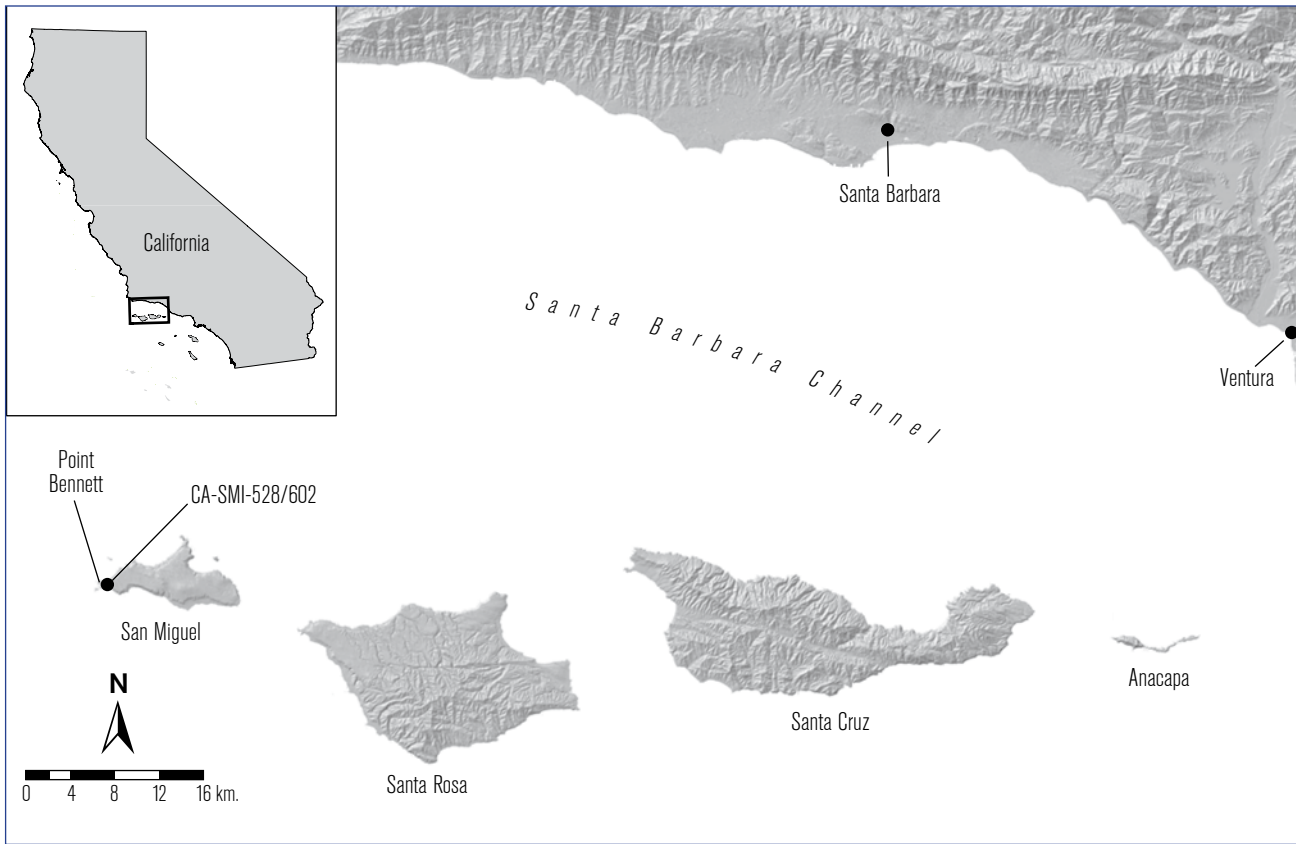
**Figure 1. Map of California's northern Channel Islands with CA-SMI-528/602 and Point Bennett indicated.**

San Miguel Island have also returned abundant evidence for sea mammal hunting (e.g., Braje 2010; Braje and DeLong 2009; Walker and Craig 1979). This fits within the broader pattern throughout the Santa Barbara Channel region, as there was a general increase in sea mammal hunting over time. This was accompanied by a similar increase in fishing and a decrease in shellfish collecting. These trends are all particularly pronounced in island contexts (Braje et al. 2007:741; Colten 2001; Glassow 1993; Jazwa 2015; Kennett 2005; Kennett and Kennett 2000; Raab et al. 1995; Rick 2007; Rick et al. 2008:81).

Evidence for sea mammal hunting extends throughout the human occupation of the islands (Braje 2007; Braje et al. 2009; Erlandson et al. 2005, 2008; Glassow et al. 2010). Braje et al. (2009) have argued that human hunting of sea otters during the middle Holocene is the most parsimonious explanation for the florescence of red abalone shell middens on the islands during this time (see also Braje 2010; Glassow 1993, 2013; Jazwa et al. 2015a; Kennett 2005; Kennett et al. 2007). Overhunting of otters would have released predation pressure on nearshore abalone populations. This is coincident with the earliest recorded cultural stratum at CA-SMI-528, which has abundant red abalone in the assemblage. During the late Holocene, an increase in sea mammal hunting was likely related to intensification of subsistence to support growing populations (Jazwa 2015; Kennett et al. 2009; Winterhalder et al. 2010). The development of sophisticated plank canoes (*tomols*), which appeared after 1,500 cal B.P. (Arnold 1992, 1995, 2001; Fagan 2004; Gamble 2002), could also have facilitated offshore sea mammal hunting.

In this study, we use a series of stable oxygen isotopic ($\delta^{18}O$) measurements from California mussel (*Mytilus californianus*) shells from CA-SMI-528 to assess site seasonality during two distinct periods of occupation associated with the middle and late Holocene. We also include $\delta^{18}O$ data from the nearby site of CA-SMI-602, which was occupied later in time, perhaps until

historical contact. We process these data in two different ways, including both a commonly used approach (see Culleton et al. 2009; Jazwa et al. 2015a) and a novel one that corrects for potential errors in $\delta^{18}O$ data analysis. The new approach provides a method for assigning $\delta^{18}O$ measurements directly to a season of harvesting rather than first calculating sea surface temperatures from these data. By considering these treatments of the data together, each of which has different strengths and drawbacks, it is possible to better assign seasonality of mussel collection to different cultural components.

Stable oxygen isotopic data from California mussel shells from two strata of CA-SMI-528 and one from CA-SMI-602 demonstrate a seasonal pattern of mussel collection at Point Bennett throughout the middle and late Holocene. At CA-SMI-528, this seasonal signature is coincident with the seasons during which sea mammals would have been most abundant at Point Bennett. This suggests a seasonal presence throughout human occupation of the site. However, the high density of sea mammal bone at CA-SMI-528 during the late Holocene suggests that occupation may have been more extensive than suggested by the $\delta^{18}O$ record. At CA-SMI-602, on the other hand, the season of mussel collection and periods of highest sea mammal density were complementary, together covering the entire annual range. This suggests a year-round human presence at Point Bennett during the latest period of occupation of the islands.

## SITE DESCRIPTIONS

CA-SMI-528 is a long, narrow shell-midden site along the spine of a high, northwest to southeast-trending dune at the edge of the present-day sea mammal rookery at Point Bennett. There are three primary strata at the site: Stratum 1 contains the densest midden and is approximately 70 cm. thick; Stratum 2 is a thin layer (25 cm.) of black abalone (*Haliotis cracherodii*) and turban snail (*Chlorostoma funebralis*) shells and sea mammal bones; and Stratum 3 is a dense red abalone (*Haliotis rufescens*) lens (24 cm. thick) containing California mussel (*Mytilus californianus*) shells and vertebrate bones. Artifacts appear limited to groundstone and lithic debitage (Walker et al. 2002).

CA-SMI-602 is a shallow, stratified shell midden in the middle of the present-day pinniped breeding ground at Point Bennett. Unlike CA-SMI-528, there is only one clear deposit at CA-SMI-602; it is about 60 cm. thick. Midden deposits at this site are very rich and contain extensive sea mammal bone, California mussel shell, and fish bone. There is also an extensive assemblage of artifacts, including *Callianax biplicata* shell beads and bead-making debris (microblades, microdrills, bead blanks; cf. Arnold 1987; Perry and Jazwa 2010), groundstone, and projectile points. The site also includes a cemetery and a house ring (Walker et al. 2002). The site structure and artifact assemblage at CA-SMI-602 are more consistent with a permanent occupation than those at CA-SMI-528.

## ANALYTICAL BACKGROUND

The measurement of $\delta^{18}O$ values is a well-established technique for determining sea surface temperature (SST; Glassow et al. 1994; Jazwa 2015; Jazwa et al. 2015a; Jazwa et al. 2012; Jew et al. 2013a, 2013b; Jones and Kennett 1999; Kennett 1998, 2005; Kennett and Voorhies 1996; Killingley and Berger 1979; Shackleton 1973; Thakar 2014). Oxygen isotopic ratios in shell contain information about the physical and chemical environment at the time of their growth. The two primary factors that contribute to this are the isotopic composition of seawater (including salinity) and water temperature (Wefer and Berger 1991). Urey (1947) demonstrated that the stable oxygen isotopic composition of the calcium carbonate of marine mollusk shells is temperature dependent and therefore reflects SST at the time that the individuals were alive. Shackleton (1973) outlined a method through which this could be used to address archaeological questions. He showed that by sampling a shell along its growth axis, it is possible to track the sinusoidal pattern of $\delta^{18}O$ values over the course of the lifetime of the individual. This can be translated into a measure of annual SST range (Epstein et al. 1951, 1953; Horibe and Oba 1972).

Once the annual range of SST is available for a given location at a particular time, it is possible to determine the season of death of a collection of shells and obtain information about seasonality of shellfish harvesting (Culleton et al. 2009; Glassow et al. 1994; Kennett and Voorhies 1996; Killingley 1980, 1981; Killingley and Berger 1979). Traditionally, season of death has been determined by placing the value for the most

recent growth band of an individual shell on the annual temperature range. However, Culleton et al. (2009) have argued that it is necessary to also collect a second sample 2 mm. from the edge of the shell to determine whether it was collected during a period when SST was increasing or decreasing, and how quickly it was doing so, to better associate it with a certain time of the year. More recent studies have suggested that the accuracy of identifying the season of collection for individual shells could potentially be improved by collecting even more samples (e.g., Glassow et al. 2012; Jew et al. 2013a, 2013b; Thakar 2014). We selected two samples from each shell to maximize the number of levels and sites that could be tested with our limited funding and to maintain consistency with previous studies (e.g., Jazwa et al. 2012; Kennett 1998, 2005).

California mussel has been used to model the seasonality of site occupation because it meets the criteria established by Shackleton (1973:134–135); it (a) deposits carbonate in a way that varies with temperature; (b) it deposits carbonate throughout the year; and (c) it has a sufficient growth rate to permit discrete increments covering no more than a few weeks. The growing environment of this species meets his other criteria, in that (d) the isotopic composition of the water in which the shell lives remains relatively constant throughout the year; (e) shell deposition takes place at sea temperature; and (f) the location undergoes a reasonably large and regular seasonal temperature variation. Furthermore, California mussels grow in a marine environment rather than in estuaries or coastal lagoons (e.g., Culleton et al. 2009; Kennett and Voorhies 1996), where salinity varies throughout the year to such a degree that it strongly influences $\delta^{18}O$ values in shell carbonate. Therefore, we are treating SST as the major driving force in $\delta^{18}O$ values in shell, assuming a constant isotopic composition of the ambient seawater. This allows us to estimate SST at the time of carbonate deposition using the equation for calcite established by Horibe and Oba (1972):

$$t°C = 17.04 - 4.34(\delta c - \delta w) + 0.16(\delta c - \delta w)^2 \qquad (1)$$

This was modified from the original equation from Epstein et al. (1953), in which $\delta c$ is the measured $\delta^{18}O$ value from the sample. We use an island-wide average of −0.26‰ for $\delta w$, the $\delta^{18}O$ of ambient seawater, obtained from 28 seawater samples around the coast of Santa

Rosa Island (Jazwa et al. 2015a). These measurements were performed at the Earth Systems Center for Stable Isotope Studies, a research center at the Yale Institute for Biospheric Studies. The Santa Rosa average for $\delta w$ was used because no similar measurements are available for San Miguel Island. Spatial differences in this value within the Santa Barbara Channel mostly result from the convergence of the southward-moving California Current and northward-moving California Countercurrent (see Kennett 2005).

## METHODS

### Site Chronology

To establish a chronology for the two sites, we obtained six radiocarbon dates from the units excavated at CA-SMI-528 and four dates from CA-SMI-602. All samples were California mussel or red (*Haliotis rufescens*) or black (*Haliotis cracherodii*) abalone shells. From CA-SMI-528, one sample was submitted from each of the two deep strata (Strata 2 and 3), and two samples each were from the two units excavated in Stratum 1 (Table 1; Kennett 1998:465; Walker et al. 2002). The samples from Stratum 1 were collected from the top and bottom of the deposits in each unit. In addition to establishing an overall chronology for the site, dates from Stratum 1 and Stratum 3 confine the two levels from which mussel shells were collected for $\delta^{18}O$ analysis. From CA-SMI-602, radiocarbon samples were taken from the base and top of deposits in excavation Units 2 and 5. All radiocarbon dates were calibrated in OxCal 4.1 (Bronk Ramsey 2009) using the most recent marine calibration curve, Marine13 (Reimer et al. 2013). We used a variable $\Delta R$ value for the Santa Barbara Channel region for samples with dates of less than 2,600 $^{14}C$ years B.P. (Table 1; Brendan Culleton, personal communication 2015; Hendy et al. 2013) and an updated $\Delta R$ value for the Santa Barbara Channel region for older samples (261±21 $^{14}C$ years B.P.; Brendan Culleton, personal communication 2012; Jazwa et al. 2012). For all excavation units with at least two dates, we programmed *a priori* information about the stratigraphic position of samples into OxCal (i.e., deeper samples within a unit are older). The software uses a Bayesian statistical model to constrain the error ranges on the 95.4% probability calibrated ranges of the radiocarbon dates.

**Table 1**

**RADIOCARBON DATES FROM CA-SMI-528 AND CA-SMI-602[a]**

| Lab Number | Stratum | Unit | Depth (cmbs) | Material | Conventional Date (B.P.) | Error | ΔR | ΔR Error | 95.4% Probability (cal B.P.) |
|---|---|---|---|---|---|---|---|---|---|
| Beta-114037 | 1 | 1 | 3 | *H. cracherodii* | 2,100 | 70 | 91 | 44 | 1,730–1,380 |
| Beta-114033 | 1 | 1 | 66 | *H. cracherodii* | 2,150 | 90 | 86 | 44 | 1,860–1,480 |
| Beta-114032 | 1 | 2 | 2 | *H. rufescens* | 1,860 | 70 | 141 | 44 | 1,490–1,130 |
| Beta-114035 | 1 | 2 | 70 | *H. rufescens* | 2,070 | 70 | 95 | 44 | 1,690–1,320 |
| Beta-114036 | 2 | N/A | 530–551 | *H. cracherodii* | 4,870 | 70 | 261 | 21 | 5,030–4,600 |
| Beta-114034 | 3 | N/A | 666–690 | *H. rufescens* | 5,670 | 70 | 261 | 21 | 5,920–5,610 |
| Beta-114533 | A | 2 | N/A | *M. californianus* | 730 | 60 | 275 | 42 | 260–140 |
| Beta-98743 | N/A | 2 | 39 | *M. californianus* | 900 | 60 | 346 | 42 | 310–140 |
| Beta-98742 | N/A | 5 | 10 | *M. californianus* | 1,100 | 70 | 329 | 42 | 490–270 |
| Beta-98744 | N/A | 5 | 48 | *M. californianus* | 1,100 | 60 | 329 | 42 | 510–300 |

[a]Kennett 1998:465. All dates were calibrated in OxCal 4.1 (Bronk Ramsey 2009) using the most recent marine calibration curve, Marine13 (Reimer et al. 2013). We used a variable ΔR value for the Santa Barbara Channel region for samples with dates of less than 2,600 [14]C B.P. Variable ΔR values were calculated by Brendan Culleton (personal communication, 2015) using AMS radiocarbon dates from paired organic and planktonic marine foraminiferal carbonate in laminated varves published by Hendy et al. (2013) from a sediment core from Santa Barbara Basin. For older samples, we used an updated ΔR value for the Santa Barbara Channel region (261±21 ^{14}C yr.; Brendan Culleton, personal communication 2012; Jazwa et al. 2012). For all excavation units with at least two dates, we programmed *a priori* information about the stratigraphic position of samples into OxCal as a "Sequence." The "Before" command is used to force dates to fall before A.D. 1820, the date for historic depopulation of the northern Channel Islands. All 95.4% probability ranges are stratigraphically modeled.

*Site Seasonality and δ^{18}O Analysis*

For this study, we sampled 20 California mussel shells from each of two excavation levels from CA-SMI-528, Stratum 3 (666–690 cm. below surface [cmbs]) and Stratum 1 (Unit 2, 50–60 cmbs), and 15 California mussel shells from CA-SMI-602, Unit 5 (40–50 cmbs). Shells for δ^{18}O analysis were chosen to fit three criteria: (1) the outer edge was intact, ensuring that the samples were collected from the final period of growth for the individual; (2) individuals were of intermediate size (~5–9 cm.) to avoid young, fast-growing shells and older, slow-growing shells; and (3) the outer, calcite layer was present to prevent sampling the inner aragonite layers, which grow in a different pattern and react differently to changes in temperature and salinity (Epstein et al. 1951, 1953; Glassow et al. 1994; Grossman and Ku 1986). We confirmed that we did not sample two hinges from the same individual mussel by determining hinge side and estimating size and shape of individuals.

All shells were first manually cleaned to remove any visible contaminants attached to the shell. They were then rinsed and sonicated in deionized water at room temperature to remove additional macroscopic contaminants. Whole shells were then subjected to a 5 percent hydrochloric acid etch in a bath of 70°C to expedite the reaction. After drying overnight in an oven set at 60°C, samples were collected using either a Lucas Model 980H dental drill or a Dremel tool to obtain powder from the shell at the growth margin and at 2 mm. from the edge along the growth band (Culleton et al. 2009). For adult, non-senescent California mussel shells, 2 mm. of shell deposition represents approximately one month of growth (Jones and Richman 1995:40). Approximately 2 mg. of sample powder was collected for each shell from both locations. They were then dried overnight in 0.5–dram vials in an oven set at 60°C. A full profile was collected from an individual shell for each of the three levels that were tested. For each profile, 20 samples were obtained from a shell at 2 mm. increments along the growth axis. Samples were cleaned, drilled, and dried as above.

Samples were analyzed in two laboratories. Individual shell profiles were run in the 1990s at the University of California, Santa Barbara using a Finnegan/MAT-251 light stable isotopic mass spectrometer with instrument precision for δ^{18}O of ±.11‰. These data are presented in Kennett (1998:522–523). The other samples from each level were submitted for δ^{18}O and δ^{13}C analysis to the Laboratory for Isotopes and Metals in the Environment (LIME) user facility at Pennsylvania State University during 2012–2013. At LIME, samples were weighed out between 0.075 and 0.25 mg. into vacuum vials. Carbon

dioxide was released from the samples using phosphoric acid with a Combi PAL auto-sampler connected to a Thermo Gas Bench. $\delta^{18}O$ and $\delta^{13}C$ were then measured using a Thermo Delta V Advantage analyzer. The resulting data were then calibrated to the scientific standard Vienna Pee Dee Belemnite (VPDB).

We treat $\delta^{18}O$ data from this analysis in two ways to compare the results of the different methods of data analysis. Measured $\delta^{18}O$ values for carbonate samples can be translated to precise measures of SST at the time of deposition on the shell using Equation 1 (e.g., Epstein 1951, 1953; Grossman and Ku 1986; Horibe and Oba 1972; Killingley and Berger 1979; Shackleton 1973). However, using these data to assign season of collection to individual shells is more subjective. Therefore, different approaches to processing $\delta^{18}O$ and SST can be used together to better infer site seasonality. For both methods, we compare measurements from the terminal growth band and one sample 2 mm. from the edge for a set of 15–20 shells against an annual range obtained from a single shell sampled in 19–20 points along the growth axis of the shell at 2 mm. increments. Ideally, the annual range would be generated from full profiles of more than one shell to reduce the chance that the SST range was skewed by a shell that grew during a period of anomalous temperature. However, these additional measurements are not available here.

The first method was presented by Culleton et al. (2009) and expanded upon by Jazwa et al. (2015a). In this method, we use modern instrumental data from a buoy to the north of San Miguel Island to create an annual SST curve. We use the annual range from the full shell profile from each of the strata that we are testing to establish the annual ranges of SST variation near the site at different times. The modern curve is then adjusted to maintain the estimate of annual dynamics, but maximum and minimum temperatures within the year are shifted to past values, as calculated from $\delta^{18}O$ values using Equation 1. Estimated SST values from samples from the edge of all of the tested mussel shells for the appropriate stratum are plotted, with the points for the samples collected 2 mm. from the edge set back by one month (Jones and Richman 1995:40). Because each SST value other than the maximum and minimum is reached at least twice per year, the direction of change in SST at the time of shell collection was used to determine where
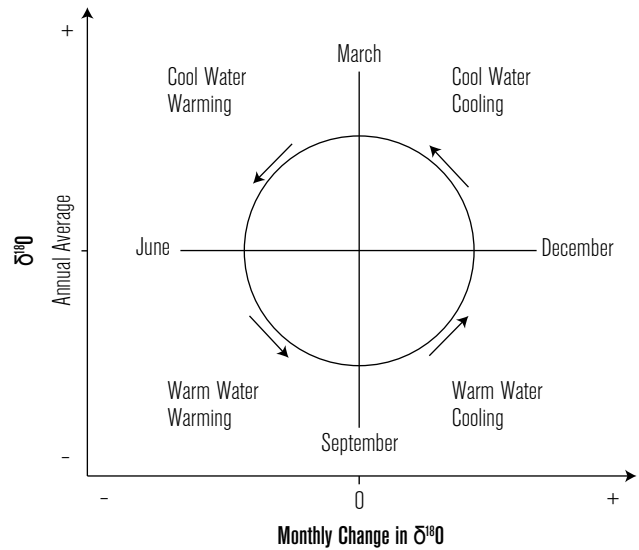


**Figure 2. Schematic for the plot of $\delta^{18}O$ vs. monthly change in $\delta^{18}O$ for individual mussel shells. The arrows represent the seasonal cycle in this measurement. SST has a negative relationship with $\delta^{18}O$, thus the counterclockwise cycle.**

the point fit on the curve. In cases in which the values for the edge of the shell were not within the range of the model, they were placed to season based on the slope of the change in SST over the course of the last 2 mm. (~1 month) of the individual's growth. This partially corrects for cases in which the full shell profile does not fully encompass SST variation for a given period in the past.

The second method is a newer approach. Rather than calculating SST values and placing them along the curve, we plot $\delta^{18}O$ for the growth edge (time of collection) vs. the difference between $\delta^{18}O$ at the growth edge and 2 mm. from the growth edge (monthly change). Warmer SST corresponds with lower $\delta^{18}O$ values and vice versa. Therefore, when subtracting $\delta^{18}O$ for 2 mm. from $\delta^{18}O$ at the growth edge, the more negative the resulting value, the more quickly SST is increasing; the more positive, the more quickly SST is decreasing. We divide the plot into four quadrants: cool water cooling (winter), cool water warming (spring), warm water warming (summer), and warm water cooling (fall; Fig. 2). These quadrants are bounded by the annual $\delta^{18}O$ average as calculated from the individual shell profile and a monthly change in $\delta^{18}O$ of zero. These can be used to infer season of collection. The seasonal progression is counterclockwise on this plot because of the negative relationship between $\delta^{18}O$ and SST. By not converting to
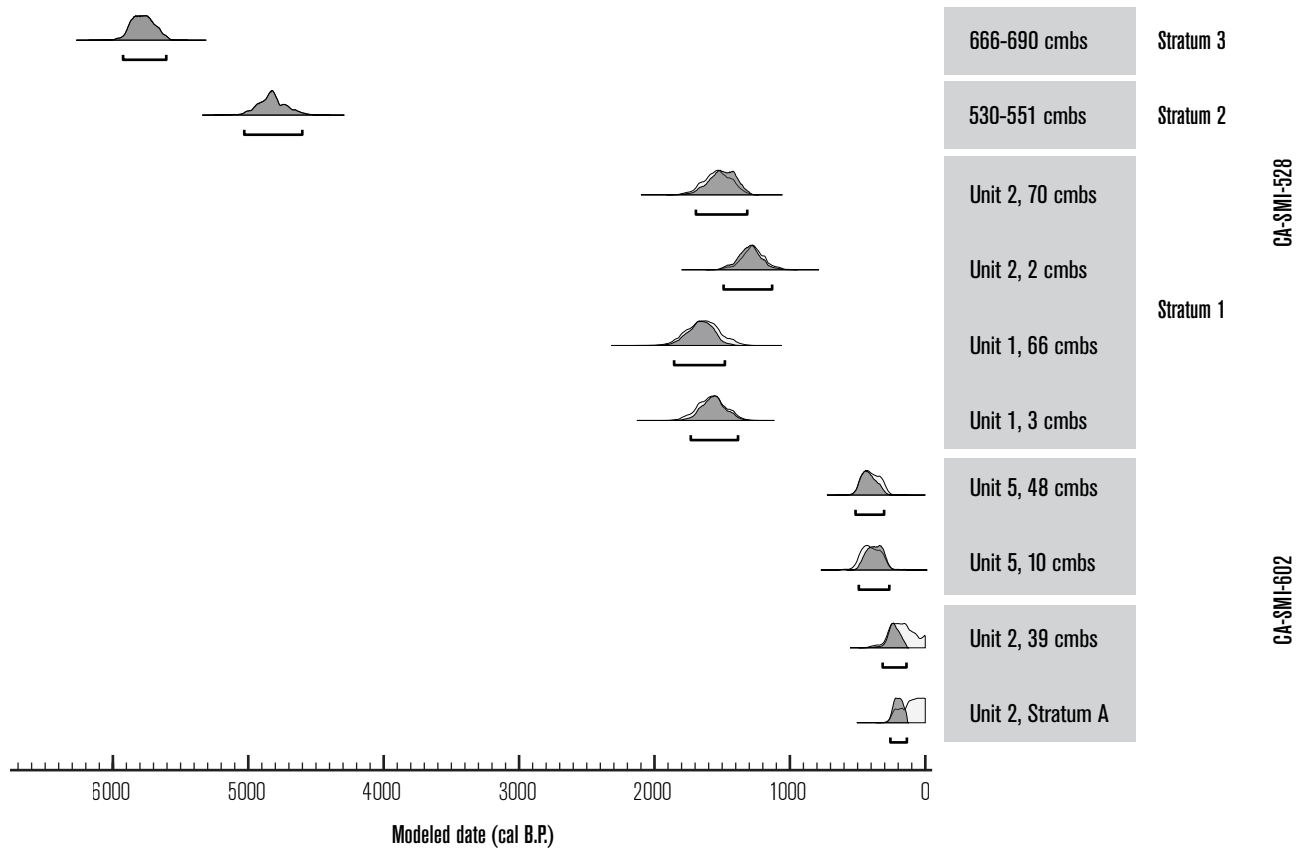
**Figure 3. 95.4% probability for the radiocarbon dates from CA-SMI-528 and -602. All dates were calibrated in OxCal 4.1 (Bronk Ramsey 2009) using the most recent marine calibration curve, Marine13 (Reimer et al. 2013). Dates were modeled in OxCal as a "Sequence" to account for stratigraphy within excavation units. For all excavation units with at least two dates, we programmed *a priori* information about the stratigraphic position of samples into OxCal. Dark gray distributions are modeled 95.4% probability ranges that account for this and light gray distributions are not.**

SST, we avoid potential error introduced by employing the island-wide average seawater $\delta^{18}O$ value from Santa Rosa Island. This method also uses two samples per shell to include both measurement from the time of collection and direction of change. It reduces the subjectivity associated with placing the data points on a curve to determine season of collection.

## RESULTS

*Site Chronology*

SMI-528 was occupied during at least two distinct periods—during the middle Holocene (Strata 2 and 3), and during the late Holocene (Stratum 1; Table 1; Fig. 3). All dates are given as a 95.4% probability range. The individual dates from Stratum 3 (5,920–5,610 cal B.P.) and Stratum 2 (5,030–4,600 cal B.P.) do not overlap,

and there is more than a meter difference in the depth of the two deposits, suggesting that there was a gap in occupation between them. Nonetheless, both have dense midden deposits that include some sea mammal. The late Holocene deposits from Stratum 1 of the site date from 1,860–1,480 cal B.P. (Unit 1, 66 cmbs) to 1,490–1,130 cal B.P. (Unit 2, 2 cmbs). These dates fall within the Middle Period (2,550–800 cal B.P.) of Chumash prehistory (Arnold 1992; King 1990). This range is coincident with the later deposits at nearby CA-SMI-525, a similar midden site with sea mammal deposits (Kennett 1998). Earlier deposits at CA-SMI-525 date to the beginning of the late Holocene, postdating those from CA-SMI-528 by approximately 2,000 years. CA-SMI-602 dates later in time than CA-SMI-528, with a range of radiocarbon dates from 510–300 cal B.P. to 260–140 cal B.P. These dates fall within the Late Period (650–168 cal B.P.) of Chumash

**Table 2**

**δ¹⁸O AND ESTIMATED SST DATA FROM INDIVIDUAL FULL CALIFORNIA MUSSEL SHELL PROFILES[a]**

| CA-SMI-528, Stratum 1 | | | CA-SMI-528, Stratum 3 | | | CA-SMI-602, Unit 5, 40 − 50 cmbs | | |
|---|---|---|---|---|---|---|---|---|
| Distance (mm.) | δ¹⁸O | Temperature (°C) | Distance (mm.) | δ¹⁸O | Temperature (°C) | Distance (mm.) | δ¹⁸O | Temperature (°C) |
| 0 | 0.25 | 14.9 | 0 | 0.15 | 15.3 | 0 | 1.37 | 10.4 |
| 2 | − 0.64 | 18.7 | 2 | − 0.11 | 16.4 | 2 | 1.26 | 10.8 |
| 4 | − 0.66 | 18.8 | 4 | 0.26 | 14.8 | 4 | 1.66 | 9.3 |
| 6 | − 0.88 | 19.8 | 6 | − 0.16 | 16.6 | 6 | 1.28 | 10.7 |
| 8 | 0.22 | 15.0 | 8 | − 0.15 | 16.6 | 8 | 1.33 | 10.5 |
| 10 | 0.08 | 15.6 | 10 | − 0.16 | 16.6 | 10 | 0.78 | 12.7 |
| 12 | 0.08 | 15.6 | 12 | 0.27 | 14.8 | 12 | 0.78 | 12.7 |
| 14 | − 0.17 | 16.7 | 14 | − 0.05 | 16.1 | 14 | 0.96 | 12.0 |
| 16 | 0.01 | 15.9 | 16 | − 0.26 | 17.0 | 16 | 1.00 | 11.8 |
| 18 | 0.11 | 15.5 | 18 | − 0.65 | 18.7 | 18 | 0.90 | 12.2 |
| 20 | −1.19 | 21.2 | 20 | − 0.55 | 18.3 | 20 | 0.68 | 13.1 |
| 22 | − 0.88 | 19.8 | 22 | − 0.25 | 17.0 | 22 | 0.72 | 13.0 |
| 24 | −1.10 | 20.8 | 24 | 0.32 | 14.6 | 24 | 0.91 | 12.2 |
| 26 | − 0.81 | 19.5 | 26 | − 0.03 | 16.0 | 26 | 0.65 | 13.2 |
| 28 | − 0.63 | 18.6 | 28 | 0.00 | 15.9 | 28 | 0.89 | 12.3 |
| 30 | − 0.53 | 18.2 | 30 | − 0.01 | 15.9 | 30 | 1.55 | 9.7 |
| 32 | -0.44 | 17.8 | 32 | 0.08 | 15.6 | 32 | 1.54 | 9.8 |
| 34 | -0.39 | 17.6 | 34 | -0.55 | 18.3 | 34 | 1.39 | 10.3 |
| 36 | 0.45 | 14.0 | 36 | -0.27 | 17.1 | 36 | 0.96 | 12.0 |
| | | | 38 | -0.25 | | | | |

[a] Kennett 1998.

prehistory, during which time island populations had reached their highest population densities and exhibit the most evidence for sociopolitical complexity (Arnold 1992; King 1990). The dates from these sites suggest that people occupied the Point Bennett region and exploited the sea mammal resources there over a broad span of time from the middle Holocene through European contact.

*Site Seasonality and δ¹⁸O Analysis*

*Individual Shell Profiles.* We used SST calculated from the individual shell profiles (Table 2) to calculate annual ranges for Stratum 1 and Stratum 3 of CA-SMI-528 and 40–50 cmbs of CA-SMI-602, Unit 5. For Stratum 3, SST ranges between 14.6 and 18.7°C (δ¹⁸O range of 0.32 to −0.65‰), with a mean of 16.4°C. For Stratum 1, SST has a wider range, between 14.0 and 21.2°C (δ¹⁸O range of 0.45 to –1.19‰), with a mean of 17.6°C. For CA-SMI-602, the SST range is lower, between 9.3°C and 13.2°C (δ¹⁸O range of 1.66 to 0.65‰), with a mean of 11.5°C. These

ranges for SST are used to create the curves presented in the next section for yearly fluctuations in SST. The δ¹⁸O values obtained from these profiles are used to reconstruct the ranges used in the following section for plotted changes in δ¹⁸O.

*Modeled Daily Average SST.* We plotted the δ¹⁸O data against a model of daily average SST obtained from modern instrumental data collected from a buoy near San Miguel Island by J. Engle approximately twice per week from April 1981 through December 1992. Raw SST data were measured to the nearest 0.5°C. Over the course of the 12-year span during which data were collected, at least one value was available for each day except December 25 and January 1. Values for each day were averaged, with a value for December 25 obtained by averaging December 18–24 and 26–31, and a value for January 1 obtained by averaging December 26–31 and January 2–8. We smoothed the curve using a 15-day running average (Fig. 4). For each stratum, we shifted
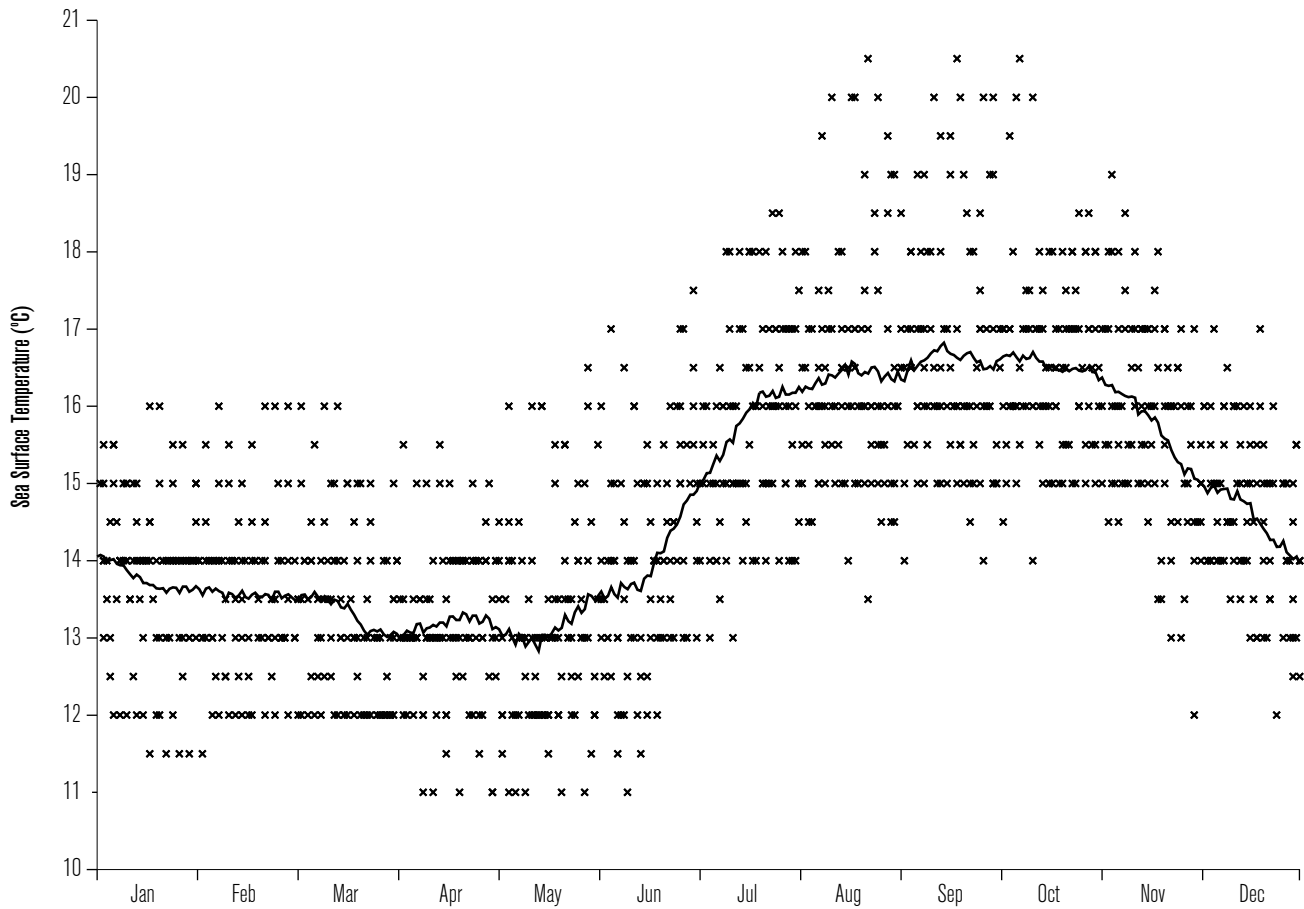
**Figure 4. Model of daily variation in SST near San Miguel Island. The curve is a 15-day running average of daily average SST from instrumental data collected by J. Engle from April 1981–December 1992. Individual data points are superimposed over the curve.**

and stretched this curve to the ranges from individual shell profiles presented in the previous section. The instrumental data help to model annual SST dynamics.

Estimated SST values from samples from the edge and 2 mm. from the edge of the mussel shells are plotted for all three strata (Table 3; Figs. 5–7). For CA-SMI-528, some samples fall below the curve, but no samples are warmer than the maximum range of the curve. This is consistent with the interpretation that mussels were preferentially collected at CA-SMI-528 during periods of cooler SST. In the middle Holocene (Stratum 3), 5 (25%) samples can be associated with the winter, 12 (60%) with the spring, 3 (15%) with the summer, and none with the fall. In the late Holocene (Stratum 1), the pattern is similar, with 5 (25%) samples associated with the winter, 14 (70%) with the spring, 1 (5%) with the summer, and none with the fall. The direction of SST change helps to

place the samples during the winter and early spring and rule out collection during the fall. Overall, these data suggest that people preferentially did not collect mussels at CA-SMI-528 during the time of the year when SST was highest (August–October). Conversely, at the Late Period site (CA-SMI-602), there are several samples that fall above the curve, but none are below the curve. We can associate 1 (7%) sample with the winter, none with the spring, 6 (40%) with the summer, and 8 (53%) with the fall. It is clear from this method that mussel collection was clustered in the summer and late fall.

*Plotted Change in $\delta^{18}O$.* We also plot $\delta^{18}O$ for the growth edge (time of collection) vs. the difference between $\delta^{18}O$ at the growth edge and 2 mm. from the growth edge (monthly change). We generate plots for $\delta^{18}O$ from Stratum 3 and Stratum 1 at CA-SMI-528 and 40–50 cmbs at CA-SMI-602 (Fig. 8). Warm vs. cool

**Table 3**

**δ¹⁸O AND ESTIMATED SST DATA FROM INDIVIDUAL FULL CALIFORNIA MUSSEL SHELL PROFILES**

| Site | Stratum/Depth | Shell | Edge δ¹⁸O | Edge Temperature (°C) | 2 mm. δ18O | 2 mm. Temperature (°C) |
|---|---|---|---|---|---|---|
| CA-SMI-528 | 1 | 1 | 0.23 | 15.0 | 0.12 | 15.4 |
| | 1 | 2 | −0.54 | 18.3 | 0.17 | 15.2 |
| | 1 | 3 | 0.15 | 15.3 | 0.86 | 12.4 |
| | 1 | 4 | 0.33 | 14.5 | 0.91 | 12.2 |
| | 1 | 5 | −0.05 | 16.1 | 0.49 | 13.9 |
| | 1 | 6 | −0.12 | 16.5 | 0.81 | 12.6 |
| | 1 | 7 | 0.21 | 15.0 | 0.11 | 15.5 |
| | 1 | 8 | 0.23 | 14.9 | 0.73 | 12.9 |
| | 1 | 9 | 0.28 | 14.8 | 1.26 | 10.8 |
| | 1 | 10 | 0.94 | 12.1 | 0.33 | 14.5 |
| | 1 | 11 | 0.30 | 14.7 | -0.04 | 16.1 |
| | 1 | 12 | −0.32 | 17.3 | 0.81 | 12.6 |
| | 1 | 13 | 0.16 | 15.2 | 0.44 | 14.1 |
| | 1 | 14 | 0.86 | 12.4 | 0.23 | 15.0 |
| | 1 | 15 | −0.05 | 16.1 | 1.68 | 9.2 |
| | 1 | 16 | 0.41 | 14.2 | 0.69 | 13.1 |
| | 1 | 17 | 0.35 | 14.4 | 0.64 | 13.2 |
| | 1 | 18 | 0.50 | 13.8 | 0.72 | 13.0 |
| | 1 | 19 | 0.57 | 13.5 | 0.81 | 12.6 |
| | 1 | 20 | 1.01 | 11.8 | 1.17 | 11.2 |
| CA-SMI-528 | 3 | 1 | 0.26 | 14.8 | 0.19 | 15.1 |
| | 3 | 2 | 0.07 | 15.6 | 0.47 | 13.9 |
| | 3 | 3 | 0.72 | 12.9 | 1.12 | 11.4 |
| | 3 | 4 | 1.02 | 11.7 | 0.49 | 13.9 |
| | 3 | 5 | 0.27 | 14.8 | 0.26 | 14.8 |
| | 3 | 6 | 0.36 | 14.4 | 1.03 | 11.7 |
| | 3 | 7 | 0.99 | 11.8 | 0.72 | 12.9 |
| | 3 | 8 | 0.21 | 15.0 | 0.76 | 12.8 |
| | 3 | 9 | 0.23 | 14.9 | 0.65 | 13.2 |
| | 3 | 10 | −0.01 | 16.0 | 0.57 | 13.6 |
| | 3 | 11 | −0.29 | 17.1 | 0.71 | 13.0 |
| | 3 | 12 | −0.56 | 18.3 | 0.67 | 13.2 |
| | 3 | 13 | 0.10 | 15.5 | 1.53 | 9.8 |
| | 3 | 14 | −0.42 | 17.7 | -0.22 | 16.9 |
| | 3 | 15 | 0.68 | 13.1 | 1.14 | 11.3 |
| | 3 | 16 | 1.07 | 11.6 | -0.65 | 18.8 |
| | 3 | 17 | 1.57 | 9.6 | 1.19 | 11.1 |
| | 3 | 18 | 0.51 | 13.8 | 0.54 | 13.7 |
| | 3 | 19 | 0.33 | 14.5 | 1.38 | 10.3 |
| | 3 | 20 | 1.04 | 11.7 | 1.14 | 11.3 |

**Table 3** *(Continued)*

**δ¹⁸O AND ESTIMATED SST DATA FROM INDIVIDUAL FULL CALIFORNIA MUSSEL SHELL PROFILES**

| Site | Stratum/Depth | Shell | Edge δ¹⁸O | Edge Temperature (°C) | 2 mm. δ180 | 2 mm. Temperature (°C) |
|---|---|---|---|---|---|---|
| CA-SMI-602 | 40–50 cm. | 1 | 1.04 | 11.7 | 1.03 | 11.7 |
| | 40–50 cm. | 2 | 0.44 | 14.1 | 0.80 | 12.6 |
| | 40–50 cm. | 3 | −0.65 | 18.8 | 0.13 | 15.4 |
| | 40–50 cm. | 4 | 1.15 | 11.2 | 1.01 | 11.8 |
| | 40–50 cm. | 5 | 1.43 | 10.2 | 1.28 | 10.7 |
| | 40–50 cm. | 6 | 1.01 | 11.8 | 0.78 | 12.7 |
| | 40–50 cm. | 7 | 1.29 | 10.7 | 1.00 | 11.8 |
| | 40–50 cm. | 8 | 1.14 | 11.3 | 0.85 | 12.4 |
| | 40–50 cm. | 9 | 1.22 | 11.0 | 0.83 | 12.5 |
| | 40–50 cm. | 10 | 0.40 | 14.2 | 0.70 | 13.0 |
| | 40–50 cm. | 11 | 0.89 | 12.3 | 1.06 | 11.6 |
| | 40–50 cm. | 12 | 0.32 | 14.6 | 0.72 | 13.0 |
| | 40–50 cm. | 13 | 1.18 | 11.1 | 0.81 | 12.6 |
| | 40–50 cm. | 14 | 1.04 | 11.7 | 0.81 | 12.6 |
| | 40–50 cm. | 15 | 1.04 | 11.7 | 1.18 | 11.1 |

water samples are divided using the annual averages of −0.11‰ for Stratum 3, −0.37‰ for Stratum 1, and 1.08% for CA-SMI-602. A pattern emerges similar to what was observed in previous studies, with a focus on shellfish collecting in both strata of CA-SMI-528 during the winter and spring, with most samples falling during the spring. There is some evidence for mussel collection at the site into the early summer, with three samples from Stratum 3 and one sample from Stratum 1 associated with that season. The pattern at CA-SMI-602 suggests collection during the summer, fall, and winter. In all, this method confirms the seasonality of the site determined by the earlier method.

*Faunal Data*

In this paper, we incorporate faunal data for meat weight for CA-SMI-528 and -602 that were previously compiled and analyzed by Walker et al. (2002). We acknowledge that there are problems with using meat weight as a measure of diet, particularly when it comes to sea mammals (see Gifford-Gonzalez and Hildebrandt 2012; Mason et al. 1998). This is partially because of the effects of field processing, an activity which is more
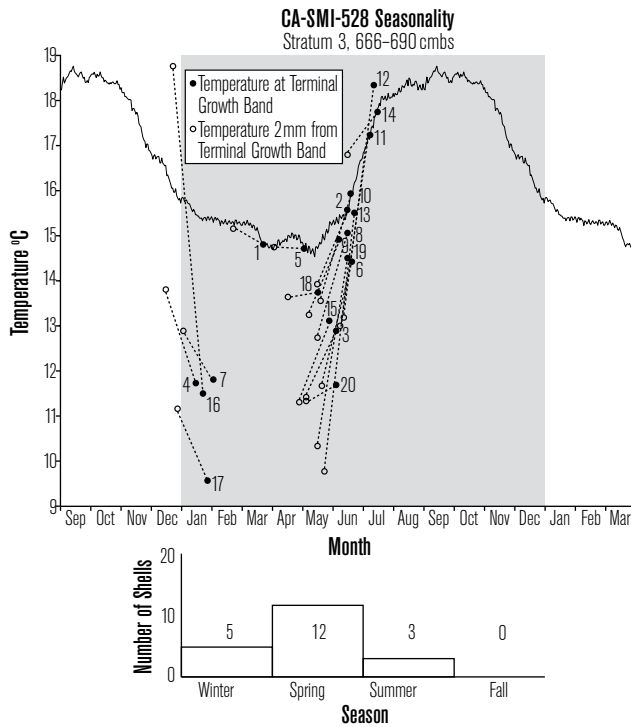
**Figure 5. Seasonal profile of *Mytilus californianus* shells from CA-SMI-528, Stratum 3. The curve was stretched and shifted to the range of temperatures from the profile of a single shell drilled at 2 mm. increments. The terminal growth band and 2 mm. (~1 month) prior are plotted to estimate season of collection. Slope is used to assign the position on the curve when temperatures are outside of the range of temperatures encompassed by the shell profile. Also included is a histogram of mussel season of collection.**



**Figure 6. Seasonal profile of *Mytilus californianus* shells from CA-SMI-528, Stratum 1, Unit 2. The curve was created and points were placed as in Figure 5.**
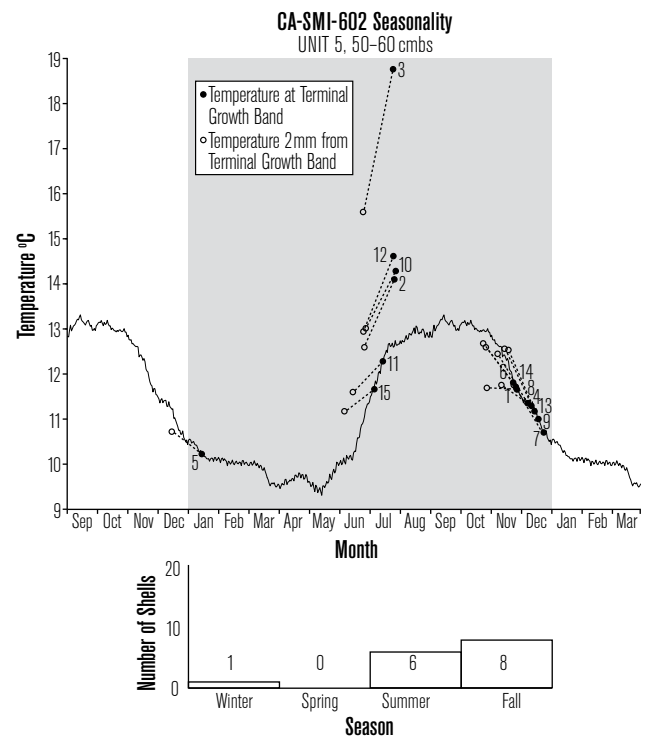


**Figure 7. Seasonal profile of *Mytilus californianus* shells from CA-SMI-602, Unit 5. The curve was created and points were placed as in Figure 5.**

common involving sea mammals than many shellfish species like mussels, although there is also evidence for field processing of red abalone on the northern Channel Islands (Jazwa et al. 2015a). Nonetheless, meat weight is what is available for these sites, and the patterns that we highlight are on a scale so broad and so stark that meat weight values are sufficient to demonstrate the relative contributions of shellfish, fish, and sea mammal to the different cultural components.

There are three primary components that we test for seasonality using δ18O measurements, two of which have detailed faunal data available in Walker et al. (2002). The faunal assemblage in Stratum 3 (666–690 cmbs) of CA-SMI-528 dates to the middle Holocene and is consistent with contemporaneous red abalone midden sites on Santa Cruz (Glassow 2013) and Santa Rosa (Jazwa et al. 2015a) islands. The dense red abalone
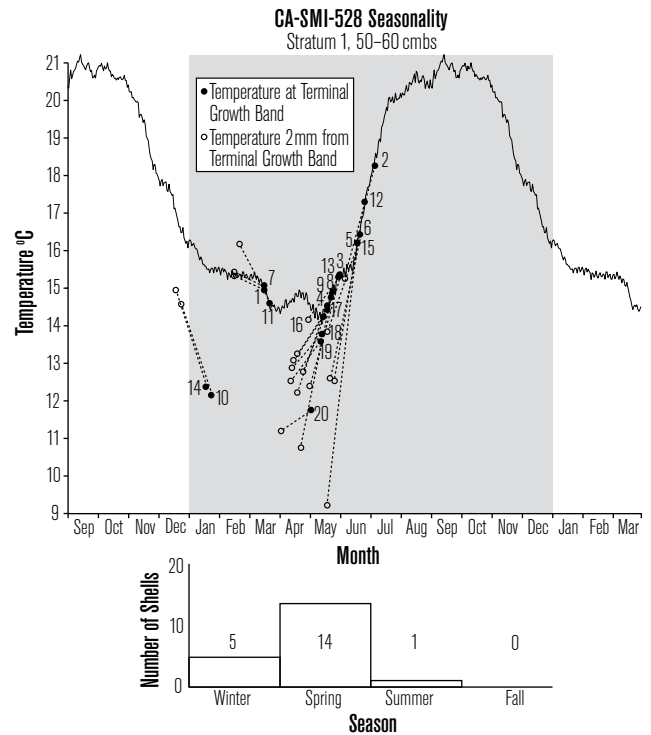
a)



b)



c)

**Figure 8. Plot of δ¹⁸O vs. monthly change in δ¹⁸O for individual mussel shells for (a) CA-SMI-528, Stratum 3 (666–690 cmbs); (b) CA-SMI-528, Stratum 1 (Unit 1, 50–60 cmbs); and (c) CA-SMI-602 (Unit 5, 40-50 cmbs). The light gray area is the range of points plotted over the lifetime of the full shell profile, which represents the annual range in δ¹⁸O values. The solid vertical line is the boundary between warming and cooling periods (i.e., 0 monthly change). The solid horizontal line is the annual average δ¹⁸O. However, because seasons do not change at the time of average δ¹⁸O, dashed lines are calculated from the annual temperature curves in Figures 5–7 using Equation (1) as δ¹⁸O values that bound spring/summer and fall/winter. Instrumental precision for δ¹⁸O is ±.11‰**

deposits at the site could be indicative of seasonal collection of the large gastropod along with other shellfish species (Jazwa et al. 2015a). Sea mammal remains are present in this deposit, but in much smaller densities than in later deposits at Point Bennett (Walker et al. 2002). Similarly, Jew et al. (2015) present faunal data from the nearby site of CA-SMI-693, which has dates ranging from 8,940–8,740 cal B.P. through 8,450–8,230 cal B.P. (68.2% confidence intervals). There, the assemblage is dominated by shellfish, with minimal fish bone and no sea mammal bone. These data, along with the observations of Walker et al. (2002), could be explained by two hypotheses about early sea mammal hunting at Point Bennett: (1) the prominent rookery at Point Bennett today either did not exist or was much less prolific during parts of the early and middle Holocene when people occupied CA-SMI-528 and -693; or (2) occupants of these sites chose not to hunt sea mammals even though they were present in high densities, instead focusing on abundant shellfish resources. For the purposes of this study, it does not matter which of these was the case for the middle Holocene occupation of CA-SMI-528. Because of the lack of other types of marine resources in the assemblage, the seasonality of shellfish collecting reflects the seasons during which people were at the site.

In both Stratum 1 of CA-SMI-528 and all of CA-SMI-602, sea mammal bone makes up a large component of the archaeological record (Table 4; Fig. 9; Walker et al. 2002). It is clear that people took advantage of adjacent breeding colonies of pinnipeds. At CA-SMI-528, in Stratum 1, sea mammal is by far the largest contributor to overall meat weight, at 1,042.14 kg./m.³ (73% of the total), with fish second at 233.59 kg./m.³ (16%) and

**Table 4**

**ESTIMATED MEAT WEIGHT VALUES AND PERCENT OF TOTAL MEAT WEIGHT FOR THE FOUR PRIMARY TYPES OF MARINE FAUNA BY ARBITRARY 10 CM. EXCAVATION LEVEL AT CA-SMI-528 (STRATUM 1) AND CA-SMI-602[a]**

| Deposit | Depth | Faunal Weights (kg./m.³) | | | |
|---------|-------|------|------------|-----------|------|
| | | Fish | Sea Mammal | Shellfish | Bird |
| CA-SMI-528, Unit 1 | 0–10 cm. | 165.62 | 198.88 | 28.89 | 8.06 |
| | 10–20 cm. | 570.27 | 3,231.41 | 144.97 | 0.00 |
| | 20–30 cm. | 231.22 | 454.08 | 100.01 | 5.12 |
| | 30–40 cm. | 142.71 | 616.43 | 73.91 | 7.54 |
| | 40–50 cm. | 48.00 | 1,314.29 | 488.98 | 0.00 |
| | 50–60 cm. | 243.67 | 437.74 | 42.69 | 0.57 |
| Unit Average | | 233.59 | 1,042.14 | 146.58 | 3.55 |
| Percent of Total | | 16.38 | 73.09 | 10.28 | 0.25 |
| CA-SMI-602, Unit 5 | 0–10 cm. | 250.72 | 32.68 | 8.11 | 5.16 |
| | 10–20 cm. | 1,218.09 | 209.01 | 19.65 | 0.00 |
| | 20–30 cm. | 1,335.67 | 220.44 | 33.62 | 9.26 |
| | 30–40 cm. | 770.64 | 238.75 | 21.39 | 0.00 |
| | 50–60 cm. | 607.23 | 612.51 | 34.7 | 14.66 |
| Unit Average | | 836.47 | 262.68 | 23.49 | 5.82 |
| Percent of Total | | 74.12 | 23.28 | 2.08 | 0.52 |

[a]Meat weight multipliers are as follows: fish = 27.7, sea mammal = 24.2, shellfish = 0.332, bird = 15 (Walker et al. 2002).
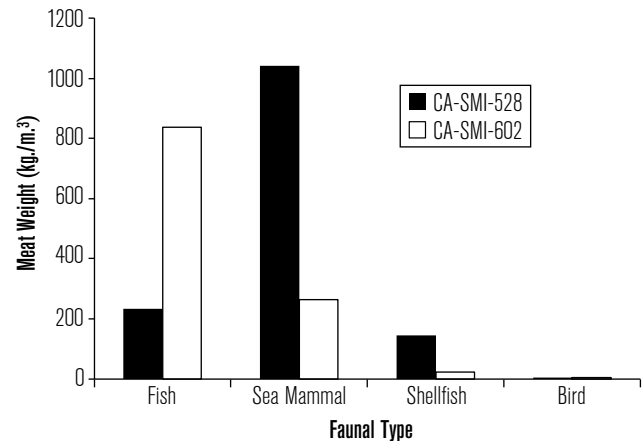


**Figure 9. Total calculated meat weight estimates for the four primary types of marine fauna at CA-SMI-528 (Stratum 1) and CA-SMI-602. Meat weight multipliers are as given in Table 4.**

prominent species in both assemblages, in that order. The presence of large numbers of female and juvenile individuals supports the assertion that people exploited breeding colonies of pinnipeds (Walker et al. 2002).

## DISCUSSION

The $\delta^{18}O$ data presented in this study and the faunal data first presented in Walker et al. (2002) suggest three different patterns of subsistence and mobility at Point Bennett during the middle Holocene (SMI-528, Stratum 3), the Middle Period (SMI-528, Stratum 1), and the Late Period (SMI-602). Although there is evidence for shellfish collecting, fishing, and sea mammal hunting in all three deposits, each was dominated by a different subsistence activity. In CA-SMI-528, Stratum 3, shellfish is the primary component of the faunal record, with fishing and sea mammal hunting less prominent. Mussel harvesting at the site at that time was largely during winter and spring, with some evidence extending into early summer. This suggests a seasonal occupation of the site. The spring presence coincides with the primary periods of breeding and pupping for many of the pinniped species on the northern Channel Islands, when they are present on the beaches in the highest densities today (Fig. 10; DeLong and Melin 2002). Therefore, if breeding times were the same during the middle Holocene, the limited sea mammal hunting that occurred at CA-SMI-528 could have been opportunistic, occurring when people were there collecting shellfish. In

shellfish 146.58 kg./m.³ (10%). At CA-SMI-602, the importance of sea mammal and fish are reversed, with fish at 846.47 kg./m.³ (74% of the total), sea mammal at 262.68 kg./m.³ (23%), and shellfish at 23.49 kg./m.³ (2%). The locations of the two sites reflect their relative focus on sea mammals and fish. CA-SMI-528 is at the edge of the modern rookery, and may have been placed there so as to not disturb the pinniped breeding colony. CA-SMI-602 is in the middle of the modern rookery, and the human occupants would have displaced the sea mammal population there. This is consistent with the change to a greater focus on fishing at the expense of sea mammal hunting. The location of the sea mammal breeding grounds likely moved or was condensed to a smaller area near Point Bennett. Nevertheless, the relative focus on the different sea mammal species is consistent between CA-SMI-528 and -602, with Guadalupe fur seal (*Arctocephalus townsendi*), sea otter (*Enhydra lutris*), northern fur seal (*Callorhinus ursinus*), and California sea lion (*Zalophus californianus*) being the four most
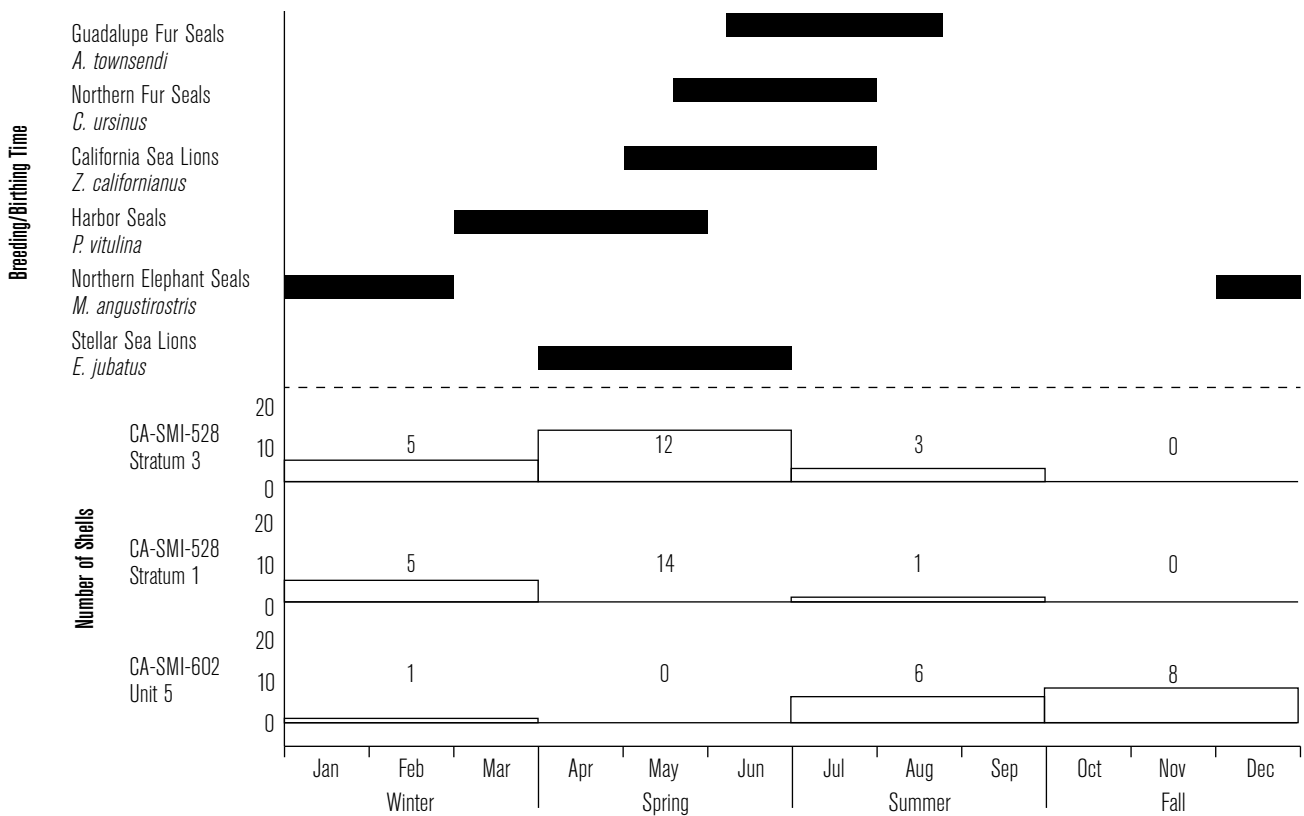
**Figure 10. Breeding/birthing seasonality of prominent sea mammal species at Point Bennett, plotted alongside the seasonality of mussel collection at CA-SMI-528 and -602. The breeding/birthing ranges are from DeLong and Melin (2002) and Lebeouf (1978). Note that sea mammals were present at Point Bennett beyond these annual ranges.**

CA-SMI-528, Stratum 1, mussel harvesting was focused on the winter and spring, coincident with the highest densities of sea mammals. The seasonal overlap of the highest sea mammal densities and seasonality from mussel $\delta^{18}O$ suggests that CA-SMI-528 may have been occupied seasonally, with the primary objective being the hunting of sea mammals, perhaps for longer periods than when mussels were collected. At CA-SMI-602, the fact that the annual period of highest sea mammal density is opposite the seasons of observed mussel harvesting (summer-fall) more clearly suggests a year-round occupation of the site. This is supported by the presence of the house ring and cemetery, and by the high diversity of artifacts at the site. Although there is evidence for permanent occupation of CA-SMI-602 during the Late Period, it appears that Point Bennett was not the location of one of the permanent village sites observed at the time of historical contact (Glassow et al. 2010).

The $\delta^{18}O$ record from CA-SMI-528 suggests that occupation of Point Bennett during the middle Holocene was seasonal. This reflects observations from the faunal record that people exploited shellfish and some sea mammals (Walker et al. 2002). The early occupation of CA-SMI-528 fits into a middle Holocene pattern of seasonal mobility that was characteristic of the Channel Islands as a whole (e.g., Glassow 2013; Kennett 1998, 2005; Perry 2003). It is unclear whether occupation of this site was timed to coincide with occasions when sea mammals were present in the highest densities, or whether occupants of the site just hunted them opportunistically. These deposits contain a large quantity of red abalone and were contemporary with middle Holocene red abalone midden sites across the islands (e.g., Braje et al. 2009; Glassow 2013; Jazwa et al. 2015a). Braje et al. (2009) have argued that red abalone populations may have peaked at this time as a result of

a decrease in sea otter populations on the islands from human overhunting. It is possible that sea otter hunting at CA-SMI-528 may have contributed to this pattern, although a complete analysis of the faunal record from Stratum 3 is necessary to support this conjecture.

A number of cultural, technological, and environmental changes occurred during the late Holocene (Glassow et al. 2010; Jazwa and Perry 2013; Rick et al. 2005). The trend toward an intensification of marine fishing and sea mammal hunting began before the development of the *tomol* (after ~1,500 cal B.P.), but the introduction of this technology would have made it much easier to hunt sea mammals offshore. It allowed islanders to travel more quickly, venture further from shore into pelagic waters, and carry larger amounts of cargo, while also providing a more stable platform. The dates that we obtained from Stratum 1 are roughly coincident with the appearance of the *tomol*. It is possible that islanders would have then been able to hunt sea mammals both on- and offshore, which may have contributed equally to the faunal record. Sea mammals hunted using these techniques would be difficult to distinguish in the archaeological record, however.

During the late Holocene, it appears that despite the dense midden at the site, CA-SMI-528 was still occupied seasonally. The isotopic record from mussel shells suggests that this may have been a logistical camp that people would have visited seasonally to exploit sea mammal resources before they returned to other permanent village sites. Establishing a permanent village near Point Bennett could have potentially displaced the sea mammals that visited the location every year. Nevertheless, the thick midden deposits at the site suggest that the people who occupied it did so intensively and repeatedly, perhaps while processing the sea mammals that they hunted before they were transported back to other locations. An analysis of the relative abundance of different elements could provide valuable information about whether field processing occurred at CA-SMI-528 or whether sea mammals were primarily consumed on site. The occupation associated with Stratum 1 occurred during a period of higher residential mobility than during the subsequent Late Period, at which time populations condensed to a smaller number of larger village sites (Glassow et al. 2010; Jazwa 2015; Johnson 1982, 1993; Kennett 2005).

There was at least a 600-year gap between the late Holocene occupation of CA-SMI-528 and the first evidence for occupation of CA-SMI-602. Beginning around 1,300 cal B.P., population increase and growth in the number of permanent settlements on the northern Channel Islands accelerated (Arnold 2001; Kennett 2005; Kennett and Conlee 2002; Kennett et al. 2009; Winterhalder et al. 2010). Institutionalized differences in social status also appeared at this time (Kennett et al. 2009). These changes are roughly contemporaneous with the latter half of the range of late Holocene occupation of CA-SMI-528, and they precede the occupation of CA-SMI-602. This period is also coincident with the Medieval Climatic Anomaly (MCA; 1,150–600 cal B.P.), a period of extreme and persistent drought conditions that had broad impacts on human populations living throughout the American Southwest (Bocinsky and Kohler 2014; Jones et al. 1999; Jones and Schwitalla 2008). In the Santa Barbara Channel region, Lambert and Walker (Lambert 1993, 1997; Lambert and Walker 1991; Walker 1989; Walker and Lambert 1989) documented declining health and increased violence in skeletal collections from this period, which they associate with an increase in sedentism and diminishing supplies of fresh water and terrestrial foods. It is unclear whether these developments were related to the abandonment of CA-SMI-528, which occurred around or shortly before the beginning of the MCA. The reoccupation of Point Bennett at nearby CA-SMI-602 occurred after the end of the MCA.

There is a clear difference in the seasonality of mussel harvesting at Point Bennett in the Late Period deposits from CA-SMI-602. Unlike in the earlier periods of occupation at CA-SMI-528, mussel collection at CA-SMI-602 occurred during the seasons complementary to the highest densities of sea mammals during the breeding/birthing season. This is stronger evidence for a year-round presence at the site than exists at CA-SMI-528. Furthermore, fishing was the dominant subsistence pursuit at CA-SMI-602, with fish comprising 74% of the total meat weight. Fishing can be done year-round, and the diet would have been supplemented seasonally with sea mammals and shellfish that were available nearby. Because sea mammals were less important at this time than earlier, the placement of the site, which is today at the center of the pinniped rookery, would not have harmed subsistence pursuits. Sea mammal populations

may have been dispersed, but people would have had more coastal access for fishing. Furthermore, the cultural record of bead-making tools and debris, groundstone, a house ring, and the presence of a cemetery all support the interpretation of year-round occupation at CA-SMI-602. Nonetheless, there is no record of a named historical village at Point Bennett, suggesting that the site may not have been occupied at the time of Spanish contact (Glassow et al. 2010; Johnson 1993).

This study highlights an important limitation intrinsic to the current methodology of using California mussels to infer site seasonality—i.e., that it can only directly provide information about the season of mussel harvesting, and not about the full range of seasonal occupation of the site. It is likely a good proxy during periods and in places where shellfish were the primary food source (SMI-528, Stratum 3; see also Jazwa et al. 2015a). When mussels were only one component of overall diet, it is necessary to consider other factors that supplement interpretations about site seasonality. This is the case for CA-SMI-528, Stratum 1, in which shellfish make up 10% of the total meat weight, and for CA-SMI-602, where shellfish make up only 2% of the total meat weight. In those cases, seasonal variability in the abundance of sea mammals is used to better understand site seasonality.

A second contribution of this study is the use of a new approach to analyze $\delta^{18}O$ data to infer site seasonality. The method currently used—in which a second sample is drilled in each shell—is a major improvement over the use of a single sample from each shell (Culleton et al. 2009). The most important advance it offered was that it helped to distinguish shells collected during periods of intermediate temperature (spring and fall), by providing information about whether the SST was increasing or decreasing during the month prior to the time when the shells were collected. It also helped to more accurately place mussels on the annual curve if the calculated SST at the time of collection was outside the range of the individual profile shell (e.g., Fig. 5). This method also provides a very intuitive way to look at where individual mussels fit on the seasonal SST cycle. However, there are three important limitations to this method. First, where points are placed on the curve is subjective and a potential source of error. Second, points tend to cluster during periods of rapid SST change,

primarily because of the large range of SST that it includes. And third, estimating SST from Equation 1 is a potential source of error, since the value of −0.26‰ we use for $\delta w$ is an island-wide average for Santa Rosa Island drawn from samples collected during the summer of 2014. This should vary geographically and temporally, and could influence the estimated SST values.

The new method, in which $\delta^{18}O$ is plotted against the monthly change in $\delta^{18}O$, helps to remedy these limitations. Most obviously, by plotting only isotopic values rather than calculated SST, any error in the seawater $\delta w$ value that is used is mitigated. Additionally, the placement of the points in graphical space is less subjective, which addresses the first two limitations of the previous method. However, in the new method, the seasonal boundaries are less concrete, with the division between warm and cool water still dictated by an individual shell profile, which may not be fully representative of the full range of SST fluctuation. Additionally, it is not as intuitive as the annual curve method. Therefore, using both methods together to analyze isotopic data could be a beneficial approach to verify interpretations about the season of mussel harvesting.

## CONCLUSION

Evidence for mussel harvesting from the midden assemblage at CA-SMI-528 is primarily focused during the spring, although there is evidence of winter and early summer collection as well. This pattern was evident during both the middle (Stratum 3) and late (Stratum 1) Holocene. This range is coincident with the periods of highest sea mammal density at Point Bennett, and suggests that occupation of CA-SMI-528 may have been part of a seasonal mobility strategy. During the middle Holocene, people likely visited the site seasonally to collect shellfish, including large red abalones, and opportunistically hunt sea mammals. The high density of sea mammal remains in the late Holocene deposits suggests that use of the location was related to hunting the large populations of sea mammals near the site. CA-SMI-528 is located at the edge of the rookery, likely in part to prevent the displacement of the sea mammal populations.

There is a shift in the record of season of mussel harvesting at Point Bennett during the Late Period at the nearby site, CA-SMI-602. At that time, the $\delta^{18}O$ data

suggest mussel harvesting during the early summer and the fall, but not during the spring. This could suggest an expansion in the annual range of occupation of the location, with mussel collection opposite the periods with the highest density of sea mammals. This, along with other evidence of permanent occupation, including bead-making tools and debris, groundstone, a house ring, and the presence of a cemetery, all support the interpretation of year-round occupation at CA-SMI-602. It is clear that people shifted their attention to fishing at this time, and they may have disturbed patterns of sea mammal breeding by moving into their territory. Nonetheless, there is still evidence of sea mammal hunting at this site, suggesting that humans did not completely displace the rookery at Point Bennett.

This study builds upon the well-established technique for determining site seasonality using stable oxygen isotopic analysis. We demonstrate the benefits and limitations of two methods for analyzing $\delta^{18}O$ data and inferring season of collection. By both plotting shells against an annual SST curve and plotting the stable isotopic value against monthly change, we can check both methods and attempt to negate the drawbacks of each. By increasing the precision with which we can assign occupation of a site to an individual season, there are many archaeological questions that can be addressed. This includes studies of seasonal subsistence patterns, resource availability, technological change, and settlement permanence. These are all factors that we have applied to Point Bennett and California's Channel Islands, but they are also applicable in many other coastal environments where site seasonality is common. By studying seasonal movements among human populations, it is possible to better understand human subsistence and decision-making in light of both annual and long-term patterns of environmental change.

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