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– ARTICLE –

Shellfish, Seasonality, and Sedentism: $\delta^{18}O$ Analysis of California Mussels from Early Holocene Shell Middens on San Miguel Island, California

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ABSTRACT

We estimate seasonality of shellfish harvest and site occupation for four Early Holocene shell middens on California's San Miguel Island using a dataset of 449 $\delta^{18}O$ measurements from 84 mussel shells (*Mytilus californianus*). Seasonality was assigned to prehistoric mussels using paleo sea-surface temperature (PSST) estimates from isotopic data obtained across full shell profiles. The results suggest that PSSTs around San Miguel Island were generally cooler between ~10,000–8600 calBP and that mussels were harvested in a range of water temperatures which suggest a mix of seasonal and year round harvesting at the four sites. Two substantial shell middens dated to ~10,000 and ~9000 calBP appear to have been residential basecamps where Paleocoastal peoples harvested shellfish during all four seasons. These data suggest that Early Holocene peoples occupied the Channel Islands year round and highlight the importance of stable isotope analysis of marine shells for helping evaluate human settlement and subsistence strategies along the Pacific Coast.

Keywords: California's Channel Islands, stable oxygen isotopes, Paleocoastal adaptations

INTRODUCTION

There is growing interest among researchers regarding the antiquity of maritime adaptations, the productivity of marine environments, and early human commitment to island and coastal lifeways throughout the Pacific region (see Des Lauriers 2006; Erlandson 2001; Kirch & Hunt 1997; O'Connor *et al.* 2011; Yesner *et al.* 2004). California's Northern Channel Islands (NCI), colonised by Paleocoastal peoples at least 13,000 calendar years (calBP) ago, have produced some of the earliest evidence for maritime adaptations and seafaring in the Americas (see Erlandson *et al.* 2011). Despite the great antiquity of a human presence on the NCI, some scholars have questioned the permanence of their early occupation or the level of human commitment to maritime lifeways in the New World (e.g., Balter 2011; Yesner *et al.* 2004). Because the islands have been situated within 10–20 km of the adjacent mainland since the Terminal Pleistocene, it is possible that the earliest island sites represent brief forays by mainland peoples who were primarily terrestrial foragers. We evaluate this hypothesis in this paper using stable isotope analysis of archaeological shells.

At the end of the Last Glacial Maximum (LGM), the NCI formed a single landmass known as Santarosae (Johnson 1983; Kennett *et al.* 2008; Orr 1968; Porcasi *et al.* 1999). Since then, climate change and deglaciation of continental ice sheets have increased global sea levels 100–120 meters on the NCI, submerging paleoshorelines and restructuring nearshore ecosystems, with the islands approaching their modern configuration approximately 7500 calBP (see Glassow *et al.* 2010; Kennett *et al.* 2008; Muhs *et al.* 2012). Despite landscape changes and loss of ~75% of island mass since the LGM, over 75 Paleocoastal sites (~13,000 to 7800 calBP) have been identified so far (Erlandson *et al.* 2008, 2011; Rick *et al.* 2005, in press). The lack of structural features and dearth of technologies at many of these early sites led archaeologists to believe that humans only permanently occupied the islands after ~7500 calBP (see Fitzhugh & Kennett 2010:74; Kennett 2005:1; Rick *et al.* 2005:181; Winterhalder *et al.* 2010). Several large and/or dense island shell middens dated to as early as 10,000 calBP have been identified recently, however, suggesting that some degree of sedentism may have developed a millennium or two earlier than previously believed.

Stable oxygen isotope ($\delta^{18}O$) analysis of marine mollusks is an established method for reconstructing sea-

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surface temperatures (SST), near-shore ecology, human settlement patterns, and past environments (e.g. Andrus 2011, 2012; Bailey *et al.* 1983; Culleton *et al.* 2009; Eerkens *et al* 2010; Epstein *et al.* 1951, 1953; Glassow *et al.* 1994; 2012, Jones *et al.* 2008; Kennett 2005; Kennett & Voorhies 1995; Killingley 1981; Kimball *et al.* 2009; Rick *et al.* 2006; Shackleton 1973; Schweikhardt *et al.* 2011). On the NCI, $\delta^{18}O$ analysis has provided a wealth of information for reconstructing paleo-SST (PSST) and identifying seasonality of shellfish harvesting and site occupation (e.g. Glassow *et al.* 2012, Gusick 2012; Jew *et al.* 2013, in press; Kennett 2005, Rick *et al.* 2006, Robbins & Rick 2007). Combining traditional archaeological data with isotopic analysis of shell midden constituents at early sites can provide detailed information about whether specific sites or islands were inhabited by humans seasonally or year round. Recently, Jew *et al.* (2013) examined seasonality of mussel harvesting from shells recovered from Paleocoastal sites on San Miguel and Santa Rosa islands. At CA-SMI-693, a small and sparse 8800 year old shell midden on western San Miguel Island that produced almost no artifacts, analysis of mussel shells supported a seasonal occupation during the summer-fall months (Jew *et al.* 2013). In contrast, analysis of mussel shells from a large 8200 year old shell midden (CA-SRI-666) on eastern Santa Rosa Island, suggested that shellfish were harvested during all four seasons of an annual cycle. Year round occupation of CA-SRI-666 was supported by a diverse assemblage of marine and estuarine shellfish and lithic artifacts, the latter including bifaces, unifaces, cores and core tools, flake tools, and abundant chipped stone tool debris.

Building off our earlier work at CA-SRI-666 on Santa Rosa Island, in this study we use $\delta^{18}O$ analysis of California mussel (*Mytilus californianus*) shells from four sites on San Miguel Island to examine the nature of human settlement on the NCI between ~10,000 and 8600 calBP. We begin by describing the sites investigated and establishing baseline predictions about the seasonal vs. year round occupation of each site. We then create PSST estimates for each component using $\delta^{18}O$ data from extended shell profiles adjusted using seasonal ranges from modern SST near San Miguel Island. From these data, we identify shellfish harvesting patterns, and discuss human mobility and sedentism on San Miguel Island during the Early Holocene, demonstrating the importance of our results and approach for archaeologists throughout the Pacific Rim.

PALEOCOASTAL SITES ON SAN MIGUEL ISLAND

From east to west, the NCI include Anacapa, Santa Cruz, Santa Rosa, and San Miguel. Today, the islands lie ~20 to 42 kilometers off the California Coast and range in size from the smallest (Anacapa) at ~2.6 km² to the largest (Santa Cruz) at ~249 km². During the LGM, the eastern end of Santarosae was only six to eight km from the mainland (Kennett *et al.* 2008). Because the NCI are a continental island group, Paleocoastal peoples from the adjacent mainland may have used the islands seasonally, operating from residential bases along the mainland coast. Unlike many more remote Pacific Islands, the close proximity to the mainland raises questions about whether the NCI were first colonised by humans on a permanent or year round basis.

For this study, we selected four Early Holocene shell middens on San Miguel Island (Figure 1) for $\delta^{18}O$ analysis: CA-SMI-261, CA-SMI-507, CA-SMI-522, and CA-SMI-604.

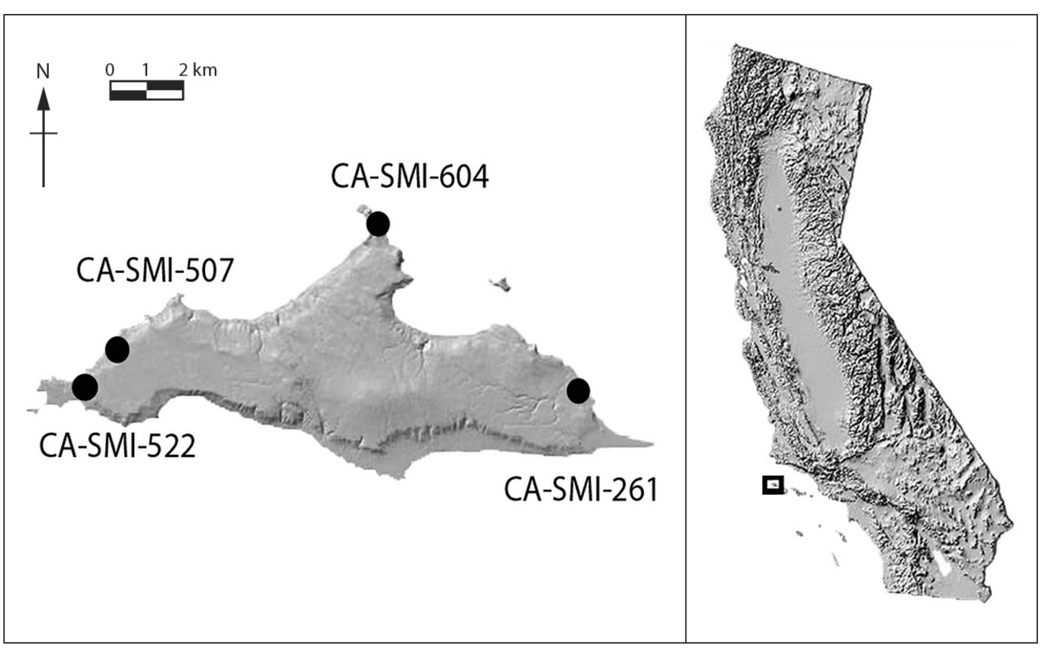

Figure 1. Map of San Miguel Island including the approximate locations of Paleocoastal sites selected for $\delta^{18}O$ analysis.

Each of these sites produced well-preserved mussel shells, contextual data from surface surveys and subsurface excavations, and radiocarbon dates ranging from ~10,000 to 8600 calBP (Table 1). Estimating the nature of Paleocoastal occupations on the NCI is difficult because many early sites have been lost to or damaged by sea level rise, coastal erosion, pinniped trampling, and other erosion or destructive processes (Rick 2002; Rick *et al.* 2009). Many Paleocoastal sites on the NCI are lithic scatters without faunal remains, or small middens that appear to have been short-term camps or shellfish processing sites where artifacts are rare (Erlandson *et al.* 2008; Rick *et al.* 2005, in press). Despite these issues, preliminary predictions for the length and intensity of individual site occupations can be inferred from site size, the density and diversity of faunal assemblages, and the range of artifact types recovered.

CA-SMI-261 (Daisy Cave), located on the northeast coast of San Miguel, is a multi-component cave and rock shelter occupied between ~11,600 and 700 calBP (Erlandson *et al.* 1996). Cordage and basketry (Connolly *et al.* 1995), sea mammal hunting, fishing technologies (Rick *et al.* 2001), and chipped stone bifaces (see Erlandson & Jew 2009) have been found in the Early Holocene strata E and F, dated between about 10,000 and 8600 calBP (Erlandson *et al.* 1996: 365–366). California mussels were selected for $\delta^{18}O$ analysis from stratum E1, dated to ~8600 calBP. The Early Holocene strata at Daisy Cave include several thin midden layers and it is thought that stratum E was deposited during a relatively intense seasonal occupation (Erlandson *et al.* 1996: 64).

Located on the northwest coast of San Miguel Island near Bath Beach Cove, CA-SMI-507 is ~60 meters wide and 100 meters long. Dated to about 9000 calBP, the site was ~1.5 kilometers from the coastline at the time of occupation and near a freshwater spring (Erlandson *et al.* 2009a). Although heavily impacted by wind erosion and water runoff, intact remnants of CA-SMI-507 include several hearths associated with a shell midden eight to 10 cm thick. Excavated samples of this shell midden are dominated by California mussel shells, with lesser amounts of black abalone (*Haliotis cracherodii*), sea urchin (*Strongylocentrotus purpuratus*), and other shellfish and fish remains. The technological assemblage consists of over 100 chipped stone artifacts including numerous leaf-shaped bifaces, cores and core tools, and retouched flake tools. The large size of the site, the abundance and diversity of artifacts, and dense midden deposits suggest that the site was occupied for a substantial period of time (Erlandson *et al.* 2009a: 204) and may have served as a residential base.

Also situated on the northwest coast of San Miguel, CA-SMI-522 is dated to ~10,000 calBP and is the deepest of 11 Early Holocene sites recorded in the area. It extends for approximately 10–12 meters along an exposed sea cliff face, with shell midden deposits ranging between ~25 and 50 cm thick (Erlandson & Rick 2002; Watts 2013). Kritzman described CA-SMI-522 as a likely candidate for a permanent or semi-permanent residence (Rozaire 1965). This substantial midden deposit is dominated by California mussel, black abalone, and other rocky shore shellfish, but also contains marine mammal, fish, and bird bone, as well as bone gorges, chipped stone bifaces, cores and flake tools, a sandstone grinding slab, and Olivella spire-removed beads (Erlandson *et al.* 2008; Watts 2013).

CA-SMI-604 (Seal Cave) is a small rock shelter located near the tip of Harris Point on San Miguel Island's north coast. Seal Cave is a multi-component site with basal midden deposits dated to ~10,000–9200 calBP and is thought to have been used episodically (and perhaps seasonally) during the Holocene (Erlandson *et al.* 2009b). The excavated cave deposits contain a stratified midden ~20–40 cm thick, with the Early Holocene strata dominated by California mussel and to a lesser extent owl limpet (*Lottia gigantea*), black, and red (*Haliotis rufescens*) abalone, fish remains, and an array of technologies including stone and bone tools (see Erlandson *et al.* 2009b). California mussel shells from the basal layers of the midden deposits were selected for oxygen isotope analysis. Watts (2013) also conducted $\delta^{18}O$ analysis on several whole black abalone shells from the site.

Table 1. *Descriptions of four Early Holocene shell middens on San Miguel Island*

Site Name	Location on Island	General site description	Age (calBP)	References
CA-SMI-261 (Daisy Cave)	Northeast coast	Stratified multi-component cave. Early Holocene (10,000–8600 calBP) strata have produced a wide variety of technologies and faunal remains	~11,600–700 (Sampled shells from 8600)	Erlandson *et al.* 1996, 2007; Rick *et al.* 2001, 2003
CA-SMI-507	Northwest coast; Bath Beach Cove	Dense shell midden consisting of rocky shore shellfish, fish and diverse chipped stone tool assemblage	~9000	Erlandson *et al.* 2009a
CA-SMI-522	Northwest coast; Point Bennett area	Large and dense shell midden containing rocky shore shellfish and diverse artifact technologies	~10,000	Erlandson & Rick 2002; Watts 2013
CA-SMI-604 (Seal Cave)	North-central coast; Harris Point	Stratified multi-component shell midden containing a variety of faunal remains and artifacts	~10,100–700 (Sampled shells from 10,000 to 9300)	Erlandson *et al.* 2009b; Rick *et al.* 2003

METHODS

Stable Oxygen Isotope Analysis

Sampling 20 California mussels and one shell profile (at least 12 calcite samples per shell) from each site produced 449 powdered calcite samples for $\delta^{18}O$ analysis. To minimise the effects of variation in mollusk growth rates (see Glassow *et al.* 2012; Jew *et al.* 2013) we selected mid-size mussel shells between ~50–85 mm long. In their first year, California mussels grow between 1 to 5 mm per month, averaging approximately 9 to 12 mm per season (Coe & Fox 1942: 60, 1944; Richards 1946; Phillips 2005; Schmidt 1999). Our selection and sampling methods were adapted from several studies (e.g. Glassow *et al.* 2012; Kennett 2005; Jew *et al.* 2013, Rick *et al.* 2006; Robbins 2011) which include sampling at least five growth bands at 3 mm intervals for 12 mm of growth per shell. This sampling strategy increases the likelihood of identifying PSST changes for the season prior to harvest and improves the accuracy of seasonality determinations (Jew *et al.* 2013).

Prior to submission, shells were inspected for intact terminal growth bands (TGB) and gently scraped with a dental pick, rinsed in deionized water, and etched in a 10 percent HCl solution to remove foreign substances and diagenetically altered carbonate (Bailey *et al.* 1983; Culleton *et al.* 2006; Jones *et al.* 2008; McCrea 1950; Rick *et al.* 2006; Robbins & Rick 2007). Calcite samples were removed from shells using a Sherline 5410 Micromill. Starting with the terminal edge, each shell was drilled at 3 mm intervals for a total of 12 mm of growth. One shell from each assemblage was sampled across the full shell length to provide an extended isotopic sequence for estimating PSST variation through an annual growth cycle. Samples were analyzed in the Stable Isotope Laboratories at the University of Oregon (UO) and Oregon State University (OSU). At both facilities, samples were loaded into exetainers which were placed in an autosampler, flushed with helium, and reacted with several drops of orthophosphoric acid (H_3PO_4, 100 percent concentration) to produce carbon dioxide (CO_2). $\delta^{18}O$ and $\delta^{13}C$ were measured at UO with a Finnigan MAT253 isotope ratio mass spectrometer with continuous helium flow. At OSU, samples were analyzed using a Finnigan/MAT252 isotope ratio mass spectrometer with a deltaPlusXL-continuous flow system. At both laboratories, samples were repeatedly calibrated against standard NBS-19 with precision of oxygen and carbon isotopic ratios was ±0.2‰ (1σ). The results are reported in δ (delta) notation in per mil (‰) in Vienna Pee Dee Belemnite (VPDB) standard using the formula:

$$\delta^{18}O = ((R_{sample} - R_{standard})/R_{standard})X1000$$

where *R* represent heavy/light ratio for the abundance of any two isotopes. A positive δ value represents a more enriched heavy isotope in comparison to the standard where negative δ values are associated with the depletion of heavy isotopes.

Numerous studies have examined mollusk skeletal geochemistry, isotopes temperature conversions, and seasonality in various environments (see Andrus 2012; Epstein 1953; Ford *et al.* 2010; Horibe & Oba 1972; Toro *et al.* 2004; Wanamaker *et al.* 2007, 2008). To remain consistent with previous studies in the region (e.g. Glassow *et al.* 1994; Kennett 2005; Rick *et al.* 2006; Robbins 2011; Robbins & Rick 2007; Watts 2013) we use the Epstein *et al.* (1953) conversion equation, as adjusted by Killingley (1981) to:

$$T(°C) = 16.4 - 4.2(\delta^{18}O_{cc(PDB)} - \delta^{18}O_{water(smow)}) + 0.13(\delta^{18}O_{cc(PDB)} - \delta^{18}O_{water(smow)})^2$$

where T represents temperature, $\delta^{18}O_{cc(PDB)}$ is the oxygen isotope value reported in VPDB, and $\delta^{18}O_{water(smow)}$ is the reported value of the standard mean ocean water (SMOW). The selected $\Delta 0m\ \delta^{18}O_{sw}$(‰) for Early Holocene components were calibrated using Fairbanks (1989: 639) SST averages for the Pacific Ocean. Ice volume corrections ($\delta^{18}O_{water(smow)}$) were further adjusted for local SST variation using an ocean water sample of −0.32‰ taken from waters near Old Ranch Canyon on eastern Santa Rosa Island (see Robbins & Rick 2007: 30). The $\delta^{18}O_{water\ (smow)}$ for mussel shells from each site were adjusted based on the estimated age of the component and reported SST averages for the Pacific. The ice volume correction for Daisy Cave was adjusted to −0.02‰ from 0.3‰ (adding −0.32‰), Seal Cave: 0.13‰ from 0.45‰, CA-SMI-522: 0.28‰ from 0.6‰, and CA-SMI-507: 0.08‰ from 0.4‰. Isotopic determinations for shell profiles are expressed as relative PSST, representing approximate annual temperatures for each component. The water temperature estimates are scaled to seasonal ranges using reported modern SST for near-shore waters around San Miguel Island.

Reconstructing Paleo-SST and Seasonality

For San Miguel Island, the coldest SST occurs during the winter and spring months between December through May, while warmer SST occurs during summer and fall from June through November (see Kennett 2005). Modern SST averages off San Miguel (Figure 2) place the coldest

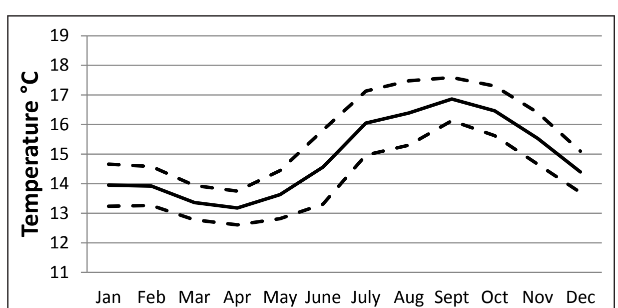

Figure 2. Modern SST averages for ten years (1981–1991, see Kennett 2005: 56) near waters around San Miguel Island, including upper and lower confidence intervals (95%).

water temperatures (~12.5°C) during March-May (spring), with increasing temperatures (~14–16+°C) between June and September (summer-early fall), declining temperatures (16–14°C) from October to December (late fall-early winter), and further decline (14–12.5°C) during January and February (winter). The seasonal ranges of modern SST provided parameters for estimating PSST seasons which are adjusted using isotopic values and inferred temperatures from shell profiles for each site component.

$\delta^{18}O$ values and estimated temperatures from mussel profiles indicate that Early Holocene water temperatures around San Miguel Island were generally cooler with higher variation than modern SST (Figure 3, see online supplementary file for data). Modern $\delta^{18}O$ values reported for California mussels from the Santa Barbara Channel region typically range between ~0.8‰ (12.8°C) to -0.6‰ (18.9°C) (Kennett 1998: 451–453, 2005: 66; Kennett and Kennett 2000: 384) where Early Holocene $\delta^{18}O$ profile values for CA-SMI-604 range between 0.3‰ to 1.3‰, CA-SMI-522 ranges from 0.3‰ to 1.5‰, CA-SMI-261 values are between -0.1‰ to 1.6‰ and CA-SMI-507 are from 0.3‰ to 1.4‰. For estimated PSST for CA-SMI-261, isotopic measurements for a mussel profile (SMI-261#21a-21j) ranged from 10°C to 16.9°C with a mean water temperature of 13.4°C and median of 13°C. Isotopic measurements and inferred PSST for the CA-SMI-604 mussel profile (SMI-604#21a-21l) ranged from 11.1°C to 15°C, with a mean of 12.9°C and a median of 13°C. PSST values for the CA-SMI-507 shell profile (SMI-507#21a-21m) ranged between 11.2°C and 15.6°C with a mean of 12.8°C and a median of 13.4. The profiled shell from CA-SMI-522 (SMI-522#21a-21n) produced water temperature estimates ranging from 10.1°C to 15.4 °C, with a mean of 12.2°C and a median of 12.8°C. The values for each profile provided annual ranges of PSST which were adjusted using the seasonal distributions of modern SST near San Miguel Island (Figure 4).

Seasonal PSST distributions for each component reflect estimated annual water temperature where the warmest temperatures are late summer to early fall and coldest are late winter to early spring (Table 2). The TGB PSST value for each shell is represented by *x* which signifies water temperatures at the point of harvest. The *y* value represents the comparative growth bands or PSST for 3 to 12 mm of extended changes in water temperature for at

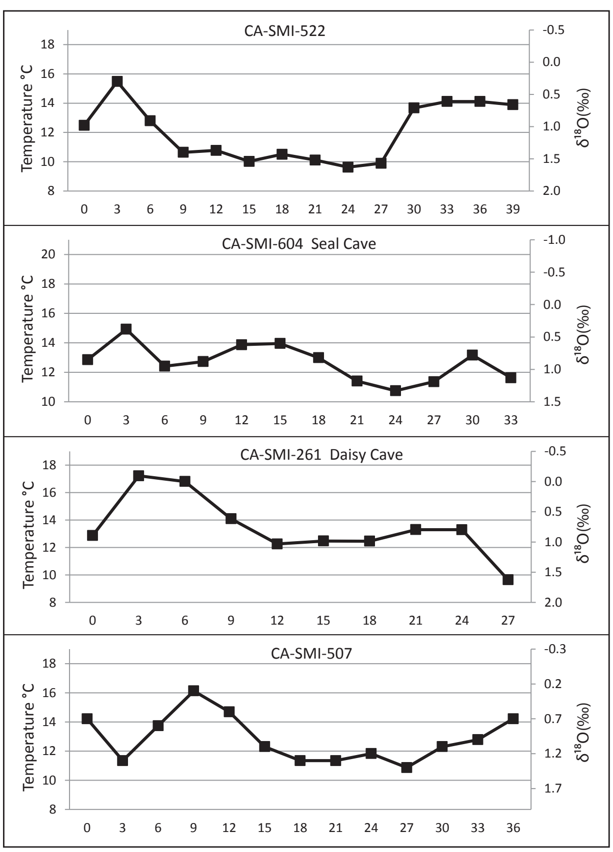

Figure 3. Isotopic profiles and estimated temperatures for each component showing seasonal variation. Mussel profiles include: CA-SMI-522#21(a–n), CA-SMI-604#21(a–l), CA-SMI-261#21(a–j), and CA-SMI-507#21(a–m). The x axis represents the distance from the TGB in mm.

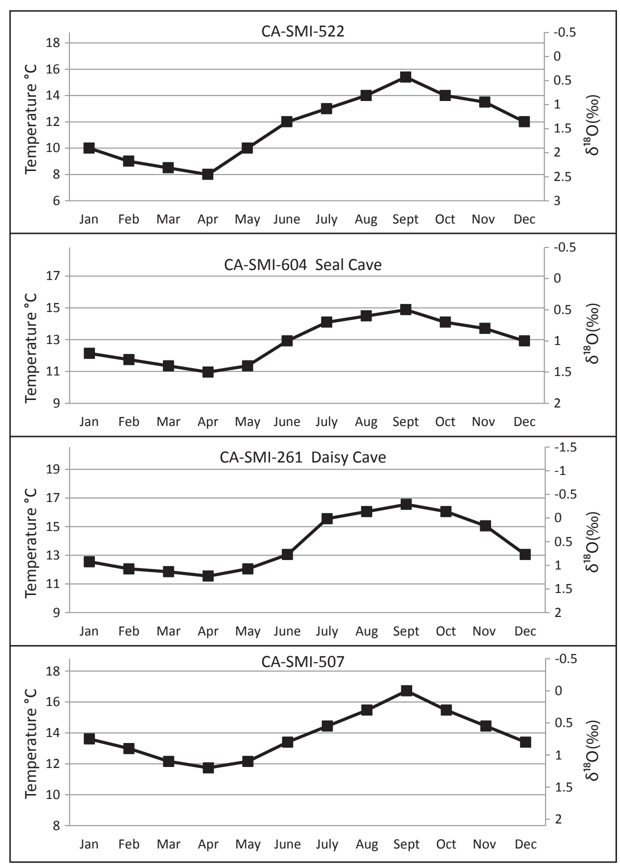

Figure 4. Paleo-SST estimates for CA-SMI-522, CA-SMI-604, CA-SMI-261, and CA-SMI-507 based on inferred temperature ranges for profiled California mussel for each Early Holocene site adjusted to modern seasonal temperature distributions.

Table 2. *Seasonal PSST expectations for selected Paleocoastal assemblages. Values for x represents the TGB PSST and y equals inferred temperatures ranges for 12 mm growth.*

Site / Season	Winter (L. Dec–E. Mar)*	Spring (L. Mar–E. June)	Summer (L. June–E. Sept)	Fall (L. Sept–E. Dec)
CA-SMI-261	x ≤ 13.5°C	x ≤ 13.5°C	x ≥ 13.5°C	x ≥ 13.5°C
CA-SMI-507	x ≤ 13.4°C	x ≤ 13.4°C	x ≥ 13.4°C	x ≥ 13.4°C
CA-SMI-604	x ≤ 13°C	x ≤ 13°C	x ≥ 13°C	x ≥ 13°C
CA-SMI-522	x ≤ 12.8°C	x ≤ 12.8°C	x ≥ 12.8°C	x ≥ 12.8°C
TGB and 3–12 mm comparison	x < y	x > y	x > y	x < y

* Abbreviations for late (L.) and Early (E.)

least one full season of growth (Jew *et al.* 2013). Evaluating the relationship between the two values (*x* and *y*) permits us to distinguish between overall warming and cooling trends prior to harvest and further separate summer-fall and winter-spring. PSST values for each individual shell were compared to modeled seasonal estimates and assigned a season of harvest. Seasonality for each shell is summarised by component and reported in percentages. To compare similarities and differences in estimated PSST from recovered shells at each site, we conducted an analysis of variance (ANOVA) using an orthogonal multiple comparisons test to identify statistically significant and non-significant subsets. These results are used to discuss similarities and differences between water temperatures around San Miguel Island during the Early Holocene.

RESULTS

Our analysis suggests that on San Miguel Island between 10,000 and 8600 calBP, the harvesting of shellfish occurred during all four seasons, although the seasonal signatures varied between sites (Table 3). At CA-SMI-522, the oldest site sampled at ~10,000 calBP, seasonal signatures suggest that mussels were harvested during all four seasons of an annual cycle, with an emphasis on summer (n=8) and fall (n=6), and lower intensity during spring (n=3), and winter (n=3). This is consistent with results obtained by Watts (2013) from an analysis of several black abalone shells from the same midden deposits. The basal layer of CA-SMI-604, dated between ~10,000 and 9300 calBP, contained mussels harvested in fall (n=8), summer (n=6), and winter (n=6), with no evidence for spring collecting. About 9000 years ago at CA-SMI-507, our data suggest that mussels were harvested during four distinct seasons, in the summer (n=6), winter (n=6), spring (n=5), and fall (n=3). Similar to Seal Cave, mussels recovered from the 8600 year old component of Daisy Cave appear to have been harvested in summer (n=10), fall (n=8), and to a lesser extent winter (n=2), with no evidence for spring harvest.

Reconstructed water temperature estimates from mussel shells recovered from Early Holocene components on San Miguel Island ranged primarily between ~10°C to 16°C (Figure 5), with water temperatures slightly cooler than modern SST. For reported temperatures by component, CA-SMI-261 and CA-SMI-604 produced the highest overall mean PSST at ~14°C followed by CA-SMI-522 with a mean of 13.6°C and CA-SMI-507 with the coldest reported mean at 12.7°C. Daisy Cave is the youngest of the components at ~8600 calBP and is also located furthest east, where modern average SST tend to be increasingly warmer. The highest PSST variation within a component is CA-SMI-522 with a maximum estimated temperature of 19.1°C and minimum of 8.3°C. CA-SMI-522 is the oldest and westernmost of the site components analyzed, and appears to have been occupied during four distinct seasons.

The results from the ANOVA using orthogonal multiple comparisons for PSST averages between all sites were statistically significant ($F=14.12$, $df=3,396$, $p<0.01$) including water temperatures for shells from CA-SMI-507 and CA-SMI-522 ($F=14.18$, $df=1$, $p<0.01$). There were no significant differences between CA-SMI-604 and CA-SMI-261 ($F=.12$, $df=1$, $p=0.7$). Comparing mean temperatures for all TGB

Table 3. *Seasonal distribution and percentages of harvested California mussel shells from Early Holocene sites on San Miguel Island.*

Site (SMI-)		Component Age (calBP)	Winter	Spring	Summer	Fall
261	Unit D stratum E	~8600	2 (10%)	0 (0%)	10 (50%)	8 (40%)
507	Unit 1 level I	~9000	6 (30%)	5 (25%)	6 (30%)	3 (15%)
604	Unit 1 level III & IV	~9300–10,000	6 (30%)	0 (0%)	6 (30%)	8 (40%)
522	Unit 2 levels I & II	~10,000	3 (15%)	3 (15%)	8 (40%)	6 (30%)

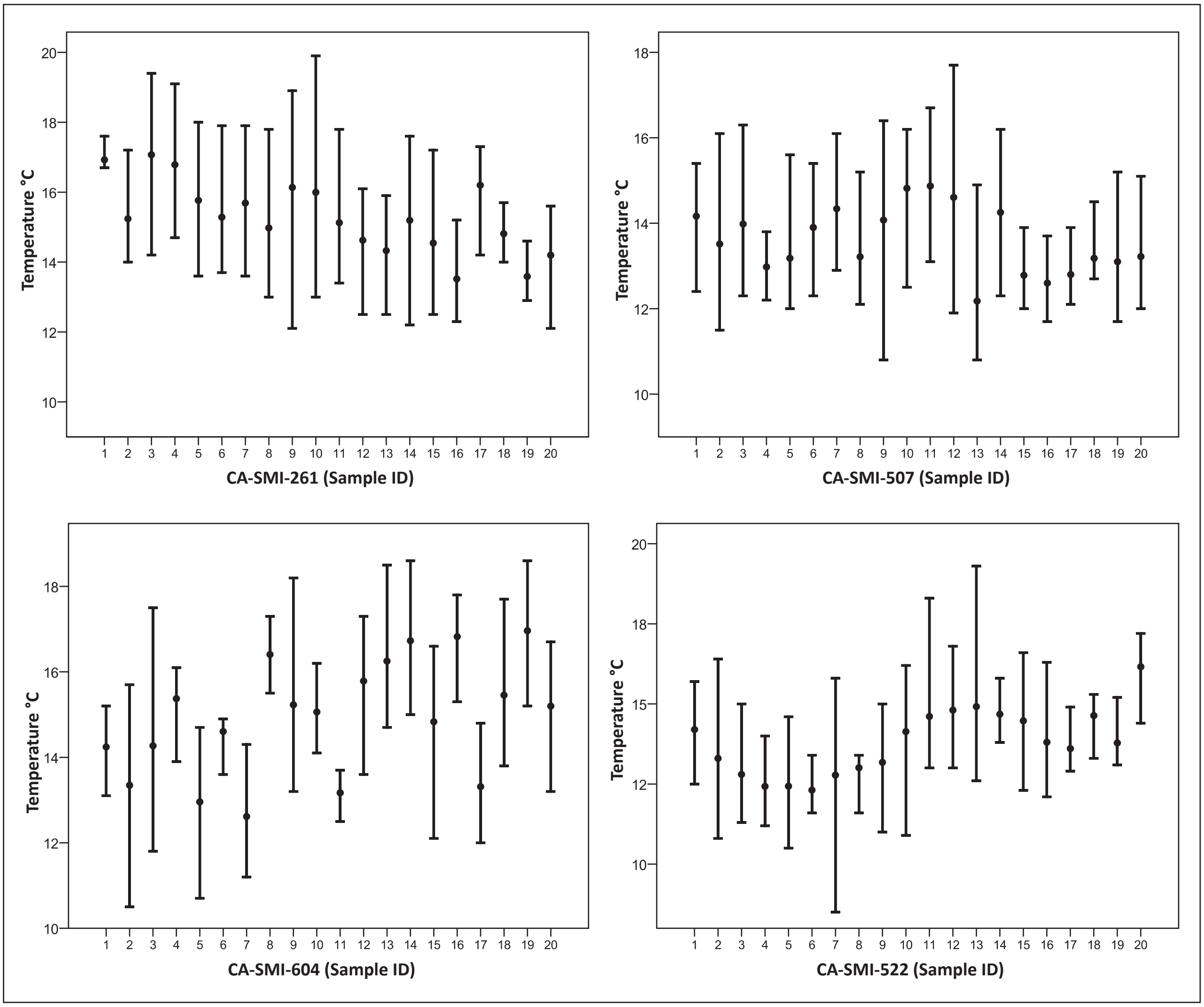

Figure 5. Minimum, maximum, and means for sampled shells. Sample ID #s are presented along the x-axis

shells at each site revealed that shellfish were harvested in cooler water temperatures than modern SST. The warmest average TGB water temperature was from CA-SMI-261 (0.6‰, 13.9°C) and CA-SMI-522 (0.9‰, 13.8°C) with cooler harvesting temperature averages at CA-SMI-604 (0.9‰, 13.3°C) and CA-SMI-507 (0.9‰, 12.8°C). These reported averages for total shells and the TGB align closely with our profiled shell averages at each component and also our PSST seasonal estimates.

DISCUSSION AND CONCLUSIONS

Paleo-sea surface temperatures off the coast of San Miguel Island varied during the Early Holocene by geographic location. Based on our statistical analyses, average PSST for CA-SMI-507 and CA-SMI-522, located near the western end of San Miguel Island were statistically different. While these sites are located within 1 kilometer of each other, differences between mean PSST may be explained by several factors including PSST fluctuations between ~10,000 and 9000 years ago, seasonal differences between shellfish harvesting, or mussels deposited at CA-SMI-507 originating in cooler intertidal or subtidal zones. Explaining the similarities in water temperatures between CA-SMI-604 and CA-SMI-261 is difficult because of high PSST fluctuations reported for Early Holocene mussels recovered from CA-SMI-261 (see Kennett *et al.* 1997), but similarities may be attributed to when these sites were occupied between 10,000–8600 years ago. Paleocoastal peoples may also have harvested mussels from relatively large areas around each site, leading to some overlap in foraging catchments for each site. Several environmental factors also influence SST in shellfish, including surface air exposure, episodic events, changes in salinity, and upwelling. Compared to modern SST around San Miguel Island, however, mean water temperatures at various locations during the Early Holocene appear to be slightly cooler. On the western end of San Miguel ~10,000 calBP, for instance, $\delta^{18}O$ values are generally enriched and estimated SST is slightly cooler, on the northern tip between ~10,000–9200 calBP and along the northeast coast at ~8600 calBP, PSST were one to two degrees warmer on average than the west end. General trends for reported PSST at each site are also affected by seasonality of shellfish harvest. At CA-SMI-261, for instance, the higher reported water temperatures may be attributed to a predominately summer and fall harvest when SST is typically the warmest.

Based on our results, three of the four sites corroborate earlier predictions based on archaeological evidence. At Daisy Cave, $\delta^{18}O$ analysis suggests shellfish were collected and deposited in strata E1 seasonally during the summer and fall, consistent with earlier predictions by Erlandson *et al.* (1996: 64). Two shells (CA-SMI-261# 5, 7) assigned winter harvesting produced TGB values of 12.4°C, approximately one degree cooler than estimated seasonal PSST values. For both shells, the average extended growth values were 15°C which suggest that these shells were harvested in late fall. However, to remain consistent in assigning seasonality, we left these as winter harvest because of the relatively low TGB PSST values. Given the seasonal distribution of the other shells at this site, these outliers likely represent cold episodic events during the end of fall. At Seal Cave, shellfish were collected mostly in fall, followed to a lesser extent in summer and winter. Seal Cave was thought to be used episodically, and the seasonal distribution of shellfish may represent a multi-seasonal occupation or more likely, short-term use throughout different seasons over an extended period of time. Unlike open air sites, cave sites are ideal locations to return to seasonally, where people could process shellfish or perform other activities sheltered from wind and rain.

Seasonal distributions of shellfish deposited at CA-SMI-507 and archaeological evidence suggests year round occupation of the site ~9000 years ago. Here, California mussels were harvested relatively equally throughout all seasons. The expansive shell midden contains a variety of shellfish available year round including significant quantities of black abalone, owl limpet, and sea urchin. Located near a freshwater spring, the site contains large numbers and a wide variety of chipped stone tools that suggest other activities beyond shellfish processing (Erlandson *et al.* 2009a).

CA-SMI-522, also located in proximity to a freshwater source, contains a diverse faunal assemblage of marine shellfish, some fish and marine mammal remains, and a variety of bone, shell, and stone artifacts. Based on our isotopic results, mussels were collected throughout the year with decreased harvesting during spring and winter. The decreased reliance on mussels during these seasons may have been substituted by other marine shellfish including black abalone and owl limpet or fish such as rockfish (*Sebastes* sp.), surfperch (Embioticidae), California sheephead (*Semicossyphus pulcher*), and cabezon (*Scorpaenichthys marmoratus*) – all of which have been found in the assemblage (Watts 2013). Similar to CA-SMI-507, this site provides archaeological and isotopic evidence consistent with a relatively permanent residential base camp.

Several lines of evidence suggest that Paleocoastal peoples were more sedentary and held a stronger commitment to the NCI well before 7500 calBP. A large cemetery at CA-SRI-3 on the northwest coast of Santa Rosa Island, radiocarbon dated to ~7400 calBP, has long been viewed as the earliest evidence for a sustained and sedentary occupation of the islands (Erlandson 1994: 188–189; Kennett 2005; Orr 1968; Winterhalder *et al.* 2010). Recent analysis of California mussel shells from a large shell midden (CA-SRI-666) located on eastern Santa Rosa produced evidence of year round shellfish harvesting and probable sedentism at ~8200 calBP (Jew *et al.* in press). The remains of migratory geese at CA-SRI-512 at ~11,750 calBP suggest a late fall or winter occupation of central Santarosae (Erlandson *et al.* 2011). Winter shellfish harvesting at CA-SMI-507, CA-SMI-604, and CA-SMI-522 also documents winter occupations on San Miguel Island. Evidence of year round shellfish harvesting at CA-SMI-507 and CA-SMI-522, combined with archaeological evidence suggests that these sites were probably residential base camps ~10,000–9000 years ago. Distinctive Paleocoastal chipped stone projectiles – Channel Island Barbed (CIB) and Channel Island Amol (CIA) points (Erlandson 2013; Erlandson *et al.* 2011; Glassow *et al.* 2008) – that are relatively common on the NCI are also rare on the adjacent mainland, suggesting that islanders and mainlanders had only limited interaction during the Paleocoastal period.

These archaeological and archaeometric data sets suggest that Paleocoastal peoples occupied the NCI year round at least two millennia earlier than previously believed. Further isotopic analyses and archaeological surveys and excavations are needed to increase our understanding of the permanence of Paleocoastal occupations on the Channel Islands. Considering that much of the coastal landscape these early maritime peoples inhabited prior to Holocene sea level rise is now underwater, the large number of early sites identified is impressive. This implies that there were larger numbers of people on the NCI, apparently occupying the islands year round, during a time period that has generally been considered to be one of low population densities, high human mobility, and limited effects on island ecosystems.

Ultimately, our results suggest that the NCI were not a marginal habitat compared to the mainland as has been long assumed. Rather, they were an optimal maritime landscape that provided a diverse array of marine and terrestrial resources. If the Americas were colonised via a coastal migration around the Pacific Rim, we might expect similar evidence for early and relatively intensive island occupations to emerge from other continental island groups. This idea is supported by recent data from the Queen Charlotte Islands and Cedros Island (Des Lauriers 2006; Erlandson *et al.* 2008; Fedje *et al.* 2005), but has yet to be more widely applied to other continental island groups around the Pacific Rim. Our study also demonstrates the importance of stable isotope analysis for investigating a range of issues of importance to coastal and island archaeologists throughout the Pacific, especially issues of mobility and sedentism that can help track maritime migrations and a range of cultural and environmental events.

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