PALEOCOASTAL RESOURCE USE AND HUMAN SEDENTISM IN ISLAND ENVIRONMENTS: A CASE STUDY FROM CALIFORNIA'S NORTHERN CHANNEL ISLANDS

by

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A DISSERTATION

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DISSERTATION ABSTRACT

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Title: Paleocoastal Resource Use and Human Sedentism in Island Environments: A Case Study from California's Northern Channel Islands

The peopling of the Americas, including the possibility that maritime peoples followed a coastal route from Northeast Asia into the New World, is a topic of major interest in archaeology. Paleocoastal sites on California's Northern Channel Islands (NCI), dating between ~13,000 and 8000 years ago, may support this coastal migration theory. Until recently, however, we knew little about Paleocoastal technologies, settlement, and lifeways on the islands. Combining traditional archaeological approaches with experimental and archaeometric techniques, I examine Paleocoastal settlement and resource use on San Miguel and Santa Rosa islands.

Recently discovered Paleocoastal sites have produced sophisticated chipped stone technologies, with bifacially-flaked points and crescents of extraordinary craftsmanship. Exploring lithic raw material procurement strategies, I demonstrate a Paleocoastal preference for island cherts from sources centered on western Santarosae. Using experimental and archaeometric techniques, I show that Paleocoastal peoples

systematically employed heat-treatment to manufacture finely crafted bifaces from island cherts.

Using stable oxygen isotope ($\delta^{18}O$) analyses of marine shells from Paleocoastal sites, I examine paleo-sea surface temperatures, seasonality of shellfish collecting, and human sedentism. Evaluating whether such occupations were seasonal or year-round, I tested different sampling strategies for California mussel shells, showing that a method used by many California archaeologists provides erroneous seasonality interpretations for ~35 percent of sampled shells. Using a more intensive sampling strategy, I demonstrate that some Paleocoastal sites were used seasonally, but three substantial middens dating to 8200, 9000, and 10,000 cal BP produced evidence for shell harvesting during all four seasons. This suggests that the NCI were occupied more or less permanently and year-round by at least 10,000 years ago.

My research suggests that Paleocoastal peoples had a strong commitment to maritime and island lifeways starting at least 12,000 years ago. From that time until ~8000 years ago, Paleocoastal peoples relied primarily on island resources despite their close proximity to the mainland. The presence of a relatively large, permanent, and distinctive Paleocoastal population on the NCI may also support the coastal migration theory and an even deeper antiquity of human settlement and sedentism on the NCI.

This dissertation includes previously published and unpublished co-authored material.

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CHAPTER I

INTRODUCTION

In the popular imagination, islands have always been exotic places of mystery, isolation, and strange cultural traditions. Archaeological interest in islands, coastal, and maritime environments has flourished since the 1970s, partly due to MacArthur and Wilson's treatise (1967) on quantitative island biogeography. Their principles of island biogeography were incorporated into archaeology by Evans (1973, 1977) and others, who maintained that islands could be studied as isolated laboratories ideal for the scientific archaeologist. During the 1980s, the view of islands as primitive isolates was critiqued by archaeologists (see Fitzpatrick 2004; Rainbird 2007) who argued that humans had the technological capability to transcend oceanic barriers and other physical boundaries.

If waterways did not limit human movements—or did so differentially depending on geographic distance from the mainland, technology, and other factors—how can archaeologists generalize isolation and interaction in island societies when they are typically referring to remote oceanic islands? More importantly, how do the availability, location, and abundance of island resources influence human decisions to colonize islands in more continental rather than oceanic island environments?

Along with the degree to which limited resources and geographic or cultural isolation affect island societies, archaeologists and other scholars have also debated the antiquity and productivity of coastal adaptations (see Erlandson 2001; Osborn 1977; Sauer 1962; Yesner 1980) and commitment to island lifeways. Lingering concepts of island biogeography, islands as laboratories, and the marginality of island and coastal resources (see Fitzpatrick 2004) have strongly influenced the general theoretical development of island archaeology.

Of course, islands vary in size, biodiversity, available resources, and distance to other habitable land masses. A 'true island' is defined as a landmass completely bounded by water and includes oceanic, continental shelf, dry and non-marine islands (Whittaker 1998:7). Continental islands are further divided (see Broodbank 2000) into sub-continental islands or what Held (1989:10) referred to as 'matchbox continents' (e.g. Japan, Britain, and Madagascar) and smaller continental islands (e.g. California's Channel Islands).

A strong theoretical focus on oceanic islands of "smallness and remoteness" (Rainbird 2007:20) has limited current understanding of the geographical and temporal variability of islands within island archaeology (see Moss 2004:166). With some exceptions (e.g., California's Channel Islands, the Alexander Archipelago in Southeast Alaska, New Guinea, the Bismarck Archipelago and Solomon Islands, see also Allen 1996), studies in island archaeology have been dominated by remote oceanic islands with a relatively short history of human occupation spanning the last 5000 years or less. Recent debate about the need for a sub-discipline of island archaeology (see Fitzpatrick

2004), as well as general theories pertaining to isolation, interaction, and circumscription have been supported and developed based on studies in the Pacific, Caribbean, and Mediterranean.

Because the human colonization of many remote islands did not occur until the Middle or Late Holocene, the effects of natural geographic changes on island cultures have been relatively neglected in general theory building for island colonization studies (Nun 1990). Studies in Remote Oceania, for instance, explore themes (see Kirch and Weisler 1994) of colonization and social complexity (e.g. Anderson 2002, 2008; Clark et al. 2006; Gibbons 2001; Kirch 1996; Matisoo-Smith 2009), environmental degradation through human impacts (e.g. Anderson 2002; Kirch 1996), and subsistence activities such as the translocation of resources and agriculture (e.g. Jones et al. 2007; Kirch et al. 2004; Matisoo-Smith 2007), most of which occurred during the Late Holocene. Pacific studies of ‘non subsistence’ resources (see McCoy 1990) have focused on the diffusion of Lapita pottery (see Clark et al. 2000; Kirch 1997; Smith 1995; Summerhayes 2000) and stone-tool transport/provenience, including studies on Rapa Nui (a.k.a., Easter Island; see Ayres 1998; Ayres and Beardsley 1988; Ayres and Spear 2000; De Paepe and Veauwen 1997; Lipo et al. 2010), Micronesia (Ayres et al. 1997), and Polynesia (e.g. Sinton and Sinoto 1997; Weisler 1998; Weisler and Kirch 1996).

For islands occupied for more than 5000 years, island size, terrestrial and marine productivity, connectivity to the mainland (see Moss 2008a), and the availability of resources may have changed significantly due to the effects of postglacial sea-level rise and coastal erosion over the millennia. Archaeologists have become increasingly aware of the need to expand the general focus of the archaeology of islands to accommodate a broader geographic range of island types containing deeper histories of human settlement (see Erlandson et al. 2008a, b; Fitzpatrick 2004; Kennett 2005; Moss 2004, 2008b; Winterhalder et al. 2010, and others).

Recent research has shown that seafaring Paleoindians were present on California's Northern Channel Islands (NCI) by Clovis times (~13,000 cal BP). By at least 12,000 calendar years before present (cal BP) these Paleocoastal peoples, possessing stemmed points and crescents similar to those found in Western Stemmed Tradition (WST) or Western Pluvial Lakes Tradition (WPLT) sites of the Far West, were hunting sea mammals, seabirds, and waterfowl, catching fish, and collecting shellfish (Erlandson et al. 2011; Johnson et al. 2002). Skeptics (see Balter 2011; Yesner et al. 2004) have suggested that these Paleocoastal sites may represent seasonal or occasional visits to the islands by mainland peoples, questioning the level of commitment to maritime and island lifeways.

In the last 20 years more than 75 Terminal Pleistocene and Early Holocene sites have been identified on the NCI (see Erlandson et al. 2008a, 2011; Rick et al., 2005, 2013), including some relatively large middens that contain a diverse array of faunal remains and artifact types. The large number of early sites, despite the loss of ~70% of the islands' land area to rising postglacial seas, has led some scholars to suspect that island Paleocoastal populations may have been larger and more permanent than previously believed. Nonetheless, the relatively ephemeral nature of many early NCI shell middens, the absence of structural features, and the dearth of technology at many sites has led most archaeologists to assume that the NCI were only seasonally occupied during the Terminal Pleistocene and Early Holocene, with permanent settlements only appearing after ~7500 cal BP or later (see Fitzhugh and Kennett 2010:74; Kennett 2005:1; Rick et al. 2005:181; Rogers 1929:339; Rozaire 1967:328 Winterhalder et al. 2010).

Important questions, therefore, are whether the earlier NCI Paleocoastal sites represent seasonal or year-round occupations and if island resources such as lithic sources and shellfish were exploited on a limited basis, perhaps seasonally by peoples of the adjacent California mainland or were used more intensively by peoples inhabiting the islands year-round. The presence of permanent resident populations on the NCI during the Paleocoastal period would suggest that island resources were not marginal compared to the mainland, that intensive maritime adaptations developed relatively early along the California Coast, and may even support the coastal migration theory—the idea that some of the first Americans followed Pacific Rim coastlines from Northeast Asia into the New World (see Beck and Jones 2010; Erlandson and Braje 2011).

In this dissertation, I focus on Terminal Pleistocene and Early Holocene archaeological assemblages on the NCI to address the issues outlined above by specifically examining human resource use in continental island environments where continuous landscape change influenced human lifeways on San Miguel and Santa Rosa islands (western Santarosae). After the introduction, Chapters II and III focus on Paleocoastal chipped stone technologies, lithic raw material availability, and manufacturing techniques on western Santarosae. Chapters IV through VI focus on the Early Holocene period where I employ stable oxygen isotope analysis ($\delta^{18}O$) on California mussels from several NCI assemblages to examine seasonality, paleoecology, paleo sea-surface temperatures (PSST), human mobility, and sedentism on the NCI. While each of these chapters was written as stand-alone pieces, collectively they represent several years of research where I applied a variety of analytical and archaeometric techniques to Paleocoastal assemblages to better understand the availability of island resources and human commitment to continental island environments with an emphasis on lithic and shellfish use on the NCI between about 12,000 and 7000 cal BP.

The five articles presented in the core of this dissertation, including three that have already been published or accepted for publication, reflect several years of my own field and laboratory research including previous work on archaeological sites by individuals who share authorship on these publications. While each co-author has contributed to the recovery of artifacts, the recording of sites, or editorial and intellectual recommendations, I am primary author for all manuscripts included and responsible for the development, research design, methods (experiments), analyses, results, and interpretations presented in this dissertation. Co-authors and associated chapters include Jon Erlandson (Chapters II through VI) who has previously worked on all of the sites presented in this dissertation and provided intellectual guidance and editorial comments on several drafts of each manuscript. Frances White, co-author for chapters II and IV, reviewed my statistical analyses and helped in graphical representations of the data for two manuscripts. Other co-authors include Torben Rick (Chapters V and VI), Leslie Reeder-Myers (Chapter V), and Jack Watts (Chapter IV and VI)–who all provided editorial comments, suggestions, and field work assistance on San Miguel or Santa Rosa Islands. I have also contributed to and served as a co-author on several related papers not presented in this dissertation (e.g. Erlandson and Jew 2012; Erlandson et al. 2010a, 2011, 2012; Jew and Erlandson 2012; Rick et al. 2013).

After this introduction, Chapter II, accepted for publication in *North American Archaeology* focuses on human toolstone use and availability during the late Terminal Pleistocene through Early Holocene on the NCI. In this chapter, I examine several Paleocoastal assemblages identifying material and artifact types and discuss human preference of island cherts for formal and expedient chipped stone tool manufacture. Chapter III, published in *California Archaeology*, builds upon the previous chapter specifically looking at intentional annealing (heat treatment) of Cico, Monterey/Tuqan, and Wima island cherts using replicative and comparative studies to examine Paleocoastal lithic assemblages.

After examining toolstone use and manufacture, the next three papers focus on subsistence and settlement issues, specifically California mussel harvesting during the Early Holocene. Chapter IV, accepted for publication in the *Journal of Coastal and Island Archaeology*, examines drilling methods used for calcite sampling of California mussels for $\delta^{18}O$ analysis from CA-SMI-693, an ~8800 year old site on San Miguel Island. From these results, I determine whether mussels were harvested seasonally or year-round and propose a more intensive and systematic method for $\delta^{18}O$ sampling and analysis for California mussels. Chapter V, currently under review in the *Archaeological and Anthropological Sciences*, applies the $\delta^{18}O$ sampling protocols developed in Chapter IV to determine seasonality of shellfish harvesting, reconstruct PSST for waters near Santa Rosa Island, and discuss human sedentism at CA-SRI-666, a large ~8200 year old shell midden located on the east end of Santa Rosa. Chapter VI, which was recently submitted to the *Journal of Pacific Archaeology*, is a larger $\delta^{18}O$ study of the seasonality of shellfish harvesting and human sedentism at four Early Holocene components from CA-SMI-261 (Daisy Cave), CA-SMI-507, CA-SMI-522, and CA-SMI-604 (Seal Cave), all located on San Miguel Island. Finally, Chapter VII presents a summary of my dissertation including recommendations for future research on related issues.

Geographic and Environmental Background

From east to west, the NCI include Anacapa, Santa Cruz, Santa Rosa, and San Miguel islands (Figure 1.1). The NCI have undergone dramatic environmental changes since the end of the Last Glacial Maximum (LGM). When global sea-levels were ~100 to 125 m below present about 20,000 years ago, the NCI were united into a single landmass known as Santarosae Island, the east end of which was just 6-8 km from the mainland (see Johnson 1983; Kennett et al. 2008; Orr 1968; Porcasi et al. 1999). Since the LGM, rising seas have changed the size and configuration of the islands (Figure 1.2): fragmenting Santarosae, increasing the distance to the mainland, and decreasing the habitable land area by up to 75% (Glassow et al. 2010:1.4; Kennett et al. 2008). As sea-level rose and the islands shrank, extensive lowland areas were transformed from terrestrial to marine ecosystems, affecting the distribution and availability of terrestrial and marine resources and also habitable areas for humans. Climatic changes through the Terminal Pleistocene and Holocene also affected the productivity of terrestrial and marine ecosystems (Kennett 2005; Kennett and Kennett 1997, 2000; Kennett et al. 2007; Kinlan et al. 2005) and influenced human settlements and subsistence activities. Geologic outcrops of chert were submerged, for instance, along with coastal archaeological sites and the length and nature of shorelines and near-shore marine habitats has changed continuously (Kinlan et al. 2005:137).Climate oscillated between cool and warm periods throughout the Terminal Pleistocene and Early Holocene (see Kennett 2005:69) which influenced SST and marine productivity around the Channel Islands (Figure 1.3).

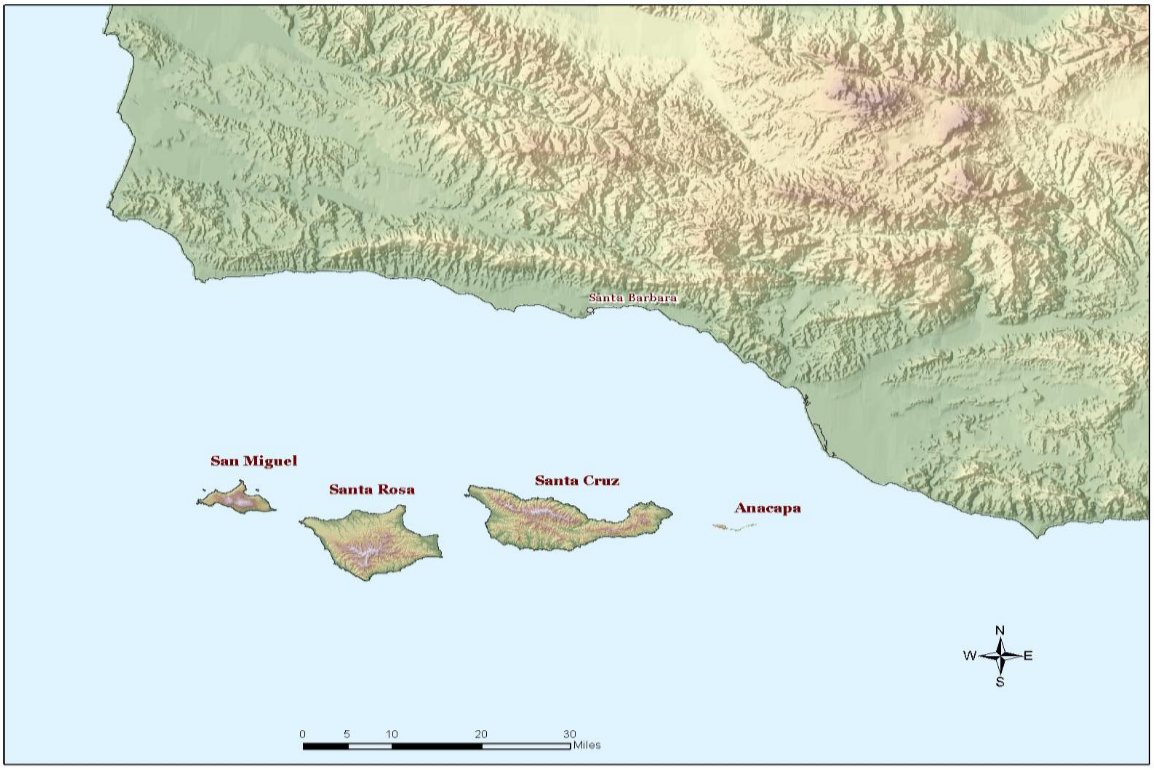

Figure 1.1. Map of Santa Barbara Basin including California's Northern Channel Islands (original by Brian Fulfrost and Jack Watts).

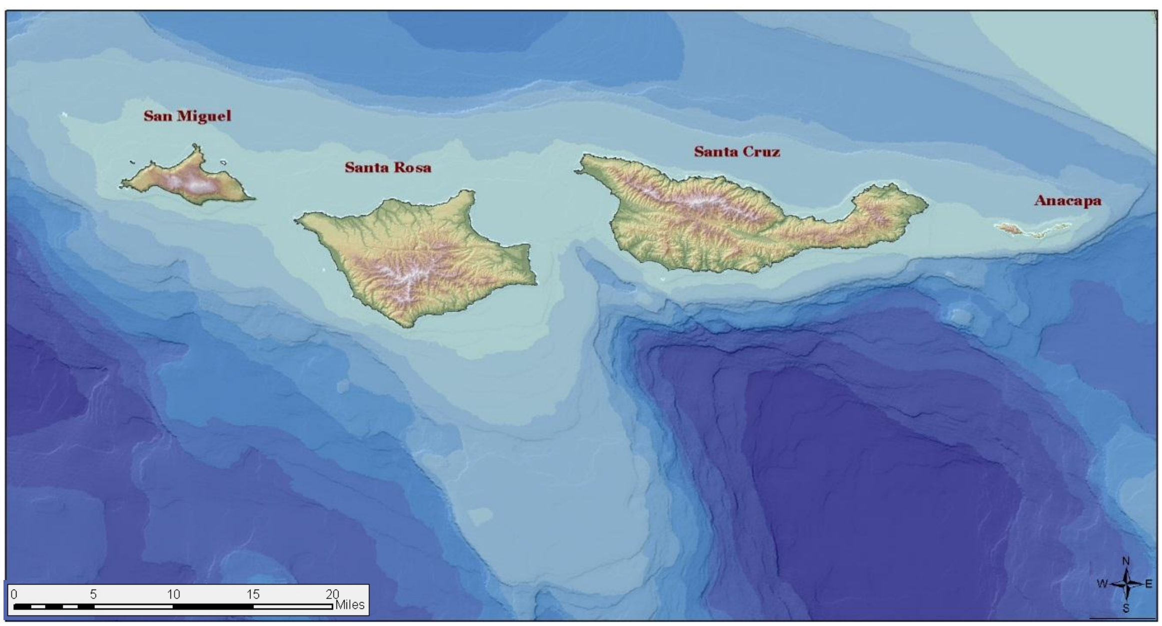

Figure 1.2. Map showing the approximate extent of paleoshorelines (light blue contours) at 12,500 and 11,000 BP (based on an original by Brian Fulfrost and Jack Watts).

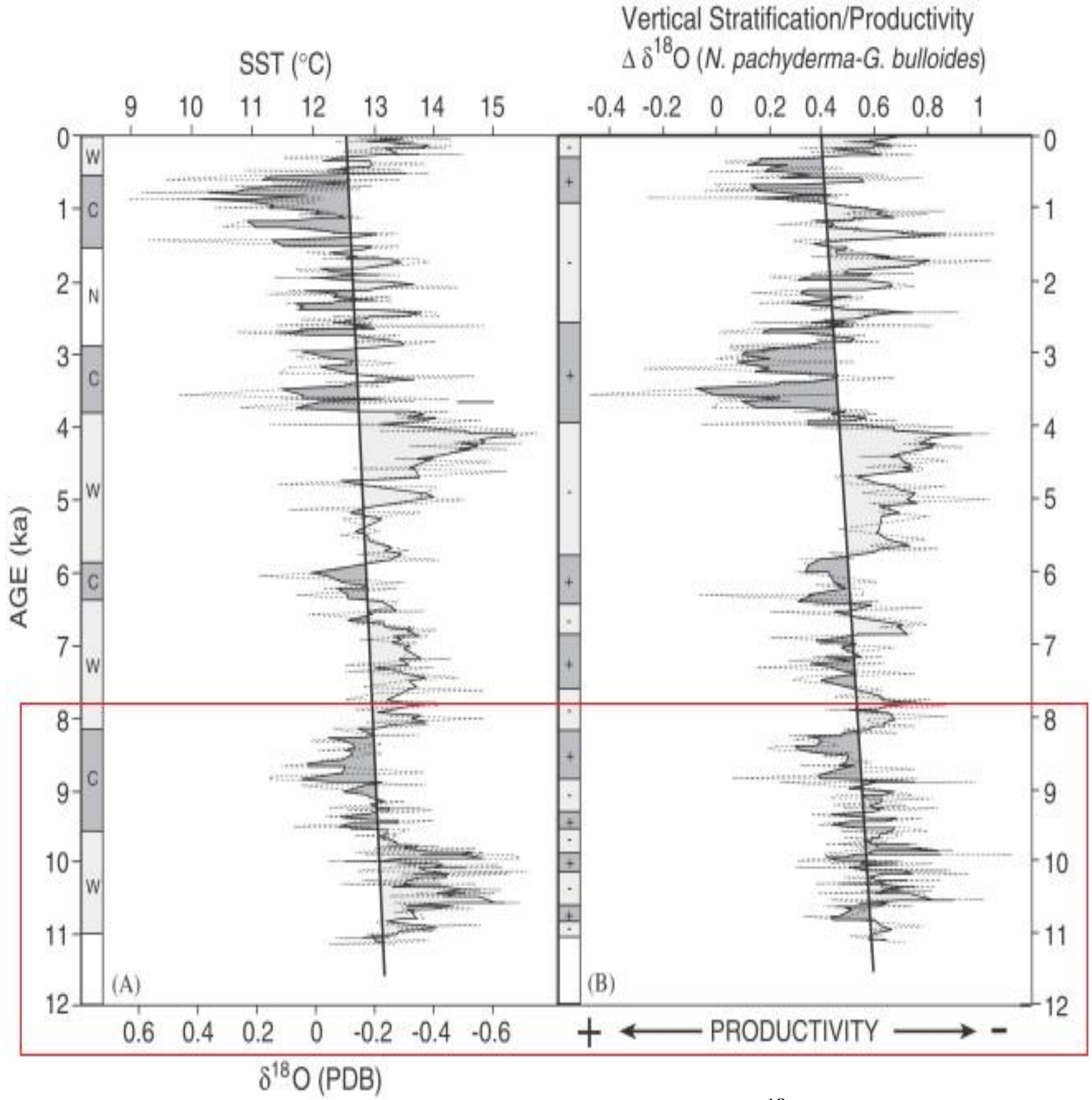

Figure 1.3. Late Pleistocene and Early Holocene (red outline) δ^{18}O sea surface temperatures and inferred paleo-productivity records for Santa Barbara Basin (adjusted after Kennett 2005:66).

Compared to the adjacent mainland, the NCI possess a limited diversity of terrestrial flora and fauna. The Channel Islands have often been portrayed as marginal when compared to the adjacent mainland, which supports theories related to the seasonal occupation of environments of relatively low productivity (Fitzhugh and Kennett 2010). After the extinction of pygmy mammoths about 13,000 years ago, and prior to the ranching era in the 1800s, the largest terrestrial species were the dog, island fox, and the skunk (Rick et al. 2005:171; Schoenherr et al. 1999), at least two of which were probably introduced by humans (Rick et al. 2009a). Vegetation varies on the islands, with the larger islands having a greater diversity of plants including bulbs and trees such as oaks, and pines (Junak et al.1995:46; Timbrook 1993:54-56). Based on the limited availability of terrestrial flora and fauna, the Channel Islands have often been portrayed as marginal when compared to the adjacent mainland, but the historic introduction of livestock and invasive species damaged or destroyed much of the native vegetation on the islands (Brumbaugh 1980; Junak et al. 1995). The recent recovery of island vegetation after livestock removal suggests that the paucity of plant resources on the NCI may have been overemphasized.

The islands and adjacent waters contain a diverse and highly productive array of marine resources, including seabirds and waterfowl, pinnipeds, cetaceans, fish, shellfish, and seaweeds (see Erlandson 1994; Erlandson et al. 2004; Kennett 2005; Rick et al. 2005) many of which are accessible year-round. Sea-surface temperatures around the NCI are influenced by wind patterns and the mixing of waters from the cold-low salinity California current (Figure 1.4) and a warm-high salinity countercurrent (Browne 1994; Hickey 1992; Kennett 2005) which seasonally affects sea surface temperatures in the Santa Barbara Channel.

Figure 1.4. Map of Santa Barbara Basin and modern sea-surface temperature distributions showing the decrease in relative SST from east to west.

Until now (see Chapters IV-VI), we knew relatively little about the PSST around San Miguel and Santa Rosa islands during early human occupations, although Erlandson et al. (2011) hypothesized from zooarchaeological data that near-shore water temperatures may have been lower during the Younger Dryas. The dynamic geography, climate, and changing landscapes of the NCI have greatly influenced human responses in settlement and subsistence strategies. As a result, a significant portion of archaeological practice on the Channel Islands has been directed towards understanding the complex cultural evolution and human behavioral responses that may have been influenced by the dynamic nature of island ecosystems (e.g., Braje 2009; Erlandson et al. 2005; Glassow et al. 2010; Kennett 2005; Kennett et al. 2008; Raab et al. 2002; Rick 2007; Rick et al. 2005).

Previous Archaeological Investigations

The history of archaeological research on the Channel Islands has been reviewed by many authors (Benson 1997; Braje 2009; Glassow et al. 2010; Kennett 2005; Rick 2007; Rick et al. 2005; and others). Archaeological research on the NCI and adjacent California Coast began in the late 1800s although it was crude and focused on cemeteries for the purposes of expanding museum collections. Antiquarians such as Dall (Rick 2007), Schumacher (1875, 1877), Bowers (1890; see Benson 1997), Jones (see Heizer and Elsasser 1956), and Glidden (1919, see Heye 1921) conducted early investigations that produced vague or incomplete reports where all or most of the recovered artifacts lacked specific provenience. Since the early to mid-20th century archaeologists (e.g. Arnold 1983, 2001; Braje 2007; Erlandson and Jew 2012; Glassow 1980; Kennett 2005; Orr 1962; Raab 1996; Rick 2007; Rick et al. 2013; Rogers 1929; Rozaire 1965, 1976) have more systematically assessed archaeological resources of the Channel Islands. Archaeological investigations in the Santa Barbara Channel area have now produced hundreds of reports and publications ranging from small scale excavations to systematic island surveys (see Glassow et al. 2010; Holmes and Johnson 1998:79-184).

Archaeologists working on the Channel Islands have examined a diverse range of issues, including the antiquity of seafaring technologies (e.g. Arnold and Bernard 2005; Erlandson 2001, 2002; Rick et al. 2001), environmental influences on cultural and social complexity (e.g. Arnold 1992, 1995, 1996, 2000, 2001; Kennett 2005; Kennett and Kennett 2000; Raab and Bradford 1997; Raab and Larson 1997), human impacts and historical ecology (e.g. Braje 2007, 2009; Erlandson et al. 2004, 2010b; Porcasi et al. 2000; Rick et al. 2009b), and exchange and trade (e.g. Arnold 1987, 1992, 2001; Gamble 2008; Johnson 2000; Kennett and Conlee 2002; King 1971; Raab and Howard 2002; Rick 2007; Vellanoweth 2001). Recently, archaeologists have focused their field efforts on the identification and investigation on a growing number of Terminal Pleistocene and Early Holocene sites to address issues and theories related to Paleocoastal lifeways on the Channel Islands (Erlandson et al. 2011; Gusick 2012; Rick et al. 2013). Understanding Paleocoastal adaptations and lifeways is particularly important as we continue to document adaptive diversity among the earliest New World peoples, including the importance of marine and other aquatic resources.

Paleocoastal Lifeways

Prehistoric human lifeways on California's Channel Islands have been reviewed by several archaeologists (e.g. Arnold 1992; Braje 2009; Erlandson et al. 2009a, b; Glassow et al. 2010; Kennett 2005; Rick 2007; Rick et al. 2005) and with few exceptions (e.g. Erlandson 1994; Glassow et al. 2008; Kennett 2005; Rick et al. 2005) cultural historical reconstructions have predominately focused on developments after ~7000 cal BP including population demographics, village life, social complexity, technology, subsistence, exchange networks, and craft specialization (e.g. Arnold 1987, 1992; Kennett 2005; King 1971). Documenting Paleocoastal colonization of the islands and associated lifeways is important for understanding long term cultural trajectories which may explain later cultural developments on the islands. In the section that follows, I summarize our current understanding of early peoples on the islands during the Paleocoastal period, providing a context for the chapters to follow. Throughout my dissertation, I have adopted time periods after Glassow et al. (2010; see also Erlandson 1994), with the Terminal Pleistocene spanning ~13,000-10,500 cal BP and the Early Holocene from 10,500-7500 cal BP. The early Paleocoastal period is roughly coeval with the Terminal Pleistocene and the later Paleocoastal period corresponds to the Early Holocene.

Terminal Pleistocene (~13,000-10,500 cal BP)

Less than a dozen Terminal Pleistocene sites have been recorded on the Channel Island (see Erlandson et al. 2011; Rick et al. 2005, 2013) but these sites have greatly increased our understanding of the earliest inhabitants of the NCI. The earliest recorded site, CA-SRI-173 is near Arlington Springs on Santa Rosa Island, where human remains and associated materials have been radiocarbon dated to approximately 13,000 cal BP (see Orr 1962; Johnson et al. 2002; Rick et al. 2005). Also located on Santa Rosa Island at the mouth of Arlington Canyon near Radio Point, CA-SRI-512 dates to ~11,800-11,500 cal BP and has produced an assemblage of waterfowl, seabird, fish, and marine mammal bones associated with a diverse lithic assemblage of crescents, Channel Island Barbed (CIB) points, and chipped stone tool debris (see Erlandson et al. 2011). CA-SRI-26, a smaller site located a few hundred meters east of Arlington Canyon, dates to ~11, 500 cal BP. This deeply buried and stratified site has produced a small assemblage of shellfish, bones of birds, fish, and marine mammals, and chipped stone tools similar to those reported from CA-SRI-512 (see Erlandson et al. 2011).

On San Miguel Island, artifacts and faunal remains recovered from stratum G at CA-SMI-261 (Daisy Cave) date to ~11,500 cal BP and include a small assemblage of chipped stone tools, debris, and shellfish remains from California mussels (*Mytilus californianus*) red abalone (*Haliotis rufescens*), and other rocky intertidal taxa (Erlandson et al. 1996). Also on eastern San Miguel Island near Cardwell Point and in proximity to large Cico and Tuqan chert sources, quarry/workshop/campsites (CA-SMI-678, CA-SMI-679, and CA-SMI-701) occupied between about 12,200-11,200 cal BP suggest that early Paleocoastal peoples manufactured a variety of stone tools from local island cherts including hundreds of chipped stone artifacts such as CIB points, Channel Island Amol (CIA) points (Erlandson 2013), crescents, bifaces, cores and core tools, flake tools, and byproducts such as chipping debris and waste flakes (see Erlandson et al. 2011). Despite an abundance of hunting-related tools, these Cardwell Bluffs sites have produced no animal bone. Shellfish remains from rocky intertidal habitats are abundant, however, and the abundance of cool water taxa such as red abalone, California mussel, and giant chiton (*Cryptochiton stelleri*) suggest that sea surface temperatures off the coast of western San Miguel Island (western Santarosae) were colder than present at that time.

Based on data from these early sites, current evidence suggests that Terminal Pleistocene peoples occupied areas in close proximity to caves, freshwater springs, and chert sources (Erlandson 1994; Erlandson et al. 2009b; Rick et al. 2005), manufactured a variety of expedient and formal chipped stone tools, and maintained a diverse maritime subsistence economy consisting of bird and sea mammal hunting, fishing, and shellfish gathering from subtidal, intertidal, kelp forest, and estuarine environments. Based on the presence of stemmed points and crescents, Erlandson et al. (2011) suggested that these early Paleocoastal peoples were technologically related to interior peoples associated with the Western Stemmed or Western Pluvial Lakes traditions, which Beck and Jones (2010) suggested were descended from coastal immigrants moving from Northeast Asia and Beringia down the Pacific Coast of North America.

Early Holocene (10,500-7500 cal BP)

Compared to the small number of Terminal Pleistocene sites documented on the Channel Islands, we have a wealth of information from over 60 Early Holocene sites (see Erlandson et al. 2008b; Rick et al. 2005:178-179). Many of these assemblages suggest a heavy emphasis on shellfish harvested from rocky intertidal habitats (see Erlandson et al.

2009a:40; Rick et al. 2005:185). The dominant taxa vary by site but typically include California mussels, black abalone (*Haliotis cracherodii*), red abalone, owl limpet (*Lottia gigantea*), giant chiton, black turban (*Chlorostoma funebralis*), and others. On Santa Rosa Island near Old Ranch House Canyon, several assemblages (e.g. CA-SRI-666 and CA-SRI-84, see Rick 2009) contain estuarine shellfish taxa such as Washington clams (*Saxidomus nuttalli*), Venus clams (*Chione* spp.), and oysters (*Ostrea lurida*) supplementing rocky intertidal and subtidal shellfish collecting. While shellfish were important resources for Paleocoastal peoples on the NCI, additional archaeological evidence demonstrate a more diverse subsistence economy. Glassow et al. (2010:2.2) for example, suggests that plant foods such as seaweeds, pine nuts, acorns, bulbs (e.g., blue dicks, or cacomites (*Dichelostemma capitatum*)) likely provided carbohydrates and calories for Paleocoastal peoples.

Archaeological and faunal remains recovered from Early Holocene NCI sites suggest island peoples subsisted on a variety of other marine resources. At Daisy Cave and Cave of the Chimneys (CA-SMI-603), numerous bone bipoints (fish gorges), associated with over 27,000 fish bones indicate that fish played an important role in Early Holocene diet (see Rick et al. 2001, 2005). Important fish taxa at these sites include sheephead, rockfish, sculpin, and perch, all of which are found in nearshore ocean habitats.

Chipped stone technologies included a variety of bifaces and leaf-shaped projectile points, cores, hammerstones, expedient flake tools, and macrodrills (see Erlandson et al. 2009a), facilitating a range of activities from bird and sea mammal hunting to skinning, drilling, and chopping or grinding materials. Other artifacts, such as sea grass cordage from Daisy Cave and Cave of the Chimneys (Connolly et al. 1995; Vellanoweth et al. 2003) and spire-lopped Olivella shell beads possibly used for personal adornment from CA-SMI-604 (Seal Cave) (see Erlandson et al. 2009b) add to the range of technologies used during this time.

Kelp forests, intertidal and subtidal zones, and estuarine environments provided the bulk of faunal resources for early peoples on the Channel Islands. The identification and excavation of every new Paleocoastal site creates a more complex picture of early island life where dynamic landscape change and diverse habitats influenced human settlement on the islands. Erlandson et al. (2009a:33-34) describe geographic features that may have attracted Paleocoastal peoples to settle in a variety of localities on the islands including: 1) cave and rockshelters which provided protection from wind and rain; 2) near freshwater springs providing potable water; and 3) in proximity to lithic sources used for toolstone manufacture. Despite sea-level rise which probably submerged a large portion of early coastal sites on the islands, there is evidence of intensive occupation of the islands during the Paleocoastal period where peoples subsisted on rich marine and estuarine environments and utilized local materials for stone tool manufacture. A question addressed in this dissertation, however, is whether Paleocoastal peoples occupied the islands more-or-less permanently on a year-round basis or seasonally and intermittently as part of mainlanders' seasonal rounds.

Bridge

In the previous chapter, I provided a general introduction outlining the theoretical scope of my dissertation research, including the geographical, environmental, and culture historical context. The next chapter (II), which I co-authored with Jon Erlandson and Frances White, has been accepted for publication in the peer-reviewed journal *North American Archaeology*. This chapter is the product of several field seasons and extensive laboratory analysis, processing, and classifying lithic artifacts recovered from Paleocoastal sites. Chapter II focuses on early human procurement of, use of, and preference for island cherts on San Miguel and Santa Rosa islands. Prior to about 10,000 years ago, these two islands comprised the western end of the larger island of Santarosae.

I compared the frequencies and distribution of lithic raw materials and artifacts between eight Terminal Pleistocene and Early Holocene assemblages, discussing the role of island materials used for manufacturing a variety of tools such as Channel Island Barbed (CIB) and Amol (CIA) points, crescents, bifaces and expedient flake tools. The results of my lithic and statistical analyses show a strong preference by Paleocoastal peoples for using local Tuqan Monterey cherts, which are particularly abundant in raised beach deposits on eastern San Miguel Island for biface manufacture. Coarse-grained metavolcanic rocks, which are much more widely available on the NCI, appear to have been used primarily for the production of expedient tools.

CHAPTER II

PALEOCOASTAL LITHIC USE ON WESTERN SANTAROSAE ISLAND, CALIFORNIA

Introduction

California's Northern Channel Islands (NCI) have produced some of the earliest evidence for seafaring and maritime adaptations in the New World (see Erlandson et al. 2011; Johnson et al. 2002). Recent evidence demonstrates that Paleocoastal peoples manufactured a diverse array of formal and expedient chipped stone tools. The former include intricate and finely-crafted Channel Island Barbed points (CIB), serrated Channel Island Amol (CIA) points (Erlandson 2013), and chipped stone crescents (Erlandson and Braje 2008; see Figure 2.1). These formal tools were manufactured from a variety of cherts obtained from sources on San Miguel and Santa Rosa islands, and possibly the adjacent mainland (see Erlandson et al. 1997, 2008, 2012). On Santa Cruz Island, in contrast, four CIB points from an Early Holocene component (~8200-7800 cal BP) at CA-SRI-109 probably were made from Santa Cruz Island cherts (see Glassow et al. 2008; Gusick 2012).

Figure 2.1. Paleocoastal chipped stone tools from CA-SRI-512, CA-SMI-679, and CA-SMI-261. Top row: crescents (left to right SRI-512-513, SMI-679-67, and SMI-679-214); middle row: CIBs (left to right SRI-512-28, 31, and 390) and CIAs (SMI-679-376, 25b, and 28); bottom row: expedient tools (left to right: SMI-261-7409, 7430, and 7735; and bifaces SMI-679-76 and SRI-512-297) (photo by N. Jew).

Until recently, research on stone tool manufacture on the NCI had focused primarily on chert sources located on eastern Santa Cruz Island (SCRI; see Arnold 1987; Perry and Jazwa 2010) that were heavily used during the Late Holocene for microblade production. Microdrills fashioned from Santa Cruz Island cherts were used to perforate Olivella shell beads which were an integral part of island craft specialization and extensive exchange systems (see Arnold 1983; Preziosi 2001). Study of this Late

Holocene microblade industry has greatly increased our understanding of social complexity, resource control, and craft specialization among the Chumash (see Arnold 1987, 1990, 1992, 1995; Arnold et al. 2001; Kennett 2005; Perry 2004, 2005; Perry and Jazwa 2010; Pletka 2001, and others). While it is well established that some of the highest quality cherts on the NCI come from eastern Santa Cruz Island (see Arnold 1987; Perry and Jazwa 2010) and the adjacent California mainland (see Erlandson et al. 2008), there has been only limited discussion of earlier patterns of chert and other toolstone use on the NCI, including the Paleocoastal period. Erlandson et al. (1997) analyzed a trans-Holocene sequence of chipped stone artifacts from Daisy Cave (CA-SMI-261), for instance, noting a heavy reliance on Monterey cherts and siliceous shales during the Early Holocene and Terminal Pleistocene. Paleocoastal components at Daisy Cave and recently identified Terminal Pleistocene sites on San Miguel and Santa Rosa islands (see Erlandson et al. 2011) predate the earliest known evidence for intensive quarrying of Santa Cruz Island chert (see Gusick 2012; Perry and Jazwa 2010:180) by several millennia, providing an opportunity to explore earlier patterns of lithic resource procurement and use by Paleocoastal peoples on the NCI.

To develop a better understanding of the use of chipped stone raw materials by island Paleocoastal peoples, we examined the frequency and proportions of raw material types from eight lithic assemblages dated between ~12,200 and 7500 years ago and distinguish formal artifact types from six assemblages. Through our analyses, we provide a deeper history of lithic raw material procurement and availability on the NCI, spanning a period during which there was a dramatic reduction in the size of the islands, a substantial increase in human population density, and significant changes in settlement and subsistence. Some of these early changes undoubtedly contributed to the development of complex exchange networks and specialized craft production (see Arnold 1983) that focused on intensive mining of Santa Cruz Island cherts, microdrill production, and shell bead making.

Chert Variability on the Northern Channel Islands

Mineral and stone resources on the NCI include a variety of cherts, siliceous shales, metavolcanics, basalt, quartzites, sandstones, steatite, asphaltum, red ochres, and others (Erlandson et al. 2008; Perry and Jazwa 2010). For the past century, the distribution of lithic materials for the Santa Barbara Channel region has been of interest to geologists (Meyer 1967; Muhs et al. 2008; Rand 1930; Weaver 1969; Weaver and Meyer 1969) and archaeologists (Arnold 1987; Curtis 1964; Heizer and Kelley 1962; King 1971, 1981; Moore 1989; O'Neil 1984; Orr 1967; Perry 2004, 2005; Rozaire 1978; Rudolph 1984). In the last 15 years, however, four new and distinctive chert sources have been identified on the NCI (see Erlandson et al. 1997, 2008, 2012) and there is still no comprehensive inventory of mineral resources available for the islands today, much less the larger island of Santarosae in the past (Erlandson and Braje 2008).

On the NCI, the availability of chert and other knappable stone was influenced by dynamic paleoenvironments. Between 18,000 and 10,000 years ago, when sea levels fluctuated between ~100 and 40 meters below present (see Kennett et al. 2008; Muhs et al. 2012), the NCI coalesced into a single larger island known as Santarosae (Figure 2.2, see Orr 1968). At the end of the Terminal Pleistocene and the onset of the Holocene, sea level was roughly 40 meters below modern (Muhs et al. 2012). As sea level rose, the surface area of the islands shrank and chert outcrops were likely submerged (see Erlandson et al. 2008; Watts et al. 2011) decreasing the number of available toolstone sources on Santarosae. Archaeological evidence shows that the inhabitants of western Santarosae utilized a variety of lithic raw materials for stone tool manufacture– most of which were accessible during the Terminal Pleistocene and Early Holocene (see Erlandson et al. 1997, 2008, 2012).

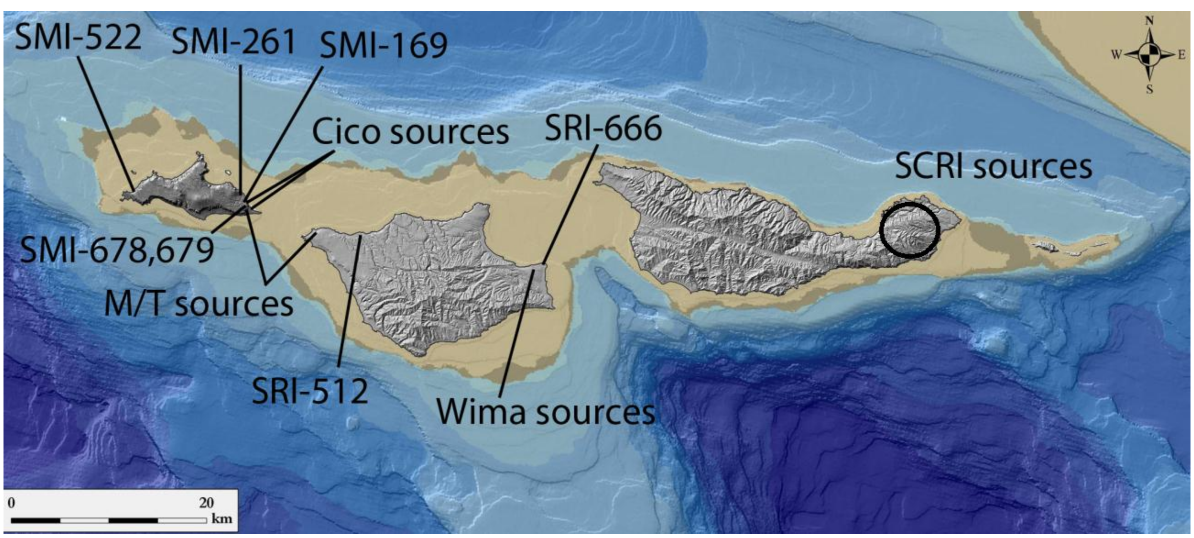

Figure 2.2. Map of Santarosae showing approximate paleoshorelines at ~12,500 cal BP and 11,000 cal BP and known chert outcrops and raised beach deposits on NCI in relation to selected Paleocoastal sites (based on an original by Brian Fulfrost and Jack Watts).

Santa Cruz Island (SCRI) chert sources are found primarily on eastern Santa Cruz, what would have been eastern Santarosae in the Terminal Pleistocene. There have been at least 26 chert quarries identified on Santa Cruz Island (see Arnold 1987; Perry and Jazwa 2010). SCRI cherts are generally translucent and predominantly blonde to light brown in color and found in shades of white, grays, and browns (Arnold 1987:97). Among the Paleocoastal assemblages we analyzed, CA-SRI-666 is the closest study site to known SCRI chert quarries, located approximately 30 km to the west.

On San Miguel and Santa Rosa islands, chert sources of various grades and types have been found ranging from scattered pebbles located in alluvium or raised beach deposits to bedrock outcrops of substantial size. Tools manufactured from Tuqan, Cico, and Wima cherts represent some of the most complex and intricate Paleocoastal technologies in the New World (see Erlandson et al. 2011; Jew and Erlandson 2013), although most of the more elaborate chipped stone tools appear to have been made from Tuqan chert.

Cico cherts, found in bedrock outcrops and as cobbles in raised beaches on eastern San Miguel Island, typically consist of cloudy translucent chalcedonies (see Erlandson et al. 1997). Cico chert can macroscopically overlap with Santa Cruz Island cherts, but given the abundance of Cico nodules near the San Miguel Island sites we studied—and clear Cico clasts in the assemblages—we assumed that the few ambiguous artifacts were made from Cico chert. On San Miguel and Santa Rosa islands, most Tuqan

(Monterey) chert nodules have a distinctive white or gray weathering rind (see Erlandson et al. 2008:26) and occur in colors ranging from black, gray, brown, and buff. Typically, Tuqan chert is found as cobbles or pebbles located in modern or raised beach deposits and artifacts such as cortical flakes and cores can be distinguished from mainland Monterey cherts. Without a visible cortex, however, most artifacts made from Tuqan and mainland Monterey cherts cannot be effectively differentiated. Due to the relative abundance of Tuqan chert in the area, similarities in physical characteristics between source materials and artifacts found in Paleocoastal assemblages (see Erlandson et al. 2008), and the identification of Terminal Pleistocene quarry workshops (CA-SMI-678, 679) on San Miguel Island–we assumed that most of the Monterey chert came from local Tuqan sources rather than being imported from the mainland. Recently, Wima cherts have been identified on Santa Rosa Island (see Erlandson et al. 2012), consisting of opaque cherts and cherty shales found in shades of brown (reddish brown, yellowish brown, greenish brown), with some black and gray variants. On San Miguel Island, white or buff siliceous shales derived from the Monterey formation are also found in beach deposits and as artifacts in some archaeological sites.

Another common toolstone on the NCI are andesitic metavolcanic rocks found in cobble form in modern and ancient beach deposits. These metavolcanics are accessible throughout various parts of the NCI and are commonly used for hammer stones, cores, and large expedient flake tools or choppers. Although much less common, smaller numbers of quartzite and fine-grained basalt cobbles also are found in raised beaches and alluvial deposits on the islands and were occasionally used to make stone tools.

Methods

Paleocoastal peoples on the NCI relied heavily on stone for manufacturing a variety of tools but few studies have examined the overall proportions of specific material types and their relative distribution among discrete tool types. For the current study, 8,183 lithic artifacts from eight Terminal Pleistocene and Early Holocene assemblages (Table 2.1) were classified based on material composition from descriptions above. San Miguel Island sites include Terminal Pleistocene components from CA-SMI-678 and CA-SMI-679, and Early Holocene components from CA-SMI-169, CA-SMI-522, and CA-SMI-261. Paleocoastal assemblages from Santa Rosa include Terminal Pleistocene site CA-SRI-512 and Early Holocene site CA-SRI-666. All these sites have been ^{14}C dated and have well established chronologies based on the analyses of organic samples from intact midden deposits (see Erlandson et al. 1996, 2011; Rick et al. 2005). Each site has also been excavated to some extent, producing sizeable lithic assemblages for comparative analysis.

To calculate the distribution of material types for each assemblage, we included all formal and expedient tools, cores, and debitage from excavated units or additional systematic surface collections. Because we are interested in the frequency of materials for each assemblage and tool type, we quantified all materials to determine the relative proportions present at each site. Lithic materials were classified into five categories including Tuqan chert, Wima chert (including similar siliceous shales for San Miguel Island sites), Cico chert, metavolcanic, and miscellaneous other material types. Miscellaneous material types include rare basalt, quartzite, Franciscan chert, and other rocks.

For each component, the frequencies and percentages that raw material types contributed to various formal and expedient tool categories were calculated. We separated lithic artifacts (excluding miscellaneous other) into seven subgroups including Channel Island Barbed and Amol points, crescents, other biface/point types (see Figure 2.2), expedient tools, cores, and debitage. Bifaces are defined as artifacts systematically flaked on both sides that are not recognized as specific point types. Expedient tools include macrodrills, scrapers, and/or flakes that exhibit retouching or other edge damage resulting from possible tool use. Debitage consisted of waste flakes, shatter, and other chipped stone debris. The frequencies of these seven artifact subgroups were calculated into percentages by artifact and material types.

We used G tests of independence (Sokal and Rohlf 1995) to test for similarity or differences in proportions in 1) lithic material types among sites, 2) raw materials used for each artifact type, and 3) tool types among sites. G tests of independence (a.k.a., the log-likelihood ratio test) test for dependence or independence between two or more variables of nominal values (e.g. artifact and material types) and multiple groups or categories such as archaeological assemblages. A significant result means the relative proportions are dependent between variables and groups. A non-significant result suggests that two variables between groups are independent. Unlike the chi-squared test, the results of G tests are additive, so that overall significant results can be teased out to identify which values are significantly contributing to any overall differences between groups.

We tested for similarities (non-significant subsets) between each grouped data set, using frequencies of Tuqan chert, Wima chert/siliceous shale, Cico chert, and metavolcanic for lithic material comparisons. The other lithic material types were not included as they were rare and included a variety of material types that were not present in all assemblages. Comparison of formal artifacts included CIAs, CIBs, crescents, bifaces, and expedient tools. Tests were run in BiomSTAT (Rohlf and Slice 1995) and all G values are reported with Williams correction with degrees of freedom (df) and p values expressed are < 0.05 (unless otherwise specified). The results were used to identify patterns which might indicate differences between sites, material preference for specific tools, or changes in formal or expedient artifacts between Terminal Pleistocene and Early Holocene assemblages.

Table 2.1. Age, location, and description of selected Paleocoastal sites on San Miguel (SMI) and Santa Rosa (SRI) Islands.

Site (CA-)	Age (cal BP)	Location	Site Description	References
SMI-678	12,200-11,400	East end of SMI near Cardwell Point	Quarry/workshop lithic scatter with at least four distinct shell midden campsite loci.	Erlandson et al. 2011
SMI-679	12,000-11,500	East end of SMI near Cardwell Point	Quarry/workshop lithic scatter with shell midden campsite locus.	Erlandson and Braje 2008; Erlandson et al. 2011
SRI-512	11,700	Northwest coast of SRI east of Arlington Canyon	Stratified, deeply buried midden with diverse assemblage of formal and expedient chipped stone tools and faunal remains.	Erlandson et al. 2011
SMI-522	10,000	Northwest coast of SMI	Small but dense shell midden with diverse artifacts and faunal remains.	Erlandson and Rick 2002, Rick et al. 2005
SMI-608	9500	South-central coast of San Miguel	Large shell midden dominated by shellfish, with a variety of artifacts, faunal remains, and a human burial.	Braje 2010; Erlandson et al. 2005
SMI-261	11,600-8500	Northeast coast of San Miguel	Multicomponent cave and rock shelter. Dense Early Holocene shell midden components contain cordage, basketry, fishing technologies and chipped stone artifacts.	Connolly et al. 1995; Erlandson and Jew 2009; Erlandson et al. 1996; Rick et al. 2001
SRI-666	8200-7800	Northeast end of SRI south of Skunk Point	Large multi-loci shell midden dominated by rocky shore shellfish and chipped stone technologies.	Rick et al. 2005
SMI-169	7550	Fish Ridge on northeast SMI, near Cardwell Point	Large multi-loci shell midden and quarry workshop site.	This paper

Results

Overall Assemblage Comparisons

For overall percentages, ~65% of the artifacts analyzed were made from Tuqan chert, followed by Cico chert (14%), Wima chert or siliceous shale (12%), miscellaneous rock types (6%), and metavolcanic andesite (3%). Except for CA-SMI-522, Tuqan chert represents the highest proportion of lithic materials present regardless of geographic location or type of occupation (e.g. quarry workshop, bone or shell midden). Looking at frequencies for individual components (Table 2.2), Tuqan chert is substantially higher than any other material present in the assemblages and the second highest material present varies by site between Cico and Wima cherts.

For Santa Rosa Island, CA-SRI-512, a stratified Terminal Pleistocene midden contained a large lithic assemblage (n=3,382) where 2,565 artifacts (76%) were made from Tuqan chert, followed by Wima chert (17%). Tuqan chert also dominated (61%) the assemblage from the Early Holocene shell midden CA-SRI-666, followed by Wima chert (30%). For San Miguel Island, the 10,000 year old shell midden at CA-SMI-522 produced the smallest lithic assemblage (n=86) and had the lowest percentage (40%) of Tuqan chert and a higher percentage (44%) of metavolcanic andesite–most of which was small shatter and chipped stone cobble debris. The high proportion of metavolcanic rock at CA-SMI-522 is probably due to the fact that it is located near the far west end of San

Miguel and Santarosae, 12 km or more from the nearest known sources of Tuqan, Cico, or Wima cherts. Terminal Pleistocene and Early Holocene quarry/workshop sites at Cardwell Bluffs near the east end of San Miguel Island contained high proportions of Tuqan chert (51-71%) and Cico chert (11-40%). High percentages of Cico chert at CA-SMI-678 (30%) and CA-SMI-169 (40%) were not surprising given the presence of abundant nearby Cico sources (see Erlandson et al. 1997). The dearth of Cico chert at Daisy Cave is more difficult to explain as it is located just a kilometer or so from sources of both Cico and Tuqan chert, but it is consistent with an overall preference for the use of Tuqan chert by Paleocoastal peoples for the production of formal tools (see below). Tuqan chert for Terminal Pleistocene components averaged ~66% where Early Holocene assemblages contained ~60%, demonstrating that from ~12,000-7500 cal BP Tuqan chert remained the highest ranked material used for chipped stone tool manufacture on western Santarosae.

Overall, the results of the G test of independence between all sites and chert types were significant ($G=2604$, $df=21$, $p< 0.001$). However, this data set contained over 30 statistically non-significant subsets that show similarity among some sites and chert types. These subsets include: CA-SRI-512 and CA-SRI-666 ($G=20.3$), CA-SMI-679 and CA-SMI-169 ($G=19.2$), and CA-SMI-261 and SRI-666 ($G=16.6$). These data reveal similarities between the overall frequencies (proportions) of chert types present in certain assemblages.

Table 2.2. Proportions of lithic materials and percentages by site and material type for San Miguel and Santa Rosa Islands.

Site (CA-)	**Period**	**Site Type**	**T-M**	**Wima S. Shale***	**Cico Chert**	**MV**	**Other**	**Total**
SMI-678	Terminal Pleistocene	Quarry site / lithic scatter	348 (53%)	9 (1%)	194 (30%)	33 (5%)	68 (10%)	**652**
SMI-679	Terminal Pleistocene	Quarry site / lithic scatter	537 (71%)	18 (2%)	84 (11%)	31 (4%)	83 (11%)	**753**
SRI-512	Terminal Pleistocene	Residential base?	2565 (76%)	578 (17%)	117 (3%)	28 (<1%)	94 (3%)	**3382**
SMI-522	Early Holocene	Dense shell midden	34 (40%)	1 (1%)	7 (8%)	38 (44%)	6 (7%)	**86**
SMI-608	Early Holocene	Residential base?	168 (88%)	-	10 (5%)	6 (3%)	8 (4%)	**192**
SMI-261	Early Holocene	Cave/ rock shelter	634 (58%)	322 (30%)	8 (<1%)	61 (6%)	62 (6%)	**1087**
SMI-169	Early Holocene	Quarry/work shop /shell midden	975 (51%)	23 (1%)	751 (40%)	6 (<1%)	143 (8%)	**1898**
SRI-666	Early Holocene	Residential base	81 (61%)	40 (30%)	8 (6%)	4 (3%)	-	**133**
Total			5342 (65%)	991 (12%)	1179 (14%)	207 (3%)	464 (6%)	**8183** (100%)

*****Material type is predominately siliceous shale for San Miguel Island assemblages and Wima chert for Santa Rosa Island. Due to certain overlaps in material variability, we selected to report these together.

Formal Artifacts

For the 581 formal and expedient artifacts (excluding debitage), Tuqan chert comprised ~81% (n=468) of the total, 13% Cico (n=74), 3% Wima (n=21), and 3% metavolcanic (n=18) (Table 2.3). Tuqan chert is the primary material used to manufacture CIBs (88%), CIAs (72%), and crescents (77%) during the Paleocoastal period. CIB points have also been reported in other Early Holocene assemblages on the NCI (e.g. CA-

SCRI-109, CA-SMI-575, and CA-SMI-608); where many of these formal artifacts are also appear to have been made from local island cherts. Crude and roughly shaped bifaces, preforms, and expedient tools are present in both Terminal Pleistocene and Early Holocene assemblages and are also fashioned primarily from island cherts—of the 305 bifaces examined, ~88% of them were made from Tuqan cherts. Expedient tools comprised just 10% of identified tools, ranging from utilized flakes to retouched scrapers and macrodrills, but if crudely-shaped bifaces are included, the total rises to 62%. Among cores and core tools (n=41), 51% of the total (n=21) are made from Tuqan chert, 20% from Wima chert and siliceous shale (n=8), and 14.5% from Cico chert (n=6) and metavolcanic (n=6). Not surprisingly, Tuqan is also the highest represented material type among the debitage, totaling 72% (n=3731), with 18% Wima chert and siliceous shale (n=947), 6% Cico chert (n=344), and 3% metavolcanic (n=177).

The G test of independence showed significant differences in the proportions of chert types among the different artifact types ($G=77.1$, $df=12$, $p < 0.001$). There were, however, many similarities (non-significant subsets) between tool and material types for CIBs, CIAs, crescents, and bifaces. The statistical significance in the data was due to a different pattern of material type in expedient and formal tools. This difference suggests that there is a consistent preference for the type of chert (i.e. Tuqan) selected to create projectile points and bifaces and Paleocoastal people were less selective over materials used for expedient tool manufacture.

Table 2.3. Artifacts from Terminal Pleistocene and Early Holocene components classified by site, artifact, and material type and reported in count and approximate percentages.

Artifact Type	Material	SMI-678	SMI-679	SRI-512	SMI-261	SMI-522	SRI-666	Total
CIB point	M-T	8(11%)	15(20%)	51(68%)	1(1%)	-	-	75
	Wima/SS	1(100%)	-	-	-	-	-	1
	Cico	4(45%)	3(33%)	2(22%)	-	-	-	9
subtotal								85
CIA point	M-T	6(37%)	10(63%)	-	-	-	-	16
	Wima/SS	-	-	-	-	-	-	0
	Cico	6(100%)	-	-	-	-	-	6
subtotal								22
Crescent	M-T	14(26%)	20(37%)	18(34%)	1(2%)	-	-	53
	Wima/SS	-	-	-	-	-	-	0
	Cico	2(12.5%)	2(12.5%)	12(75%)	-	-	-	16
subtotal								69
Other bifaces	M-T	86(32%)	142(53%)	27(10%)	10(4%)	-	3(1%)	268
	Wima/SS	-	-	-	-	-	3(100%)	3
	Cico	15(45%)	15(45%)	2(6%)	-	1(3%)	-	33
	MV	-	-	-	-	1(100%)	-	1
subtotal								305
Expedient tools	M-T	14(40%)	2(6%)	8(23%)	8(23%)	2(6%)	1(2%)	35
	Wima/SS	2(22%)	-	1(11%)	3(33%)	-	3(33%)	9
	Cico	-	-	-	2(50%)	2(50%)	-	4
	MV	-	-	-	5(45%)	6(55%)	-	11
subtotal								59
Cores/core tools	M-T	5(24%)	1(5%)	4(19%)	10(47%)	1(5%)	-	21
	Wima/SS	-	1(12.5%)	2(30%)	4(50%)	-	1(12.5%)	8
	Cico	3(50%)	1(16%)	1(16%)	1(16%)	-	-	6
	MV	1(16.5%)	1(16.5%)	-	1(16.5%)	3(50%)	-	6
subtotal								41
Debitage	M-T	215(6%)	347(9%)	2457(66%)	604(16%)	31(<1%)	77(2%)	3731
	Wima/SS	6(<1%)	17(2%)	575(61%)	315(33%)	1(<1%)	33(35%)	947
	Cico	164(48%)	63(18%)	100(29%)	5(1%)	4(1%)	8(2%)	344
	MV	32(18%)	30(17%)	28(16%)	55(31%)	28(16%)	4(2%)	177
subtotal								5199
Total		**584**	**670**	**3288**	**1025**	**80**	**133**	**5780**

The final G test of independence found that the proportion of tool types was significantly different between site types (G=221.7, df=20, $<\chi^2=231.4$, $p<0.001$). Only two sites were similar in tool type frequencies, CA-SMI-678 and CA-SMI-679, both having produced high numbers of biface preforms, crescents, and CIA and CIB points. These two large sites are found side-by-side at Cardwell Bluffs and appear to be part of a single large quarry/workshop site complex containing multiple small shell midden loci that represent short-term campsites used by Paleocoastal peoples (Erlandson et al. 2011). All other sites had significantly different ratios of tool types present, with the greatest variation in the proportion of expedient tools, which may be related to differences in site function, site preservation, or other factors.

Discussion and Conclusions

Between ~12,000 and 7500 years ago, early maritime peoples on western Santarosae acquired Tuqan, Cico, and Wima cherts from multiple sources on what are now San Miguel and Santa Rosa islands, possibly from bedrock outcrops later submerged by rising seas or from raised beaches largely exhausted in antiquity (Erlandson et al. 2008). There is little evidence that Paleocoastal peoples on western Santarosae took significant advantage of Santa Cruz Island cherts once thought to be the only significant chert sources on the NCI (see Arnold 1987). This is true even at CA-SRI-666, an ~8000 year old site on eastern Santa Rosa Island situated closest to the Santa Cruz Island sources. Overall, there is a strong preference for high quality Tuqan chert in the analyzed Paleocoastal assemblages. A similar raw material type, mainland Monterey chert, is also found along the adjacent mainland coast where it was heavily used by Millingstone peoples during the Early Holocene (Erlandson 1994). In the island Paleocoastal assemblages we analyzed, however, the artifacts containing intact cortex show that Tuqan chert (not mainland Monterey chert) was the primary material used. On eastern San Miguel, the preference for Tuqan chert is apparent at CA-SMI-169, CA-SMI-261, CA-SMI-678, and CA-SMI-679, all located near outcrops and raised beach deposits that still contain knappable Tuqan and Cico cherts, but where Cico chert is much more abundant today. Otherwise, the proportions of material types present in each assemblage appear to be related to the proximity of local chert sources. CA-SMI-522, for instance, the only site with a majority of metavolcanics and the lowest proportion of Tuqan chert, is located near the west end of San Miguel, more than 12 km from the nearest known chert source.

For Santa Rosa Island, recent surveys by Erlandson and Rick have found lesser quantities of Tuqan chert cobbles on modern beaches and raised terrace deposits, especially near the west end of the island. These include small and platy pebbles with thin sheets of pure Tuqan chert between layers of siliceous shale. These plates, both worked and unworked, have been found at many of the Paleocoastal sites recently discovered on Santa Rosa Island (see Rick et al. 2013), including CA-SRI-512 where they appear to have been split and fashioned into small, thin CIB points. Although dominated by Tuqan chert, lithic assemblages from CA-SRI-666 and CA-SRI-512 both contain relatively large percentages of Wima chert, sources of which have only been found on Santa Rosa Island. Wima chert artifacts are relatively rare in San Miguel Island sites, however, probably because higher quality Tuqan and Cico cherts were available.

If the frequencies of material present at these Paleocoastal sites reflect the general accessibility of local materials on western Santarosae, it seems likely that this paleo-landscape had extensive Tuqan, Cico, and Wima chert sources, with availability of such lithic resources varying through space and time. The general correlations between the abundance of various chert types in Paleocoastal assemblages and the known distribution of cherts in primary or secondary geological contexts suggests that most submerged sources were likely located in the same general areas they are known from today, but there may have been more extensive sources of Tuqan chert around the margins of Santa Rosa Island than are apparent today.

Our results indicate that the proportion of formal artifacts varied between sites, differences that relate primarily to site function. CA-SMI-678 and CA-SMI-679 had similar distribution of artifact types, for instance, which is best explained by their relative proximity to chert sources and to one another, as well as their apparent function primarily as quarry/workshop sites (Erlandson et al. 2011). The 7500 year old component at CA-SMI-169, in contrast, is located near the same chert sources but after numerous surveys has produced no diagnostic Paleocoastal artifacts (CIAs, CIBs, or crescents). With 40% of its assemblage consisting of Cico chert, this is the youngest assemblage we analyzed and may be transitional in nature, supporting a trend identified at Daisy Cave toward a greater emphasis on Cico chert use in the Middle Holocene (Erlandson et al. 1997).

Overall, there is a reduction in the manufacture of crescents and CIA and CIB points from the Terminal Pleistocene to the Early Holocene, with a shift to more expedient stone tools. This is a trajectory that continues into the Middle Holocene with an intensification of shellfish harvesting and an expansion of bone and shell technologies (see Erlandson et al. 2008; Reeder et al. 2008; Rick et al. 2005). Changes in both resources and stone tool technologies from the Terminal Pleistocene through the Holocene may have been influenced by sea-level rise which restructured ecosystems, submerged lithic sources, and changed the nearshore ecology around the Channel Islands. As the islands shrank, human population densities probably grew, even as kelp forest, terrestrial, and estuarine habitats were shrinking. One result was a subsistence shift towards a heavier reliance on shellfish, which require little in the way of formal stone tool technologies and less emphasis on hunting (see Erlandson et al. 2009; Reeder et al. 2008). If Paleocoastal projectile points were used primarily for hunting marine mammals and waterfowl (see Erlandson et al. 2011; Rick et al. 2005), the intensification of shellfish harvesting and a decrease in hunting may help explain an apparent decline in the intensity of Tuqan chert use, as well as a shift towards other lithic materials (e.g., Cico and Wima cherts, metavolcanics) and more expedient chipped stone tools.

A trans-Holocene review and more thorough analyses of NCI lithic assemblages are necessary to reconstruct and explain broader temporal changes in lithic technologies and material preference. Nonetheless, our preliminary findings for Paleocoastal lithic resource use on western Santarosae provide a very different view from that gained through the study of specialized Late Holocene microblade production sites on Santa Cruz Island. From Paleocoastal times to the Late Holocene, did the center of gravity for lithic production on the NCI shift from west to east? Answering that question will require comparative data from Paleocoastal sites on Santa Cruz Island, as well as greater knowledge of Middle Holocene lithic resource use. There is little evidence for extensive trade networks, resource control, or craft specialization during the Terminal Pleistocene and Early Holocene on the NCI. In contrast, it is well documented that a specialized bladelet production industry associated with intensive shell bead production developed during the Late Holocene, an industry that focused on the abundant, high quality, and suitably blocky cherts found on eastern Santa Cruz Island (see Arnold 1983, 1987, 1990; Arnold et al. 2001; Kennett 2005). Questions that remain to be resolved include how lithic resource use on the NCI was transformed from the Paleocoastal to Late Holocene patterns and why other NCI cherts do not appear to have been used in the specialized Island Chumash bladelet industry.

Less than a decade ago, we knew relatively little about Terminal Pleistocene occupations of the NCI (see Erlandson and Braje 2008; Rick et al. 2005). Since that time it has become apparent that cherts were much more abundant and varied on the NCI than previously thought, that the islands were much less marginal than once believed, and that Paleocoastal patterns of lithic resource use were very different than those of the Middle and Late Holocene. Our research demonstrates the importance of a variety of chert sources on western Santarosae. Only recently have we begun to recognize the tremendous diversity of resource availability, use, and associated technologies on the NCI. While there is no doubt that Santa Cruz Island chert sources were some of the most intensively exploited on the NCI, the available evidence demonstrates that Paleocoastal peoples relied heavily on chert sources located on western Santarosae that were not even known to exist until relatively recently. The difference between restricted access over large Santa Cruz Island quarries used to mine materials for microblade production in the Late Holocene and widely accessible chert sources used for specific tools in the Terminal Pleistocene presents a number of questions related to long-term technological and cultural changes on the NCI.

Bridge

In Chapter II, I established that Paleocoastal peoples on San Miguel and Santa Rosa islands manufactured formal artifacts (points, crescents, and other bifaces) primarily from local island cherts—with a preference for Tuqan Monterey chert. Tuqan and Monterey cherts are difficult to discriminate between without a cortex, however, proximity to local islands sources and similarities between lithic tools and source materials suggest that most of the Monterey chert identified in the Paleocoastal assemblages is Tuqan. During my detailed analysis of multiple Paleocoastal assemblages, I noticed a high incidence of heat fractures on chert artifacts and wondered if intentional heat treatment was used to improve the knappability of island chert cobbles, facilitating the exceptional craftsmanship reflected in many finished Paleocoastal points. As a result, I designed and executed a combination of experimental heat treatment of island cherts and a systematic and quantitative comparative analysis of Paleocoastal assemblages to explore the question.

In the following chapter, which was published in the peer-reviewed journal *California Archaeology* and co-authored by Jon Erlandson, I expand on my analysis of Paleocoastal stone tool manufacturing techniques, documenting evidence for the intentional annealing of island cherts. Following established protocols, I heated Tuqan, Monterey, Wima, and Cico chert samples to temperatures of 400°C and 350°C and recorded the macro/microscopic changes, including alterations in color and luster (gloss), heat crazing, potlid fractures, fissures, and scales. These experimental results were then used to compare several Paleocoastal lithic assemblages to determine if early peoples inhabiting the NCI employed heating strategies to improve the quality of island cherts for manufacturing expedient and formal chipped stone tools. My results, including the innovative and comparative use of quantitative glossmeter measurements, strongly suggest that controlled heat treatment of island cherts was an important step used by Paleocoastal peoples, especially in the production of delicate and ultrathin CIA and CIB points, many with needle-like tips, long stems and barbs, and prominent spurs or serrations.

CHAPTER III

PALEOCOASTAL FLAKED STONE HEAT TREATMENT PRACTICES ON ALTA CALIFORNIA'S NORTHERN CHANNEL ISLANDS

Introduction

Controlling fire allowed early humans to expand their geographic range, increase their security and the variety of foods they could consume, and facilitate the development of new technologies such as ceramics and metallurgy (Wrangham 2009). Another important technological innovation, apparently first utilized by anatomically modern humans (*Homo sapiens sapiens*), was the intentional application of heat treatment to some siliceous rock types (see Brown et al. 2009; Crabtree and Butler 1964). The controlled application of heat treatment to cherts and flints, in particular, changes their physical structure in ways that make them more suitable for manufacturing many flaked stone tools (Domanski and Webb 1992; Purdy 1974; Webb and Domanski 2009; see below).

Erlandson et al. (2011) described Terminal Pleistocene flaked stone assemblages from California's Northern Channel Islands (NCI) that date between ~12,200 and 11,400 years ago (cal BP) and contain finely-made projectile points made from a variety of island cherts. On the NCI, Paleocoastal peoples manufactured a variety of chipped stone tools (Figure 3.1) including thin stemmed points and crescents (see Braje et al. 2013; Erlandson 2013; Erlandson et al. 2011; Glassow et al. 2008). Without knowing their antiquity, Heye (1921:66) described stemmed Paleocoastal points as the most advanced flaked stone technology in native North America. Paleocoastal assemblages, including a large quarry/workshop/campsite complex at Cardwell Bluffs, have produced hundreds of bifaces made from island cherts, including finished projectile points that are often ultra-thin, with long narrow stems, elaborate barbs or serrations, and needle-like tips. When, analyzing these assemblages, we noted high incidences of heat crazing and pot-lids and wondered if these characteristics were the result of exposure to natural wildfires, incidental exposure to camp fires, or intentional heat treatment practices.

A variety of NCI chert sources were used by Paleocoastal peoples to make stone tools. These range from siliceous shales to cherts, including cobbles that vary in silica content, purity, and quality. The best known chert sources come from Santa Cruz Island (e.g. Arnold 1987, 1992; Kennett 2005; Perry and Jazwa 2010; Pletka 2001; Preziosi 2001; Rozaire 1993), but broader surveys have identified additional sources, including Cico, Tuqan, and Wima cherts widely distributed on San Miguel or Santa Rosa islands (see Erlandson et al. 1997, 2008, 2012).

Figure 3.1. Crescents and stemmed CIB points from CA-SRI-512 and CA-SMI-679 (two crescents at upper left are made from Wima chert, all others from M/T chert; note high gloss visible on many of the M/T chert artifacts; a single pot-lid is also visible on the crescent in the center of the middle row; digital image by N. Jew).

In this paper, we describe our efforts to determine whether Paleocoastal peoples used heat treatment to improve the workability of NCI cherts and how such techniques may have been incorporated into flaked stone technologies. First, we describe our experimental heating of cherts from NCI sources. Using the macroscopic signatures of heated and unheated cherts (gloss, heat fractures, etc.) we analyzed excavated Paleocoastal lithic assemblages from Daisy Cave (CA-SMI-261), Cardwell Bluffs (CA-SMI-679), and Radio Point (CA-SRI-512), along with diagnostic artifacts from several other Paleocoastal sites. Our results show that lithic artifacts from these Paleocoastal assemblages contain high incidences of heat fractures and a range of gloss values characteristic of intentional heat treatment.

Background

Since the 1960s (e.g. Crabtree and Butler 1964; Gregg and Grybush 1976:189; Luedtke 1992:91; Shippee 1963), there has been a growing interest in the role of heat treatment (a.k.a., thermal pretreatment or alteration and annealing) in flaked stone tool manufacturing processes. Under certain circumstances, heating cherts and flints can change their physical properties (Hester 1972; Mandeville and Flenniken 1974; Shippee 1963) by reducing tensile strength (Beauchamp and Purdy 1986; Purdy 1974) and altering microcrystalline structures (Domanski and Webb 1992), making materials better suited for knapping. Thermal alteration of some siliceous rocks may result in the loss of ambient water (Mandeville 1973; Purdy and Brooks 1971), changing the mechanics of compression, increasing brittleness, and decreasing fracture toughness (see Beauchamp and Purdy 1986). Geological material type, size, and initial quality of stone can influence the outcome, but there is a general consensus that heating some crypto-crystalline silicate rock between certain temperature thresholds can remove impurities and improve their overall quality (Crabtree and Butler 1964; Mercieca and Hiscock 2008; Schindler et al. 1982).

How materials are heated can directly affect which characteristics are prevalent in a heated specimen. Fast heating strategies (a.k.a. thermal shock; see Domanski and Webb 2007; Greg and Grybush 1974; Griffith et al. 1987), for instance, involve rapid heating and cooling of stone, which typically results in thermal fractures, pot-lids, and heat crazing. Thermal fractures vary from deep cracks in the stone to surficial hairlines. Pot-lids are small detached spalls that leave semi-circular depressions in heated stone. Crazing fractures are more widespread and irregular in nature, often exhibiting glossy surfaces. A more controlled process, referred to as the 'slow and steady strategy' (see Mercieca and Hiscock 2008:2635), involves gradual heating of lithic materials—often burying the stone under a heated source—and slow cooling to avoid fractures and heat damage (Ahler 1983; Hanckel 1985; Olausson and Larsson 1982; Purdy and Brooks 1971; Schindler et al. 1982). Some archaeologists believe that pressure flaking heat treated cherts allowed skilled flintknappers to produce needle sharp tips, thin edges, and symmetrical flake removal on thin bifaces (e.g., Mourre et al. 2010), but experimental studies and detailed archaeological analyses are needed to support such assertions.

Mercieca and Hiscock (2008) warn against polarizing fast or slow heat treatment strategies because they are part of a continuum where specimen size, material type, and temperature will affect the results. Because of such variability, experimental heating of crypto-crystalline silicates should be conducted at various temperatures on a case by case basis. This helps define criteria for evaluating whether stone tools made from a particular rock type have been heat treated. Archaeologists should also carefully consider whether incidental exposure of lithic artifacts to fire—in hearths and other cultural features vs. natural wildfires—may have been responsible for some or all of the signatures of heat treatment in a given assemblage. Distinguishing between natural wildfires and intentional heat treatment is complex, but lithic assemblages resulting from intentional treatment may contain stone artifacts with: (1) a range of high and low quantitative gloss values (Brown et al. 2009; see below); (2) patterned variation in the evidence for heat fractures among various artifacts types (e.g., cores, bifaces, expedient tools, debitage); (3) in association with unburned bone, shell, and other organics. Conversely, natural or unintentional heat alteration may be recognized in a lithic assemblage where most artifacts exhibit relatively high gloss values and more randomly distributed frequencies of thermal damage associated with combustion features (cultural or natural) and burned organic remains.

<u>California Northern Channel Islands: Paleogeography and Paleocoastal Sites</u>

Located 19 to 44 km off the southern California Coast, the NCI include Anacapa, Santa Cruz, Santa Rosa, and San Miguel. From the Last Glacial Maximum to ~10,000 years ago, when global sea-levels were ~120 to 40 m below present, the NCI were part of a larger landmass known as Santarosae Island (Figure 3.2, see Johnson 1983; Orr 1968; Watts et al. 2011). Rising post-glacial seas fragmented Santarosae, increased distances to the mainland, and decreased the habitable land area of the islands by roughly 75-80% (Glassow et al. 2010:1.4; Kennett et al. 2008). As the islands shrank, extensive lowland areas were transformed from terrestrial to marine ecosystems, affecting the distribution and availability of key resources. Geologic outcrops of chert and asphaltum were submerged (along with coastal archaeological sites), for instance, and the length and nature of shorelines and near-shore marine habitats continuously changed (Erlandson et al. 2012; Kinlan et al. 2005:137).

In the last two decades, several early Paleocoastal sites have been identified on San Miguel and Santa Rosa islands (western Santarosae), extending the antiquity of New World seafaring and maritime adaptations back to 13,000-12,000 years ago (Erlandson et al. 2011). Terminal Pleistocene and Early Holocene technologies on western Santarosae include a wide range of flaked stone artifacts (cores, choppers, expedient flake tools, leaf-shaped bifaces, crescents, and delicate stemmed Channel Island Barbed (CIB) and Amol (CIA) points) made from cherts, metavolcanic rocks, and quartzites (Braje et al. 2013; Erlandson 2013). Cherts are the most widely used rock type throughout occupation of the NCI, especially for formal artifact types.

The NCI contain extensive siliceous rocks belonging to the Monterey Formation, which contains thick sequences of deep sea sediments that include thinly bedded shales, siliceous shales, and cherts. On the islands, chert is found in a variety of forms including bedrock outcrops and pebbles, cobbles, or boulders found on modern beaches, raised marine terraces, or alluvium that contains reworked cobbles. The majority of chert artifacts found in archaeological assemblages on the NCI probably originated from local island sources, with much smaller quantities coming from mainland sources (Glassow et al. 2008; Perry and Jazwa 2010). The range of available cherts on different islands and mainland sources has resulted in artifacts manufactured from cherts of various grades, colors, and other characteristics. During the Terminal Pleistocene and Early Holocene on San Miguel and Santa Rosa islands, local Tuqan, Cico, and Wima cherts appear to be the most frequently used material in chipped stone tool manufacturing.

Cico cherts typically consist of cloudy translucent chalcedonies found in bedrock veins and as cobbles in modern and raised beaches near the eastern end of San Miguel Island (Erlandson et al. 1997:126-127). Cico chert has a microcrystalline structure similar to quartzite and sometimes contains inclusions or voids studded with quartz crystals. The texture of Cico chert can range from coarse to fine grained, with colors shading from white, blonde, light brown, gray, or in rarer instances bluish-gray.

On San Miguel and Santa Rosa islands, Tuqan chert is a variant of Monterey chert found in cobbles that have a distinct white or gray weathering rind (see Erlandson et al. 2008:26). Artifacts lacking this distinctive cortex cannot currently be distinguished from mainland variants of Monterey cherts (see Jew et al. 2013), leading us to classify some of the archaeological samples we analyzed as Monterey/Tuqan (M/T) chert. Tuqan chert occurs in colors ranging from black, gray, brown, and buff and is found as cobbles or pebbles in modern and raised beach deposits, or in alluvium derived from the erosion of such deposits. These clasts range from spherical pebbles and cobbles, to thinner and flatter nodules. Tuqan cherts range from relatively pure and high quality nodules to lower quality siliceous shale cobbles containing thin bands of chert.

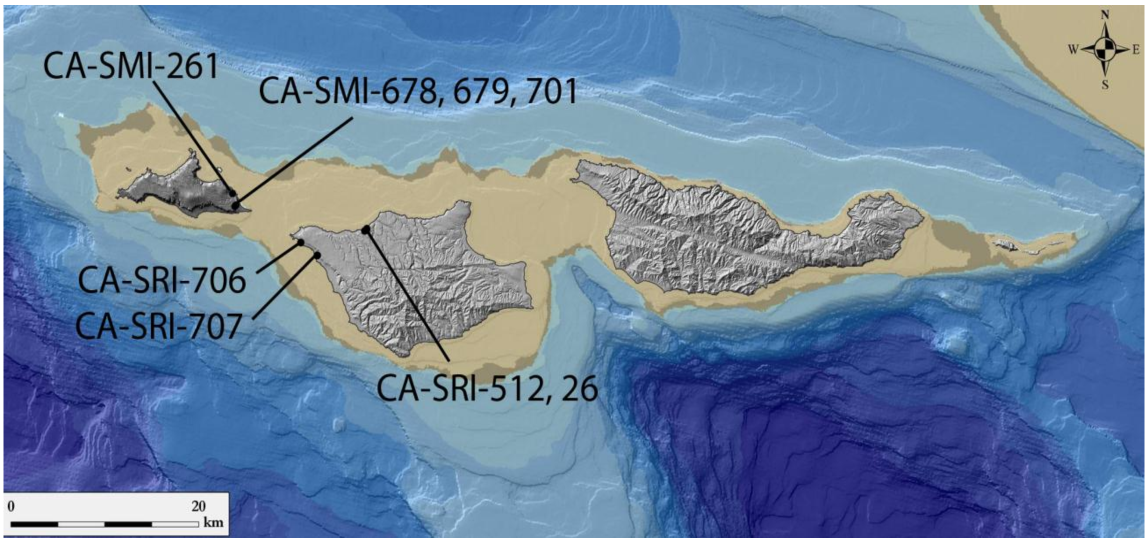

Figure 3.2. Map of the Northern Channel Islands and general locations of Paleocoastal sites showing the approximate extent of paleoshorelines at ~12,500 and 11,000 cal BP (adapted from Erlandson et al. 2011).

Wima cherts, geological sources of which have been found recently on Santa Rosa Island, include opaque cherts and cherty shales found primarily in shades of brown, reddish brown, yellowish brown, greenish brown, and some black and gray variants (Erlandson et al. 2012). Wima chert varies in composition from fine-grained porcelainites to coarser siliceous shales.

To better understand patterns of thermal alteration on Paleocoastal artifacts, we examined assemblages from Terminal Pleistocene and Early Holocene sites on San Miguel and Santa Rosa islands (Figure 3.2). CA-SMI-261, located on the northeast coast of San Miguel Island, is a complex multi-component cave and rock shelter occupied between ~11,600 and 700 cal BP (see Erlandson et al. 1996; Rick et al. 2005). The Early Holocene shell midden strata (E and F) are dated between ~10,000 and 8600 cal BP and feature extraordinary preservation of artifacts and faunal remains, including cordage and basketry (Connolly et al. 1995), bone and shell tools and ornaments, a variety of flaked stone tools (see Erlandson and Jew 2009), and a diverse array of fauna (Rick et al. 2001). Because the Early Holocene strata were rapidly buried beneath later Early, Middle, and Late Holocene sediments, wildfires are not likely to have caused incidental heating of the flaked stone assemblage.

CA-SRI-512 is a deeply buried open site dated between about 11,800 and 11,500 cal BP (Erlandson et al. 2011). This site has well-defined stratigraphy and has produced diverse assemblages of vertebrate faunal remains and flaked stone artifacts (including numerous CIB points and crescents) made from Cico, Tuqan, Monterey, and Wima cherts. So far, excavations in the buried archaeological component have produced little charcoal and no hearths that might be sources of incidental burning. After abandonment, rapid deposition of alluvial sediments also sealed the site from Holocene wildfires.

Located near the eastern end of San Miguel Island near Cardwell Point, CA-SMI-679 is a large Terminal Pleistocene site that has produced a diverse array of artifacts and shellfish remains (see Erlandson et al. 2011). The site is located atop a broad terrace and raised beach deposit where a cobble field contains rounded clasts of Tuqan and Cico chert (Erlandson et al. 2008). These cobbles were used by Paleocoastal peoples to manufacture hundreds of bifaces ranging from preforms to finished projectile points. For this paper, we analyzed the flaked stone artifacts recovered from small-scale excavations in a 12,000 year old (see Erlandson et al. 2011) shell midden locus in the southeastern site area. This midden deposit contained some charcoal and burned rock and the shallow site soils may have exposed the site contents to periodic wildfires, but the shellfish remains recovered show little evidence of burning.

Smaller assemblages of diagnostic artifacts (crescents, projectile points, and other bifaces) were also analyzed from five other Paleocoastal sites on San Miguel and Santa Rosa islands. Four of these (CA-SMI-678 and -701, CA-SRI-706 and -707) are from large exposed open sites similar to CA-SMI-679, with a combination of shallow soils and eroded lag deposits. The fifth site, CA-SRI-26, is located in a deeply buried and well-stratified setting similar to CA-SRI-512 and also dates to the Terminal Pleistocene. Only limited excavations have taken place at CA-SRI-26, but the buried ~11,500 year old component has produced small numbers of crescents and CIB point fragments, flaked stone tool-making debris, and bird, fish, marine mammal, and shellfish remains.

Methods

Archaeologists have employed a variety of methods to identify thermally altered artifacts. These include macroscopic examination, microscopic analysis (Clemente-Conte 1997), thermoluminescence (e.g. Brown et al. 2009; Godfrey-Smith et al. 2005; Pavlish and Sheppard 1983), archaeomagnetism (Borradaile et al. 1993; Brown et al. 2009), scanning electron microscopy (Domanski and Webb 1992), and quantitative glossmeters (Brown et al. 2009). Archaeologists have also experimentally heated lithic materials (e.g. Bleed and Meir 1980; Domanski et al. 2009; Purdy and Brooks 1971, Mercieca and Hiscock 2008; Richter et al. 2011) to better understand the physical changes that occur in specific materials and distinguish thermally altered from unheated artifacts. Common physical changes in heated cherts include color and luster changes, as well as heat damage in the form of pot-lids (see Richter et al. 2011), pockets, fractures, and crazing (Domanski and Webb 1992; Goksu et al. 1989; Rowney and White 1995). Because experimental studies have shown that wildfires can mimic the effects of intentional heat treatment (see Buenger 2003), archaeologists must carefully evaluate whether heat fractures and color or luster changes may have been caused by natural processes or incidental exposure to cultural fires. To help distinguish incidental vs. intentional heating of stone, Brown et al. (2009) employed a glossmeter recording the maximum gloss values of experimentally unheated, heated, and heated/flaked surfaces—providing a range of values to compare to values for diagnostics, non-diagnostics, and cores from our archaeological assemblages. To examine whether incidental heating of artifacts occurred at CA-SRI-512 and CA-SMI-261 we tested 250 non-diagnostic artifacts and compared our results to the experimental heated/unheated thresholds.

For our study, we collected chert samples from San Miguel and Santa Rosa islands similar to the source material of artifacts found in Paleocoastal archaeological contexts. Experimental heating methods were adapted from previous studies (see Bleed and Meir 1980; Brown et al. 2009; Mourre et al. 2010; Purdy and Brooks 1971), documenting microscopic characteristics of source materials before and after heating. Using a diamond-tipped lapidary saw, 14 samples were cut into three cross-sections producing a total of 42 chert specimens. Leaving one set of control samples untreated for comparative purposes, the remaining two sets were heated. Specimens were placed in a metal pan, covered in sand, and gradually heated in a Barnstead furnace. The first group of samples was heated to a maximum of 350°C and the second group to 400°C. Both groups were held at their maximum temperatures for 2 hours and were allowed to gradually cool at ~30°C per hour to avoid unnecessary thermal shock.

After the samples cooled overnight, we first documented changes in color using a Munsell Color Chart. We then reviewed and documented the resulting thermal alterations present on each experimental sample. After recording the effects of heat treatment or damage on each sample, we examined Paleocoastal assemblages looking for similar characteristics of heating. A total of 1,453 chipped stone artifacts were examined macroscopically and under a low powered microscope (20x and 200x) for evidence of heat damage or treatment. Finally, using an ETB-0686 glossmeter, we measured the maximum gloss values expressed as gloss units (GU) for experimental specimens subdivided into three categories: unheated samples, samples that were heated but unflaked, and samples heated and flaked (see Brown et al. 2009). Gloss units provide a quantitative standard for comparing the glossiness of artifact surfaces by measuring the amount of light reflected from an object, with higher GU values indicating a glossier surface. We recorded changes in gloss for the three sets and tested the statistical significance between unheated and heated/flaked maximum gloss values using a related samples t-test.

Turning to the archaeological assemblages, we analyzed 1,319 artifacts from three excavated sites (CA-SMI-261, CA-SMI-679, and CA-SRI-512) and 134 diagnostic artifacts from five other Paleocoastal sites. To evaluate whether heat damage resulted from incidental or intentional heating, we also used the glossmeter to analyze a sample of bifaces and 250 non-diagnostic chipped stone artifacts from both Daisy Cave and CA-SRI-512, recording their gloss values for comparison to our experimental control samples.

Experimental Observations and Comparative Analysis of Paleocoastal Assemblages

Experimental Results

Eight macroscopic changes were observed between heated and non-heated NCI cherts. These changes include color (Table 3.1), luster (gloss), and heat damage such as fractures, fissures, spalls, scales, crazing, and pot-lids (Table 3.2). Within our samples, variation existed among and between materials at different temperatures. Cico chert incurred heat damage at around 400°C or higher, for instance, where most Tuqan chert displayed thermal damage between 350-400°C. Heat damage for Cico chert included internal fissures, but rarely crazing, scaling or pot-lid fractures. Scales and fractures were most common among the Tuqan chert samples. One Wima chert sample (W2b) fractured and incurred heat damage at 350°C and 400°C, the other Wima samples exhibited little evidence of heat damage.

Table 3.1. Color values for unheated and heated samples of Channel Island cherts.

	Monterey Chert				**Cico Chert**				**Wima Chert**			**Tuqan Chert**		
ID#	**M1 a**	**M2 a**	**M3 a**	**M4 a**	**C1 a**	**C2 a**	**C3 a**	**C4 a**	**W1 a**	**W2 a**	**W3 a**	**T1 a**	**T2 a**	**T3 a**
Un-heated	7.5 YR 4/2	5 YR 7/1	2.5 YR N/5	10 YR 5/1	5 YR 6/1	10 YR 8/1	10 YR 8/2	2.5 YR N/6	10 YR 6/1	10 YR 7/1	10 YR 8/2	10 YR 7/1	5 YR 7/1	10 YR 6/1
350°C	2.5 YR N/4	10 YR 5/1	10 YR 4/1	5 YR 6/3	10 YR 4/1	10 YR 8/1	2.5 YR 8/2	2.5 YR N/6	5 YR 5/1	5 YR 5/4	5 YR 6/4	10 YR 5/1	10 R 5/1	7.5 YR N/ 4
400°C	2.5 YR N/4	10 YR 5/1	10 YR 4/1	5 YR 6/3	10 YR 4/1	10 YR 8/1	2.5 YR 8/2	2.5 YR N/6	5 YR 5/1	5 YR 6/3	5 YR 7/3	10 YR 5/1	10 R 5/1	7.5 YR N4

Color Change

Color change is influenced by the size of material, chemical composition, and the degree of heat exposure. Previous studies (Ahler 1983; Domanski et al. 2009; Purdy 1974) suggest that color change typically occurs between 250-300°C in most cherts, but may require an excess of 300°C. Color change alone does not provide sufficient evidence to distinguish whether an artifact has undergone thermal alteration, especially for NCI cherts because the wide range of naturally occurring colors overlaps with heated cherts. For our samples, color changes occurred in all but two translucent Cico chert nodules. Color changes typically included a reddish tint or samples grew darker in color (Table 3.1). Color penetration varied per sample and occurred on single sides, sporadically throughout the sample, or penetrated only a few millimeters beneath the cortex.

Gloss/Luster

Unheated or raw cherts may present a dull luster or non-reflective surface. Heated cherts often have a greasy, waxy, or polished appearance, but luster may not change dramatically until a freshly flaked surface is exposed. The ventral side of flakes (or their flake scars) removed from a heat treated core or biface often exhibits a measurable increase in luster and are more noticeable when adjacent to unflaked surfaces (Brown et al. 2009; Rick 1978:16). Samples that increased in luster also had a smoother surface texture and darker colored surfaces. Among experimental samples, newly exposed surfaces on heated and flaked specimens contained significantly higher gloss values than unheated samples (related-samples t test $p < .0001$) and heated but unflaked samples. The highest maximum gloss value measured from any unheated specimen was 2.2 GU while all heated and flaked surfaces measured 2.3 or higher (Table 3.3), creating a threshold for distinguishing heated /flaked and unheated artifacts in NCI archaeological assemblages made from Tuqan, Cico, and Wima cherts. If artifacts possessing heat fractures and high gloss values at these sites are the result of incidental fires, we would expect to see the majority of GU readings above 2.3, with gloss values below this threshold suggesting unheated materials in the same components. Assemblages possessing a range of gloss values above and below the threshold would suggest the preferential or intentional heat treatment of a portion of stone materials.

Thermal Fracturing

Despite using gradual heating and cooling methods and covering our samples to avoid direct heat, two of our specimens fractured during the heating process. These thermal spalls and shatter, which rose to the surface of the sand, were noted at the start of the cooling process. Samples may have fractured because they have lower temperature thresholds, contained inclusions, or a combination of factors.

Table 3.2. Characteristics of Channel Island cherts heated to 350°C and 400°C.

Thermal Alterations at 350°C

Material	Monterey				Cico				Wima			Tuqan		
ID #	*M1 b*	*M2 b*	*M3 b*	*M4 b*	*C1 b*	*C2 b*	*C3 b*	*C4 b*	*W1 b*	*W2 b*	*W3 b*	*T1 b*	*T2 b*	*T3 b*
Color change	yes	yes	yes	yes	yes	no	yes	no	yes	yes	yes	yes	yes	yes
> Luster	yes	yes	yes	yes	yes	yes	yes	yes	no	yes	no	yes	yes	yes
Fracture	yes	no	no	yes	no	no	no	no	yes	yes	no	no	yes	no
Fissures	no	no	no	yes	yes	yes	yes	yes	no	no	no	no	no	no
Spalling	yes	no	no	yes	no	no	no	no	no	yes	no	no	yes	no
Crazing	yes	yes	no	yes	no	no	no	no	no	yes	no	no	yes	yes
Scales	no	yes	yes	yes	no	yes	no	no	no	yes	no	no	yes	yes
Potlids	yes	no	no	yes	no	no	no	no	no	yes	no	no	yes	no

Thermal Alterations at 400°C

Material	Monterey				Cico				Wima			Tuqan		
ID #	*M1 c*	*M2 c*	*M3 c*	*M4 c*	*C1 c*	*C2 c*	*C3 c*	*C4 c*	*W1 c*	*W2 c*	*W3 c*	*T1 c*	*T2 c*	*T3 c*
Color Change	yes	yes	yes	yes	yes	no	yes	no	yes	yes	yes	yes	yes	yes
> Luster	yes	yes	yes	yes	yes	yes	yes	yes	yes	yes	no	no	yes	yes
Fracture	no	no	no	yes	yes	no	no	yes	yes	yes	no	no	yes	no
Fissures	no	yes	no	yes	yes	yes	yes	no	no	no	no	yes	yes	no
Spalling	yes	yes	no	yes	no	no	no	yes	no	yes	no	no	yes	no
Crazing	yes	yes	yes	yes	yes	no	no	yes	no	yes	no	no	yes	yes
Scales	no	yes	no	yes	no	no	no	yes	no	yes	no	no	yes	yes
Potlids	yes	yes	no	yes	no	no	yes	no	no	yes	no	no	yes	no

Heat Damage

Heat damage can be defined as changes to a material from excessive heating above threshold temperatures (see Domanski et al. 2009:1403), resulting in visible fractures, pot-lids, heat crazing, fissures, or scales (Figure 3.3). Heat damage can also result from rapid cooling or direct exposure to fire or heat sources (Schindler et al. 1982). These characteristics are less common among lithic artifacts completely buried during the heating process, because sand or other sediment provides a buffer between the material and a heat source. Most of our experimental specimens sustained some form of heat damage which may indicate low temperature thresholds for some materials. Some Tuqan chert appears to begin showing heat damage at 350°C, whereas Cico and Wima chert samples had a higher threshold of at least 400°C. The most common forms of heat damage on NCI cherts were pot-lids, heat fractures, and crazing. Despite containing heat damage, portions of the sample were successfully annealed and used in later trials to manufacture retouched flakes.

As defined by Clemente-Conte (1997:529-530), scales and fissures are macroscopic alterations located on or within treated surfaces. Heated fissures and scaled surfaces are visible under 20x magnification (Figure 3.3), and were apparent to some degree on all samples except for Wima chert. Internal fissures were most common among Cico chert samples and thermal scaling appeared on all material types. Scales commonly appear as raised welts or irregular cracks along the treated surface.

At 200x magnification the microcrystalline structures changed in some of our samples. Under 200x magnification, for instance, unheated Cico chert appears to be relatively fine-grained but contains concentrations of clouded areas (see Figure 3.4). After heating a sample to 350°C, the crystalline matrix still contained cloudy areas but dark inclusions also appeared. These were markedly reduced in the 400°C sample matrix, which also lost the cloudy matrix and became predominantly translucent. Unheated

Wima chert samples generally contain a more granular surface with tiny pockets and inclusions (see Erlandson et al. 2012), but samples heated to 350°C exhibited a smoother and more uniform texture (Figure 3.4). Samples heated to 400°C began to scale and show initial heat damage.

Table 3.3. Maximum gloss values (GU) for selected experimental samples. Values for unheated (control) samples are for the "a" (e.g. M1a) samples, "b" samples were heated to 350°C and "c" samples were heated to 400°C.

Sample ID	**Unheated (control)**	**Heated (unflaked)**	**Heated (flaked)**
M1b	1.4	1.9	3.7
M1c	1.4	1.7	2.6
M2b	1.8	1.5	3.2
M2c	1.8	2.0	3.1
M3b	1.5	1.3	3.7
M3c	1.5	1.1	3.2
M4b	2.0	2.5	2.9
M4c	2.0	2.6	3.7
T1b	2.2	1.9	2.6
T1c	2.2	2.4	2.9
T2b	2.0	1.5	2.6
T2c	2.0	2.5	3.7
T3b	2.1	1.5	4.5
T3c	2.1	3.4	3.9
W1b	1.4	1.6	2.6
W1c	1.4	1.4	3.7
W2b	1.7	1.2	3.1
W2c	1.7	1.8	3.2
W3b	1.5	1.2	2.3
W3c	1.5	2.3	3.1
C2b	1.7	2.6	3.3
C2c	1.7	2.6	2.9
C3b	1.1	2.8	3.1
C3c	1.1	2.2	3.2
C4b	1.3	1.1	2.9
C4c	1.3	2.3	2.7

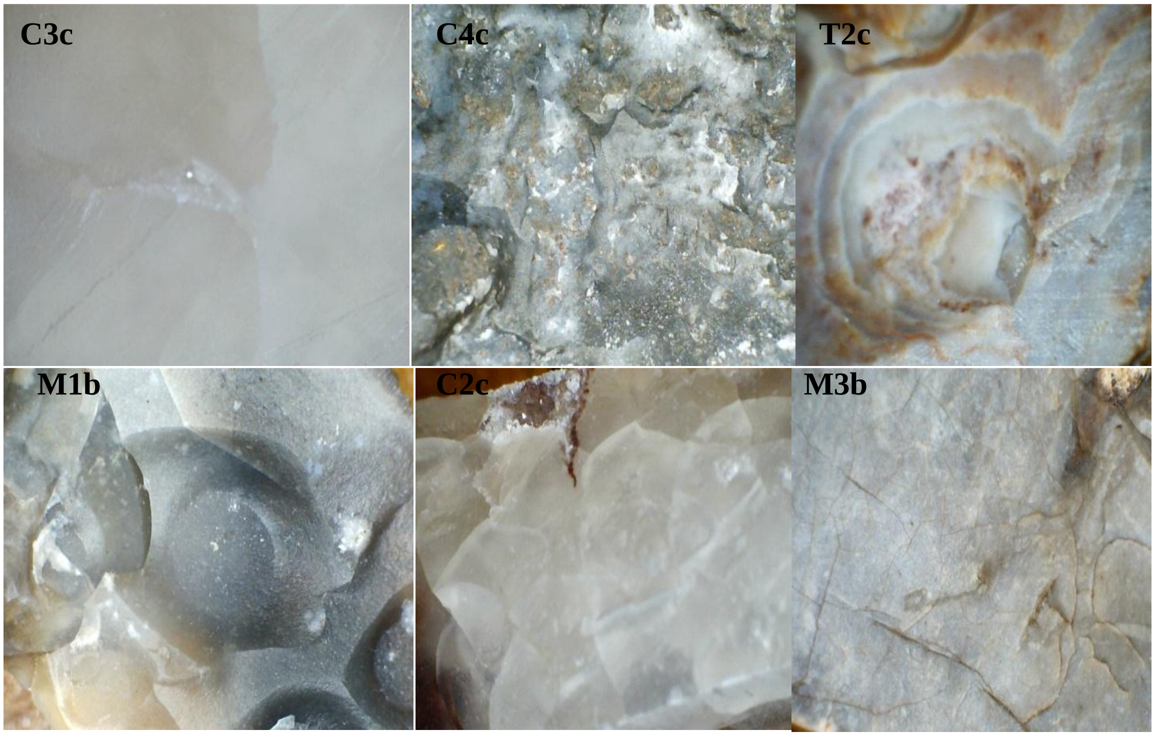

Figure 3.3. 20x magnifications including highlight boxes showing characteristics of thermal damage. C3c=fissures; C4c=thermal crazing; T2c=pot-lid; M1b=pot-lids; C2c=thermal scaling; M3b=thermal cracking (digital images by N. Jew).

Evidence for Heat Treatment in Paleocoastal Assemblages

The characteristics recorded from our heated experimental samples provided criteria to evaluate Paleocoastal artifact assemblages from CA-SMI-261 (Table 3.4), CA-SRI-512 (Table 3.5), and CA-SMI-679 (Table 3.6). First we used the glossmeter to analyze 250 non-diagnostic M/T chert artifacts from both CA-SMI-261 and CA-SRI-512, recording maximum gloss values compared to our experimental results. The maximum gloss values for these artifacts ranged from 1.0–5.0 GU (Figure 3.5), overlapping with the range of our experimental unheated and heated/flaked values. This suggests that some of the Paleocoastal artifacts were unheated (GU <2.2, n=99) while others appear to have been flaked after heating. We also examined the maximum gloss values of 20 diagnostic artifacts from CA-SRI-512 which exhibited values similar to experimental specimens that were heated and flaked. We also quantified the presence or absence of heat damage—in the form of thermal fractures such as crazing, fissures, scales, and pot-lids. Using gloss values or thermal damage as an indicator, a substantial percentage of artifacts from all three sites exhibited evidence of heat damage or relatively high luster value.

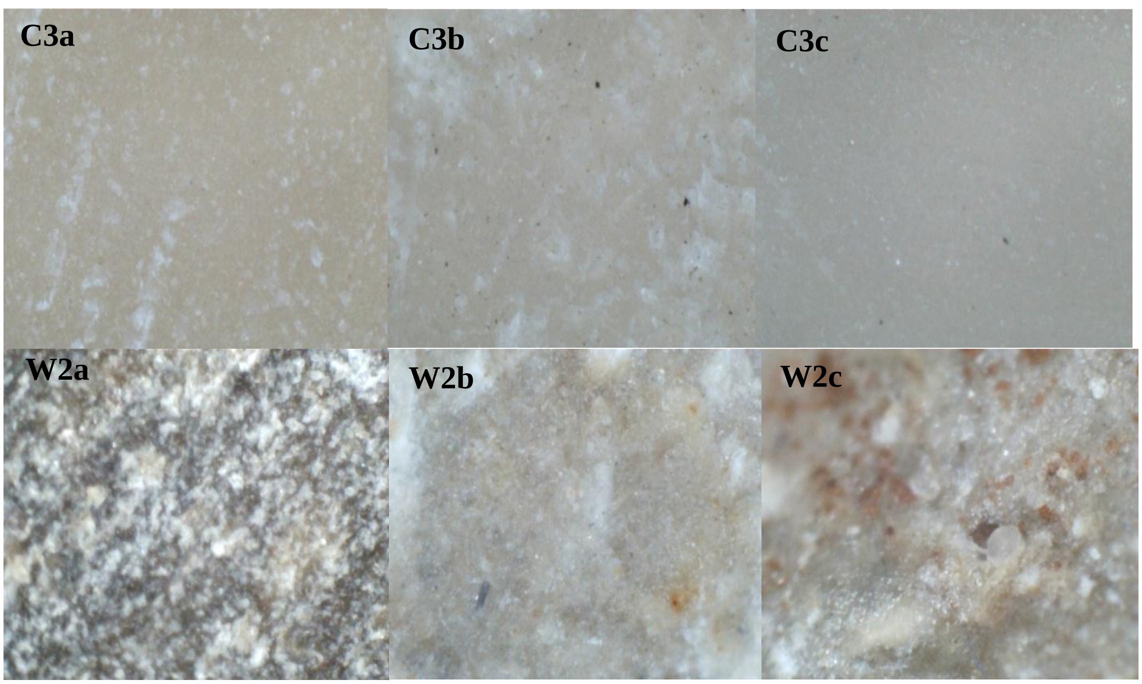

Figure 3.4. Texture variances for Cico (top row) and Wima chert (bottom row) samples at 200x magnification, from unheated (left), heated to 350°C (center), and heated to 400°C (right).

For the Early Holocene strata at Daisy Cave, we analyzed 92 lithic artifacts including bifaces, projectile points, a crescent, expedient tools, and debitage. Despite small sample sizes, 50% of the bifaces (n=10) and expedient tools (n=8) show evidence of heat damage. Three of five (60%) Cico chert flakes had fissures or scales and 20 of 67 (30%) M/T chert flakes exhibited evidence of heat crazing, scales, and pot-lids. Two formal artifacts from Daisy Cave, a crescent and a small fragment of a CIB point, had high maximum gloss values (3.2 and 3.3, respectively), but no evidence of heat damage.

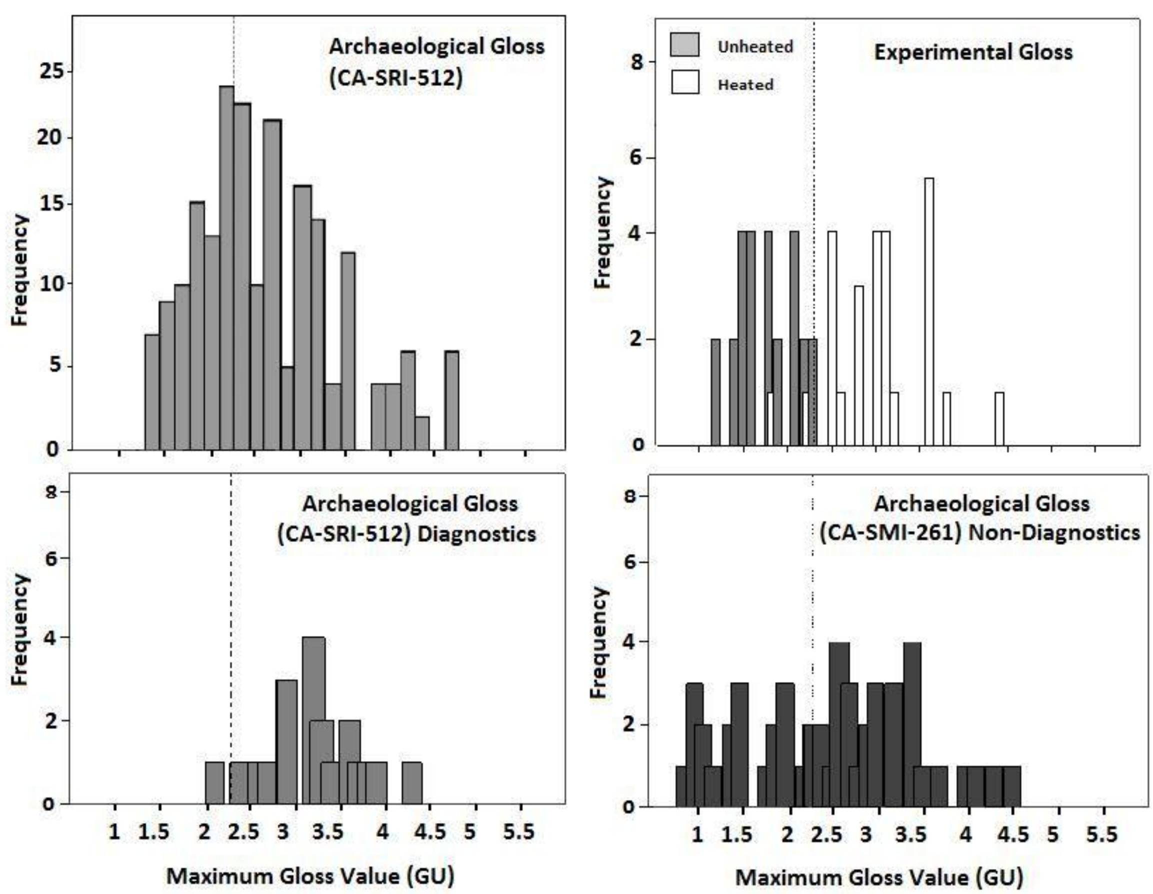

Figure 3.5. Bar graphs showing gloss values (GU) for experimental, non-diagnostic archaeological artifacts, and diagnostic artifacts. Reference line along the *X* axis represents the highest maximum gloss value (2.2) for unheated experimental samples.

From units 1-4 at CA-SRI-512, 956 artifacts were examined and 258 (27%) showed evidence of heat damage (Table 3.5). These units had over 2,000 pieces of tool-making or maintenance debris (flakes, shatter, etc.), so a sample of 847 of the larger pieces was examined. Approximately 27% of this debitage sample (n=229) showed evidence of heat damage. For diagnostic artifacts, 28% of CIB points and 24% of crescents made from M/T chert had heat damage, but most of these had just one small pot-lid. Evidence for thermal alteration was found on 35% of the other bifaces and 14% of other point fragments. Artifacts made from Cico and Wima cherts were also present in the assemblage, but had lower frequencies of heat damage.

Unit 1S at CA-SMI-679 produced 271 chipped stone artifacts—of which 28% had evidence of heat damage. Cores had the highest percentage of heat damage (80%), followed by bifaces (33%), and debitage (27%). No diagnostic artifacts were recovered from the unit. Tuqan Monterey chert is again the dominant material and 29% of the artifacts made from this material contain evidence of heat damage. Artifacts made from Cico and Wima cherts are present in smaller numbers and had lower frequencies of heat damage.

When combined with the quantitative data for maximum gloss values for experimental and archaeological samples, the consistently high frequency of heat fractures in early NCI lithic assemblages supports the conclusion that heat treatment of island cherts was used by Paleocoastal peoples to facilitate the production of flaked stone tools, including finely-made stemmed points, crescents, and other bifaces.

Table 3.4. Frequency of chert artifacts from Early Holocene strata at CA-SMI-261 with heat damage (M-T = undifferentiated Monterey or Tuqan chert).

	Material Type and Modification Status					
Artifact Type	Cico	Cico (Heated)	M-T	M-T (Heated)	Total	Total (Heated)
Lithic tools	-	-	8	4(50%)	8	4(50%)
Bifaces	-	-	10	5(50%)	10	5(50%)
Debitage	5	3(60%)	67	20(30%)	72	23(32%)
Crescents	-	-	1	-	1	-
Stemmed point	-	-	1	-	1	-
Total	5	3(60%)	87	29(33%)	92	32(35%)

Table 3.5. Frequency of chert artifacts from CA-SRI-512 (Units 1-4) with heat damage, by material and artifact types (M-T = undifferentiated Monterey or Tuqan chert).

Artifact Type	Cico	Cico (Heated)	Wima	Wima (Heated)	M-T	M-T (Heated)	Total	Total (Heated)
Stemmed point	5	1(20%)	2	-	50	15(30%)	57	16(28%)
Crescents	1	-	-	-	20	5(25%)	21	5(24%)
Bifaces	1	1(100%)	-	-	16	5(31%)	17	6(35%)
Point Fragments	1	-	1	-	12	2(17%)	14	2(14%)
Debitage	30	-	35	11(31%)	782	218(28%)	847	229(27%)
Total	38	2(5%)	38	11(26%)	880	245(28%)	956	258(27%)

Table 3.6. Frequency of chert artifacts from Unit 1S at CA-SMI-679 with heat damage (M-T = undifferentiated Monterey or Tuqan chert).

Artifact Type	Cico	Cico (Heated)	Wima	Wima (Heated)	M-T	M-T (Heated)	Total	Total (Heated)
Cores	2	2(100%)	1	1(100%)	2	1(50%)	5	4(80%)
Bifaces	3	1(33%)	-	-	3	1(33%)	6	2(33%)
Debitage	54	13(24%)	6	-	200	57(29%)	260	70(27%)
Total	59	16(27%)	7	1(14%)	205	59(29%)	271	76(28%)

In analyzing such bifacial tools from Paleocoastal assemblages, we noted a distinctive pattern of thermal damage on many of the finished artifacts. This damage pattern consisted of a single small surface depression resulting from localized heat crazing or pot-lidding (Figure 3.6). These fractures were initially noted on artifacts coming from large surface sites, suggesting that they might result from incidental contact with wildfires, but most artifacts revealed no other signs of thermal damage. When assemblages from deeply buried site components became available, we noted a similar pattern on many of the finished bifaces, leading us to examine the possibility that Paleocoastal peoples may also have used thermal treatment in the final stages of biface manufacture. Because these distinctive fractures were usually localized, quantifying their frequency was limited to the analysis of complete or nearly whole specimens. Among 37 whole or nearly whole CIB points from CA-SRI-512 made from M/T chert, 16 (43%) exhibited heat damage and six of these had localized pot-lids. Among 134 diagnostic artifacts from six other Paleocoastal sites—including stemmed points, crescents, and other bifaces—percentages of heat damage at each site ranged from 29% to 85% (Table 3.7). Localized potlids were observed on many of these, including five of 10 heat-damaged M/T crescents from CA-SMI-678 and CA-SMI-679, and two of six stemmed points. The presence of pot-lids on finished points and crescents, in both deeply buried and surface assemblages, suggests that these distinctive fractures may have resulted from heat treatment of bifaces near the final stages of stone tool production.

Figure 3.6. Localized pot-lid heat fractures on stemmed points from CA-SRI-512–catalog numbers (left to right) 268d, 397, 390 (photos by N. Jew).

Table 3.7. Number of diagnostic artifacts from Paleocoastal components on San Miguel and Santa Rosa islands with evidence for heat fracture.(M-T=Monterey-Tuqan chert; heat damaged artifacts over total number of artifacts analyzed, followed by the percentage of treated artifacts for each category).

Site	**Age**	**CIB Points**			**Amol Points**		**Crescents**			**Misc. Bifaces**			**Total**	
CA-	Cal BP	W*	C*	MT*	C	MT	W	C	MT	W	C	MT	T	Ht.
SRI 707	PC*	-	-	0/2	-	-	0/1	-	1/3 33%	1/1 100%	-	7/13 54%	20	9 45%
SRI 706	11,700	-	-	-	-	0/1	-	-	0/4	0/1	-	4/7 57%	13	4 30%
SMI 701	11,600	-	-	-	1/2 50%	-	-	-	1/1 100%	-	-	4/4 100%	7	6 85%
SMI 678, 679	12,200 11,400	1/1 100%	1/3 33%	6/16 38%	0/4	6/18 33%	-	1/2 50%	10/22 45%	-	1/3 33%	7/22 31%	87	33 38%
SRI 26	11,500	-	-	0/1	-	-	-	-	0/2	-	-	2/4 50%	7	2 29%

*abbreviations: Paleocoastal=PC, Cico=C., Wima=W., Monterey Tuqan=MT, T=total, and Ht.=heated

Discussion and Conclusions

Our experiments and analysis of archaeological collections suggest that Paleocoastal peoples—from at least 12,200 to 8600 cal BP—systematically heat treated cherts to enhance the production of chipped stone tools, including delicate projectile points used in a sophisticated maritime hunting technology. The results of quantitative glossmeter analysis of artifacts from deeply buried contexts suggest that heat treatment was intentional rather than incidental. Differential percentages of heat fractures on cores (80%) and debitage (27%) from three excavated sites suggest that island cherts were heat treated in the early stages of lithic reduction. The localized pot-lids observed on a high percentage of CIBs and crescents also suggest heat treatment may have occurred later in the reduction sequence.

Because thermal damage on chert artifacts may result from wildfires or incidental contact with hearths or ovens, researchers should carefully examine the stratigraphic context of lithic assemblages for evidence of these features. Experimental heat treatment can help identify the signatures and thresholds of heat-damage or alteration for individual chert types. Such data can be applied to the analysis of lithic assemblages, where various categories of chert artifacts should be examined for signatures of heat-treatment or incidental damage, including the presence of color and texture changes, heat-fractures, pot-lids, or crazing. Finally, following Brown et al. (2009), we found the use of a glossmeter to quantitatively measure and compare the glossiness of chert artifacts to be a valuable tool in identifying evidence of heat-treatment even when other signs of heat damage were absent.

Although a small percentage of the Paleocoastal artifacts we analyzed may have been damaged by incidental contact with natural or cultural fires, we found little evidence for hearth features or intensive burning of other site constituents directly associated with heat-altered chipped stone artifacts. At CA-SMI-261 and CA-SMI-679, in particular, heat damaged chert artifacts were found embedded in dense shell midden matrices where the surrounding shellfish remains and animal bones contained little or no evidence for burning. Exposure to occasional wildfires might explain some heat fractures, but three of the assemblages we analyzed were found in deeply buried strata that were sealed relatively quickly after deposition.

Our experimental work in heating NCI cherts, developing criteria for recognizing heat damage on island cherts, and comparative analysis of Paleocoastal lithic assemblages suggest that heat treatment was systematically employed as part of a sophisticated maritime Paleoindian technology. Future research should focus on further understanding the full range of variability among island cherts (grain size, textures, mineralogy, etc.)—including Santa Cruz Island cherts, those factors that influence how thermal alteration can improve knappability, and whether heat-treatment of island cherts continued to be part of later NCI lithic technologies. For now, our study provides a baseline for understanding the effects of heat treating NCI cherts at various temperatures, as well as criteria that can help researchers identify heat treated artifacts in lithic assemblages. Finally, our results demonstrate that the extraordinary flint-knapping abilities represented by delicate CIB and CIA points were facilitated by the controlled use of fire by Paleocoastal peoples, which increased the knappability of island cherts.

Bridge

The distribution and human preference for island cherts presented in Chapter II and evidence of heating cherts for stone tool manufacture discussed in Chapter III reflect a strong human reliance on island lithic raw materials during the Paleocoastal period. The next series of chapters examine early human mobility and sedentism on the NCI exploring seasonal and year-round mussel harvesting. Chapter IV, co-authored by Jon Erlandson, Frances White, and Jack Watts, is in press in the peer-reviewed *Journal of Island and Coastal Archaeology*. In this chapter, I compare two strategies for sampling calcite from California mussel shells recovered from an ~8800 year old shell midden on San Miguel Island. I used stable oxygen isotope ($\delta^{18}O$) analysis of these calcite samples to reconstruct paleo-sea surface temperatures and examine the seasonality of Paleocoastal mussel harvesting at the site.

Initial results using traditional methods of $\delta^{18}O$ analysis used by many California archaeologists suggested a year-round or multi-seasonal occupation of CA-SMI-693, which contradicted other archaeological evidence that suggested a short-term seasonal occupation of the site. More intensive sampling, which took into account the rapid growth of California mussels in the first year or two of their life cycle, documented a ~35 percent error rate in the traditional method and greatly narrowed the seasonality of mussel harvesting at the site. This methodological advance was used in subsequent $\delta^{18}O$ analyses at several other Paleocoastal sites, the results of which are presented in Chapters V and VI.

CHAPTER IV

SHELLFISH, SEASONALITY, AND STABLE ISOTOPE SAMPLING: $\delta^{18}0$ ANALYSIS OF MUSSEL SHELLS FROM AN 8800 YEAR OLD SHELL MIDDEN ON CALIFORNIA'S CHANNEL ISLANDS

Introduction

Archaeologists have used stable oxygen isotope analysis of marine mollusk shells for several decades to study past environments and human adaptations, including the seasonality of shellfish harvest, human settlement and mobility patterns, nearshore ecology, and sea surface temperature (SST) (see Andrus 2011, 2012; Bailey et al. 1983; Eerkens et al 2010; Epstein et al. 1951, 1953; Glassow et al. 1994; Jones et al. 2008; Kennett 2005; Kennett and Voorhies 1995, 1996; Killingley 1981; Kimball et al. 2009; Rick et al. 2006; Shackleton 1973; Schweikhardt et al. 2011). The ratio between stable oxygen isotopes ^{18}O and ^{16}O (reported as $\delta^{18}O$) reveal enriched or depleted values (Epstein et al. 1951, 1953; Killingley and Berger 1979) that provide a proxy for inferring SST for a given period of calcium precipitation during mollusk growth. Recent studies have examined the relationships among the rate of growth, calcium carbonate precipitation, and the effects of estimating season of harvest for various species (e.g., Andrus 2012; Quitmyer and DePrater 2012; Quitmyer and Jones 2012). Researchers have also employed a variety of sampling techniques to extract calcium carbonate ($CaCO_3$) for isotopic research from mollusks (see Bailey et al. 1983; Glassow et al. 1994, 2012; Jones and Kennett 1999; Kennett 1998; Kennett and Voorhies 1995; Rick et al. 2006; and others), which frequently includes sampling the terminal growth band (TGB) and additional increments along the growth axis (Figure 4.1). The total number of isotopic determinations varies between researchers, with different strategies developed to address tensions between adequate sampling of individual shells, the total number of shells to be sampled, analytical time, expenses, and available funding.

In shell middens along the California Coast, where California mussels (*Mytilus californianus*) are commonly used for $\delta^{18}O$ analysis, a small number of shells typically are extensively profiled in ~2 mm increments, with additional shells characterized through more limited sampling of the terminal growth bands (TGB) and increments ranging anywhere from one (usually 2 mm from the TGB) to several measurements (e.g., Glassow et al. 1994; Jones et al. 2008; Kennett 2005; Rick et al. 2006). For fast-growing mollusks such as California mussels (see below), however, 2 or 3 isotopic determinations spanning ~2-5 mm of growth may not represent a full season (three months) of growth. During periods of rapid growth, such small sampling increments may capture just a week or month of growth (see Bailey et al. 1983:394), while for slower growing mollusks this method may capture one or more seasons of growth. Ideally, seasonal determinations should be based on isotopic records spanning at least one or more season of growth (Bailey et al. 1983).

A sampling method designed to document at least one season of growth for a mollusk may vary depending on species, lifespan, growth rate, age, size, water salinity, food availability, habitat, SST, sex of an organism, and other factors (Goodwin et al. 2003). For California mussels, several studies (e.g., Culleton et al. 2009; Glassow et al. 1994; Jones and Kennett 1999; Kennett 1998; Killingley and Berger 1979; Rick et al. 2006; and others) employed a 2 mm interval sampling strategy as a standard unit of measure when conducting oxygen isotope analysis. The number of isotopic determinations per shell ranges from two samples (TGB+1) to extended profiles that sample 30 mm or more of shell growth.

On Santa Cruz Island, Glassow et al. (1994) fully profiled (~15-24 samples per shell) seven California mussels from a Middle Holocene shell midden, sampling ~28-48 mm of growth. Later, using mussels from Santa Rosa Island shell middens, Rick et al. (2006; Robbins and Rick 2007) sampled 4-5 increments at 2 mm intervals for every analyzed mussel shell, sampling ~8-10 mm along the growth axis. Increasingly, California archaeologists have relied on full profiles for one or more shell from each site or component, with additional shells sampled using a TGB+1 method (see Kennett 2005; Jones et al. 2008).

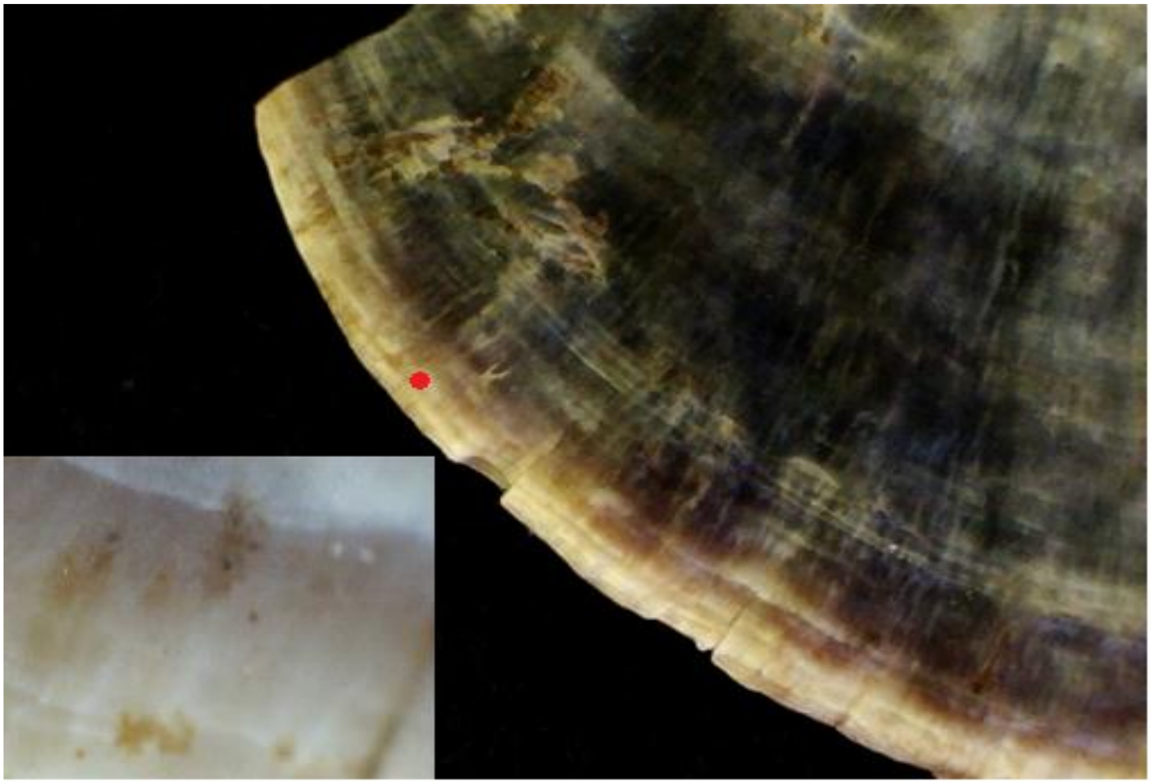

Figure 4.1**.** 20x and 200x (inset) magnification of a California mussel shell from CA-SMI-693, illustrating ~2 mm of growth (represented by the red dot) inward from the terminal edge. The inset shows the lighter and darker layers typically identified as growth bands.

Here, given what is known about the growth rates of California mussels, we examine how many isotopic determinations per shell are required to insure the sampling of at least one full season of growth—generally considered to be a minimum for accurate estimates of the season of harvest. Specifically, we consider the ecology and variable growth rates of California mussels in evaluating two different sampling strategies used to acquire isotope and seasonality data. We use the TGB+1 method and a modified TGB+6 method to evaluate seasonality determinations on California mussels from a discrete, 8800 year old shell midden feature at CA-SMI-693 located near Point Bennett on San Miguel Island. We evaluate the $\delta^{18}O$ results in relation to other archaeological evidence for the structure, function, and seasonality of CA-SMI-693. First, however, we provide background data that contextualizes the site, the paleoecology of the ancient Point Bennett area, and the ecology of California mussels.

Background and Archaeological Setting

On California's Channel Islands (Figure 4.2), the last decade has seen considerable progress on understanding the antiquity and nature of human settlement during the Paleocoastal period, from ~13,000 to 8,500 years ago (see Cassidy et al. 2004; Erlandson et al. 2011; Glassow et al. 2008; Kennett 2005; Kennett et al. 2008; Rick et al. 2001). More than 75 Terminal Pleistocene and Early Holocene sites have been identified on the northern islands alone, most of them on San Miguel and Santa Rosa islands. Less than one-third of these early sites have been tested, and most of these have seen very limited excavations.

It is often assumed that most Paleocoastal sites on the Channel Islands were short-term or seasonal campsites (see Balter 2011; Erlandson et al. 2008a; Fitzhugh and Kennett 2010; Rick et al. 2005). Rising postglacial sea levels have submerged the coastal lowlands where early maritime people probably spent most of their time (see Kennett et al. 2008) and most known Paleocoastal sites are located around pericoastal geographic features (caves, springs, chert sources) that drew ancient maritime peoples into the interior. Other than an inferred winter/early spring occupation (based on the presence of migratory waterfowl) at the 11,700 year old CA-SRI-512 on Santa Rosa Island (Erlandson et al. 2011), there is little or no evidence for the seasonality of occupation at Paleocoastal sites. There is considerable diversity in the size, depth, density, and contents of such sites, however, suggesting that Paleocoastal peoples may have occupied the larger islands year-round.

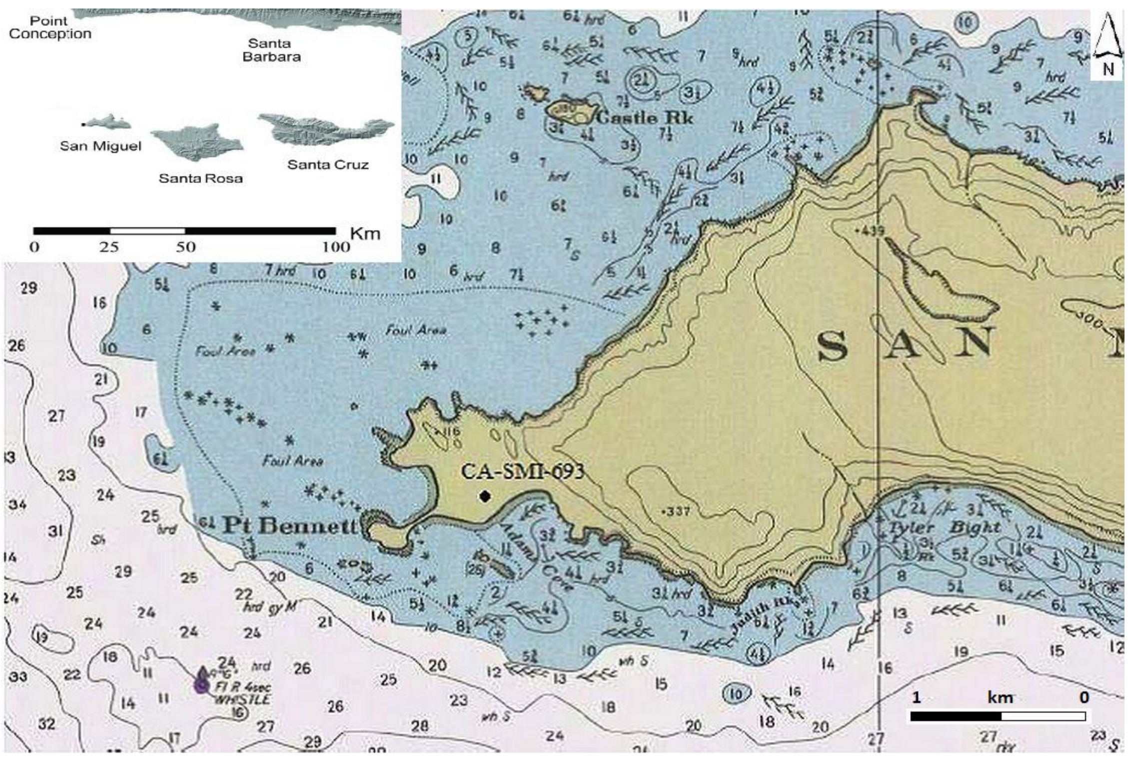

Figure 4.2. Map of the Northern Channel Islands including the approximate location of CA-SMI-693 relative to the onshore and offshore topography of western San Miguel Island, including the 10 fathom submarine contour that approximates the location of the paleo-shoreline about ~8500 cal BP (from NOAA 1987 navigation chart for San Miguel Passage).

CA-SMI-693 was discovered during a search for early sites near the west end of San Miguel Island. The site appeared to have been recently exposed by the erosion of overlying Holocene dune sand and was being destroyed by a combination of wind erosion and the activities of pinnipeds hauling out on the site. In response to this damage, the site was thoroughly surveyed in 1-2 meter transects to identify exposed artifacts, faunal remains, and features. Much of the site was heavily disturbed, leaving a deflated scatter of marine shells and occasional artifacts visible over an area about 80 m long and 30 m wide. We identified three loci (north, central, and south) where remnants of intact shell midden deposits were still concentrated. Very few artifacts were observed on the site surface and only two tools were noted still embedded in the site soil: a lightly used hammer stone and a flaked cobble core. No animal bones were observed in situ either, and excavation of a 1 x 1 m test pit in an intact midden feature in the central locus produced just two tiny unidentifiable bone fragments.

The shell midden at CA-SMI-693 was only 3-8 cm thick, but the excavation of test Unit 1 produced more than 4.6 kg of marine shell from California mussels and other rocky intertidal shellfish taxa. These included the remains of over 400 California mussels, including scores of whole and still articulated mussel shells. California mussels dominated the shellfish assemblage, comprising more than 80% of the shellfish MNI, 91% of the shell weight, and 96% of the estimated meat yield for the excavated sample. Aside from small amounts of black abalone (*Haliotis cracherodii*), black turban (*Chlorostoma funebralis*), and sea urchin (*Strongylocentrotus* spp.) shell, the other shellfish taxa were mostly epifauna, including tiny limpets and barnacles often found attached to mussels (Jones and Richman 1995).

Three well-preserved California mussel shells from the intact remnants of the central and southern loci were submitted for radiocarbon (^{14}C) dating and calibrated using a ΔR of 225 ±35 within a 1 sigma range. At the UO, the ^{14}C samples were cleaned and etched with hydrochloric acid (HCl) to remove potential contaminants, and sent to two labs for dating. First, two samples were submitted to Beta Analytic for analysis via conventional liquid scintillation counting. This resulted in ^{14}C dates of 8540 ± 50 RYBP (Beta-255083) for the southern locus and 8150 ± 100 RYBP (Beta-255084) for the central locus, with calibrated age ranges of 8980-8780 cal BP and 8510-8290 cal BP, respectively (see Stuiver and Reimer 1993). A second mussel shell (mc33) from the central locus was later submitted to DirectAMS for dating via accelerator mass spectrometry and produced a conventional age of 8440 ±40 RYBP (DAMS-1217-174; J. Chatters, p.c., 2012) and a calibrated age range of 8810-8620 cal BP. This date is consistent with Beta-255083 and suggests that CA-SMI-693 resulted from a single short-term occupation ~8800 ± 100 years ago.

A variety of evidence—including the dearth of artifacts and vertebrate remains, the thin and ephemeral nature of the midden deposits, and the limited diversity of shellfish represented—supports the conclusion that occupation of CA-SMI-693 was relatively brief and focused on the harvest and processing of California mussels. The dearth of artifacts and vertebrate remains at the site is reminiscent of several nearby Early Holocene sites that have been interpreted as short-term camps focused on shellfish collecting and processing (e.g., Erlandson et al. 2004). Because well-preserved mussel shells were abundant in the small and shallow shell feature excavated at the site, they provided an excellent opportunity to examine the seasonality of the site occupation.

Mytilus californianus Ecology and Growth

California mussels are filter-feeding bivalves that inhabit intertidal and (less commonly) subtidal zones of North America's Pacific Coast, from the Aleutians and Alaska to Alta and Baja California (Bayne 1976; Killingley and Berger 1979:187). California mussels are relatively long-lived bivalves that can live up to 20 years. They are found in rocky intertidal areas in water temperatures that range between ~8 and 26° C (Bayne 1976; Coe and Fox 1942:66). California mussels along the Southern California coast spawn throughout the year (see Suchanek 1981) with breeding peaks between July and December (Morris et al. 1980). They can begin reproducing as early as 4 months old or between 25 and 30 mm long (Shaw et al. 1988). Environmental influences such as water temperature, salinity, wave action, food (dinoflagellates, kelp spores, etc.) availability, surface exposure, sedimentation, and upwelling can vary depending on geographic location, changing growth rates of mussels by the hour, day, month, and season (Coe and Fox 1942, 1944; Denhel 1956; Fox and Coe 1943; Menge et al. 2008; Rao 1953; Richards 1946; Richards and Naylor 1990). As a response to heavy predation, California mussels generally grow very rapidly during their first year, adding as much as 6 mm of shell length per month and reaching total lengths of ~70 mm (Coe and Fox 1942). In subsequent years growth slows significantly as more metabolic energy goes to reproduction, with shell growth averaging ~35 mm in the second year, 20 mm in the third year, and just 5 mm in the fourth year (Figure 4.3). Depending on environmental conditions and the age of an individual mussel, monthly growth rates can vary dramatically, from less than 1 mm to more than 5 mm per month (Coe and Fox 1942:60). In waters south of Point Conception, where growth tends to be relatively rapid (Phillips 2005), California mussels less than ~70 mm long may grow 18 mm or more in a single season.

On the Northern Channel Islands (NCI), California mussels were harvested by humans for at least 12,000 years (see Erlandson et al. 2011) and are the most abundant type of shellfish found in most island shell middens. California mussels are nearly ubiquitous in the mid-to-low intertidal zone of rocky island shores. They attach to rocky substrates via strong byssal threads, often forming dense clusters or extensive mussel beds. Because they are abundant, readily accessible, grow rapidly, and can be easily harvested in large clumps or stripped from rocks in dense mats, they are generally considered the top-ranked shellfish on the islands (see Braje et al. 2007).

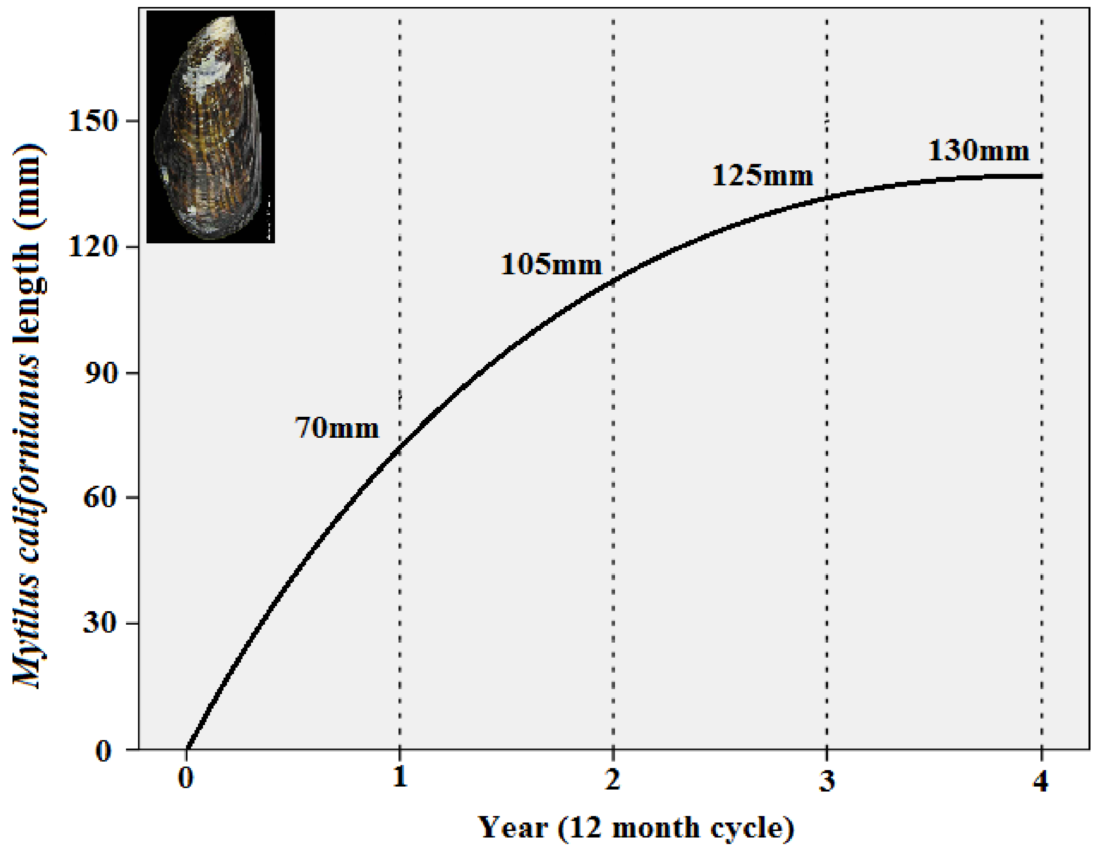

Figure 4.3. Estimated mean growth curve for >1000 California mussels over a four year period at Scripps Institute of Oceanography in La Jolla, California (after Coe and Fox 1942).

Trans-Holocene studies of mussel harvesting on San Miguel and Santa Rosa islands have shown a long-term and island-wide reduction in mean California mussel size, with most Late Holocene shell middens containing relatively small mussels averaging just 35-50 mm long (Erlandson et al. 2008b). As a result, although the Island Chumash harvested millions of mussels annually from Channel Island waters, most of these were small and less than one year old when harvested (see Figure 4.3). At CA-SMI-693, the mean length of 100 measured mussel valves was 67.8 mm, with a range of 35 to

102 mm. Growth curves for California mussels in southern California waters suggest that all these mussels were probably harvested before they were two years old, with more than half being one year old or less. How might the very rapid growth of California mussels during their first year of life affect oxygen isotope sampling methods and the inferred seasonality of mussel harvest?

Oxygen Isotope Analysis

The rapid growth of California mussels during their first year suggests that shells ~70 mm long require sampling of at least ~15-25 mm along the growth axis to adequately characterize a full season of growth. With average growth rates slowing to ~35 mm during their second year, however, mussels >70 to 105 mm long should require considerably less sampling (~9-12 mm) to span a full season of growth. The very different growth rates for California mussels in their first few years of life suggest that different isotopic sampling strategies might be appropriate for shells of different sizes. To test this, we analyzed whole California mussel shells of varying sizes using two different sampling methods.

Methods

First we selected 40 whole or nearly whole California mussels between 45 mm and 102 mm long. All shells were scraped, rinsed in deionized water, and etched in diluted HCl (0.5 M) to remove foreign substances and diagenetically altered carbonate (see Bailey et al. 1983; Culleton et al. 2006; McCrea 1950; Robbins and Rick 2007). Each shell was mounted onto a Sherline 5410 Micromill and drilled at low speeds (see Robbins and Rick 2007:29) using a carbide (.05 mm) drill bit, carefully sampling in transects following the visible growth lines while ensuring that only the exterior calcite was sampled. Powdered samples were weighed and placed in an autosampler that flushed exetainers with helium to exclude atmospheric carbon dioxide and injected with several drops of othro–phosphoric acid to release carbon dioxide from each sample. $\delta^{18}O$ and $\delta^{13}C$ were measured using a Finnigan MAT253 mass spectrometer using continuous helium flow with precision oxygen and carbon isotopic ratios at ±0.1‰ measured at 1 sigma and calibrated by repeated direct measurement against NBS-19. All isotopic determinations are reported in δ-notation in per mil (‰) using the Vienna PeeDee Belemnite (VPDB or PDB) standard and inferred SST is based on oxygen isotope signature conversion (see Epstein et al. 1951, 1953; Killingley 1981) where:

$$T\,(°C) = 16.4 - 4.2\,(\delta^{18}O_{cc(PDB)} - \delta^{18}O_{water(smow)}) + .13\,(\delta^{18}O_{cc(PDB)} - \delta^{18}O_{water(smow)})^2$$

the selected Δ_{0m} $\delta^{18}O_{sw(‰)}$ for the Early Holocene period ~8800 cal BP in the Pacific (see LaGrande and Schmidt 2009; Martinson et al. 1987:20) is ~.47‰ and was adjusted from an ocean water sample of .32‰ taken from Santa Rosa Island (see Robbins and Rick 2007:30) providing an ice volume correction ($\delta^{18}O_{water\ (smow)}$) of .15‰. The minimum and maximum temperatures in the terminal edge series represent the warmest and coldest months of harvesting (see Kimball et al. 2009:194).

Initially, we analyzed 95 carbonate samples including one fully profiled shell (Mc21, 77 mm long) and two measurements each for the other 39 shells (TGB+1; sampling the terminal growth band plus one sample 2 mm from the TGB). For our second approach (TGB+6 method), we measured 120 isotopic signatures from 20 of the previously sampled shells, 10 shells from 45 to 67 mm long and 10 larger shells from 71 to 100 mm long. Shells were sampled at 3 mm intervals for at least 18 mm of growth extending from the TGB to ensure at least 3-4 months of growth for smaller mussels, based on estimates of California mussel growth (see Coe and Fox 1942, 1944).

A Paleo-SST Model for Western San Miguel Island

For the extensively profiled shell (Mc21), we analyzed 17 samples taken in 3 mm intervals, for a total of 48 mm of growth. This extended profile (Figure 4.4) provided a standard range of SST variation over most or all of an annual cycle and was used to estimate seasonal variability in paleo-SST for waters around the western end of San

Miguel Island ~8800 years ago (Figure 4.5). Subsequent isotopic measurements were converted into estimated temperature values and compared to the paleo-SST model, adjusted from modern monthly SST averages recorded for ten years off the coast of San Miguel Island (Kennett 2005:56, 66-68). Modern SST averages off San Miguel place the coldest 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 during January and February (winter). Because SSTs around western San Miguel during the Early Holocene appear to be characterized by seasonal temperature variations of ~6°C (see Appendix A) the range of seasonal variation was adjusted to compensate for this increased variability. Overall, recent $\delta^{18}O$ values typically range between ~0.8 to -0.2 (VPDB) for the Santa Barbara Channel region (see Kennett 1998:451, 2005:66; Kennett and Kennett 2000:384) where Early Holocene $\delta^{18}O$ values for ~8800 cal BP fall between ~0.2 to-0.5 with cooler temperatures during this period (see Kennett 2005:66). As a result, our modeled temperatures were adjusted between 2-4 °C, skewed towards colder water temperatures.

We classified the season of harvest for each analyzed shell using the parameters listed below: where *X* represents the value for the TGB (season of capture) and *Y* equals the value for the comparative growth band(s) and season prior to capture, and directionality is the difference (change) between these two values. Based on these estimates, seasonal paleo-SST near San Miguel ~8800 cal BP can be divided as follows:

– Summer *(June to September): $X \geq 12°C$ and $Y < X$ (increasing warm temperatures above ~12°C)*

– Fall *(September to December): $X \geq {\sim}10°C$ and $Y > X$ (with decreasing warm temperatures)*

– Winter-Early Spring *(December-March): $X \leq {\sim}10°C$ and $Y > X$ (coldest waters)*

– Spring *(March-May): $X \leq {\sim}12°C$ and $Y < X$ (with colder temperatures below X)*

Figure 4.5 also shows at least two extended periods of relatively stable temperatures represented in the modern 10 year averages for waters off San Miguel, one during 5-6 months between December and May (winter/spring), and another of 2-3 months duration from July to September (summer). Given the overlap in SSTs between winter and early spring, these seasons were indistinguishable except in shells that contained high variability between the terminal edge and adjacent growth bands, suggesting either a dramatic warming or cooling from the prior season. Given instrumentation precision of ±0.1‰, approximate temperature values and assigned seasons are influenced by the isotopic determination of the comparative sampled interval. For example, temperatures on the border between two seasons were assigned based on the temperature of the previous season. Therefore a shell with a TGB temperature of 9.9°C could be either late fall, winter, or early spring depending on the temperature of the previous season. If the temperature of the comparative sample interval was 10.2°C it would be attributed to a winter or early spring harvest, while a shell with a comparative sample interval of 15°C would be attributed to a fall–late fall harvest as it is unlikely this high temperature would occur in late winter. Shells that contained lower SST variances between the TGB and comparative 2 mm of growth were assigned a single season as this suggests that it was harvested well into the season. Alternately, if the TGB and comparative sample interval contained high SST variances, these were assigned a corresponding season as they were most likely harvested towards the end of the previous seasons and in the early months of the season of capture.

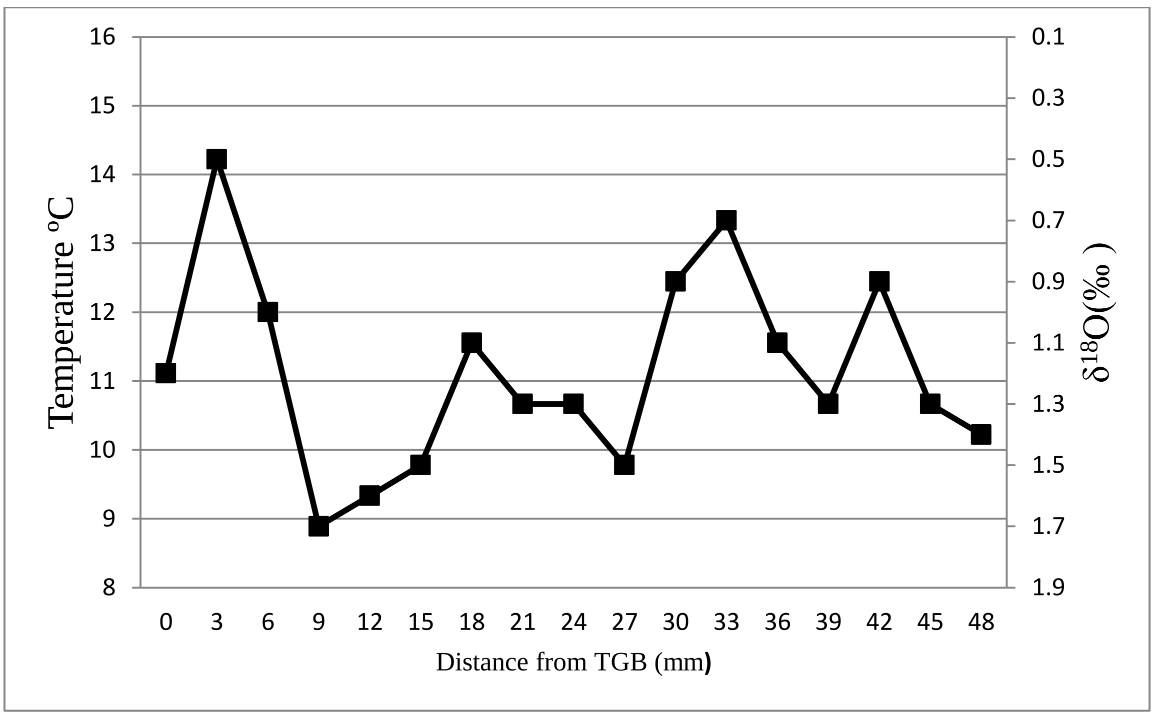

Figure 4.4. Shell profile for Mc21, showing changes in inferred temperatures through 48 mm of growth.

Initially, we assigned a prior season and season of harvest for each shell using the results from the TGB+1 sampling method. We then reassigned seasonality to 20 re-tested shells using the TGB+6 method, with sampling intervals of 3 mm capturing at least 18 mm of growth for each mussel. Comparing the two data sets, we identified where differences lie between the 2 mm vs. 18 mm sampling intervals for larger and smaller mussels. From these comparisons we discuss the efficacy of seasonality determinations for California mussels from CA-SMI-693 using the two methods.

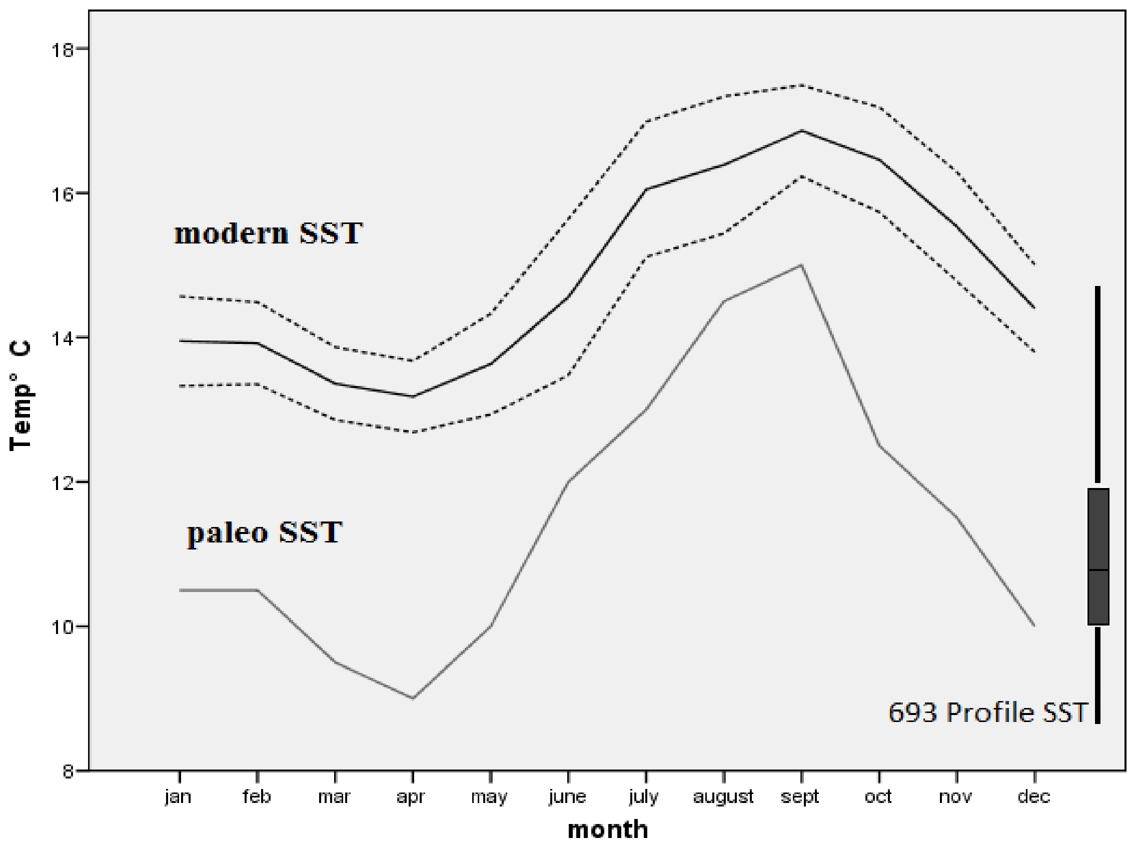

Figure 4.5. Modern estimated seasonal SST variation for San Miguel Island (top, adapted from 10 years of recorded sea surface temperatures including 95 confidence intervals (dashed lines); see Kennett 2005:56) compared to estimated seasonal SST variation for the Point Bennett area ~8800 years ago. (The boxplot, quartiles, and whiskers indicate the range of SST variation for the fully profiled mussel shell (Mc21) demonstrating the overall lower temperature ranges consistent with cooling trends during this period.

Results

The extended isotopic profile for shell Mc21 (77 mm long) includes 48 mm of growth, with temperatures ranging from 9.2°C to 14°C, with an average of ~12°C. The lowest temperature for the profiled shell is ~2 degrees cooler than modern SST, consistent with cooling trends identified for the Early Holocene (see Kennett 2005:66). Figure 4.5 plots the temperature distribution of the profiled shell, which span ~48 mm along the growth axis of the shell, which match up well with a full annual cycle of modern SST variation for San Miguel Island waters (Figure 4.5). For a shell a total of 77 mm long, this suggests that growth rates near Point Bennett ~8800 years ago were somewhat slower than those recorded for the warmer waters of La Jolla in the 1940s (Coe and Fox 1942, 1944).

TGB+1 Sampling

Isotopic determinations from 39 additional California mussel shells (Appendix A) utilized the TGB+1 method, analyzing samples from the terminal growth band and 2 mm for each shell. We then interpreted season of harvest on SST, the direction of change (warming vs. cooling) for each shell, and comparison to our paleo-SST model. The results show a wide range of enriched and depleted $\delta^{18}O$ values. TGB values varied significantly, with an overall range of ~9-16°C and an average of 12.5°C, suggesting that the shells were harvested in a wide range of water temperatures. Our results suggest that

25 of the shells were collected in waters warmer than the 12.5°C average and 15 shells in cooler waters. Comparing the TGB and 2 mm samples, 19 shells show harvesting from warmer to colder periods, 17 from colder to warmer periods, and four from moderate periods of little or no temperature change (Figure 4.6). Compared to our paleo-SST model, these distributions suggested a pattern of multi-seasonal shellfish harvesting and site use at CA-SMI-693, focused on summer (n=22, 55%) and fall (n=13, 32.5%), with only limited harvesting during winter or early spring (n=5, 12.5%). These percentages could reasonably be interpreted as evidence for a year-round site occupation (see Jones et al. 2008:2292) with reduced collection in the winter - spring and mussel harvesting focused primarily on the warmer and calmer summer and fall months.

Differences between the TGB and 2 mm samples vary from ~0.5°C to 6°C. The higher SST fluctuations represented in only 2 mm of shell growth may result from long periods of slow growth for larger mussels or episodic events dramatically changing SST within a single season for smaller mussels. Similar high variances of SST have also been identified in Middle Holocene assemblages on Santa Cruz (Glassow et al. 1994) and Santa Rosa islands (Rick et al. 2006) and can also occur in modern SST in a single month (see Kennett 2005). For both smaller and larger mussels, temperature changes (and their directionality) between the TGB and 2 mm samples may represent as little as one or two weeks of growth, short periods that may be particularly susceptible to short-term episodic events (e.g. wave activity, wind-driven upwelling, local variation in currents).

The TGB+1 evidence for mussel harvesting at CA-SMI-693 through much of the year seemed to contradict other archaeological evidence that the site occupation was relatively brief, especially given that all the mussels analyzed came from a 1 x 1 m area within a small and discrete shell midden feature. Consequently, we decided to conduct additional analysis to test these initial results. The decision to conduct further testing was also fueled by our suspicion that nearshore oceanic conditions around western San Miguel Island might be particularly complex oceanographically due to unusually strong wind regimes, high wave energy, and the interaction of complex ocean currents.

TGB+6 Sampling

To test the results of our TGB+1 analysis, we designed a second round of $\delta^{18}O$ analysis, based on more extended sampling of 20 of the original 40 shells, including 10 shells 70 mm or longer and 10 shells smaller than 70 mm. For each of these 20 shells, we analyzed six additional sampling intervals at 3, 6, 9, 12, 15, and 18 mm from the TGB. The longer profile for these 20 shells show longer time depth with slightly higher SST variances between growth periods. Overall, however, they are comparable to the general range of water temperatures established earlier for paleo-SSTs off western San Miguel ~8800 years ago. The TGB+6 method provides an extended view of water temperatures before the season of capture (TGB), including multiple periods of growth for each shell. This approach allowed us to identify SST variations across 18 mm of shell growth—

spanning one or more seasons of growth for both smaller and rapidly growing mussels and larger mussels that were likely growing more slowly.

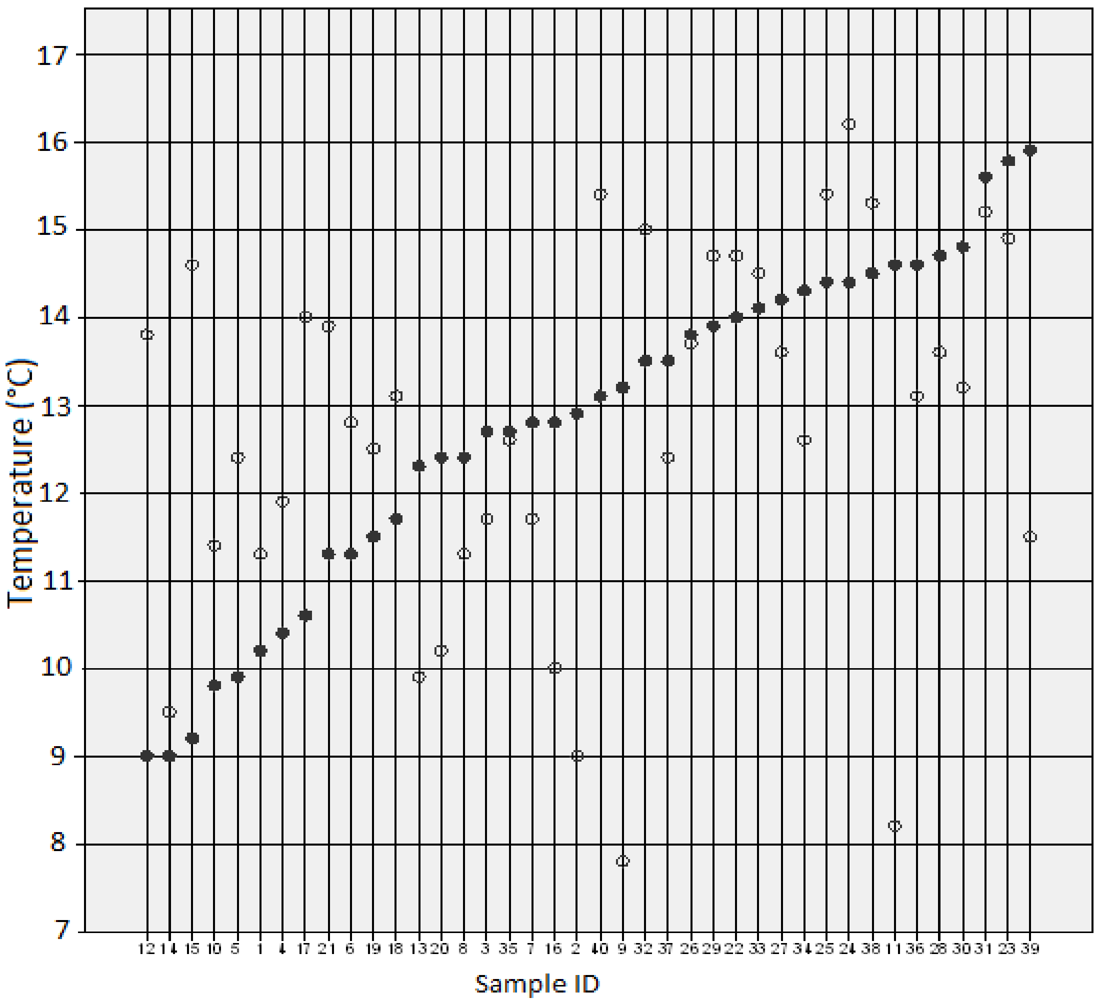

Figure 4.6. Inferred temperature distribution for 40 mussels from CA-SMI-693 analyzed with the TGB+1 sampling method including the terminal growth band (solid circles) and one adjacent band (at 2 mm; open circles); samples are ordered from lowest to highest temperature at the point of harvest. Note that mussels appear to have been harvested in waters ranging from 9-16°C and that shells are almost evenly split between specimens harvested during warming vs. cooling trends.

When comparing TGB values to those from six adjacent 3 mm increments, our estimated seasons of capture for smaller mussels range through summer (n=3), summer-fall or late fall (n=5), and winter (n=2). For the 10 larger mussels, our seasonality estimates all fell during spring-summer or summer periods. The extended isotopic determinations per shell demonstrate that water temperatures over 18 mm of growth fluctuate between ±3-7°C suggesting that seasonal variations off western San Miguel Island were relatively high. In contrast, SST between the terminal edge and 3 mm samples fluctuated a maximum of 5°C and on average ~±2°C. For example, the inferred SST for the last 18 mm of growth for shell Mc5 fluctuated between 9.9 and 14.8°C which suggest warming and cooling waters comparable to those proposed in our paleo-SST model.

Comparison of TGB+1 and TGB+6 Results

Overall 70% of the 20 shells reanalyzed after the initial TGB+1 sampling were assigned different seasonal ranges based on sampling of additional growth bands (Table 4.1.). For the 10 larger shells, more intensive analysis yielded different seasonal ranges for six shells and four were assigned different harvest seasons. All four of the latter changed from fall to summer, further concentrating the seasonality of shellfish harvesting at CA-SMI-693 in the summer months. Among the larger mussels, half also showed rapid changes in SST between the 2 mm and 3 mm samples. Reconstructed SST for the TGB of shell Mc39 (Figure 4.6) is 15.9°C, for example, followed by 11.5°C (2 mm), 15.9°C (3 mm), and 15.0°C (6 mm). The extended isotopic profile for this shell suggests a gradual warming—interrupted by a single relatively rapid cooling episode—over 18 mm of growth (from 10.5°C to 15.9°C) which indicates a summer collection when waters were warmer. The high variance between closely-spaced growth bands 2 and 3 mm from the TGB in this and other shells (Figure 4.6) probably represents short-term and episodic SST fluctuations off western San Miguel Island in the Early Holocene. If such dramatic changes in SST represented a full season of growth, ~1 mm of growth would have to represent at least 4 months, contradicting what is known of mussel ecology and growth rates even in the poorest conditions (see Coe and Fox 1942). In many such cases, without a more extended profiling of the shells, season-of-harvest estimations would be misinterpreted.

Table 4.1. Estimated season of harvest (in bold) for California mussels from CA-SMI-693, including 20 samples reanalyzed with extended-measurements.

Shell ID#	**Length (mm)**	**TGB+1 (0-2 mm)**	**TGB+6 (0-18 mm)**
1	73	fall-**fall**	–
6	71	summer-**fall**	–
8	49	spring-**summer**	–
9	60	spring-**summer**	–
11	55	spring-**summer**	–
13	62	spring-**summer**	–
15	102	fall-**early winter**	–
18	71	summer-**fall**	–
19	58	summer-**fall**	–
20	72	spring-**summer**	–
23	60	summer-**summer**	–
24	72	summer-**fall**	–

Table 4.1. (continued)

Shell ID#	Length (mm)	TGB+1 (0-2 mm)	TGB+6 (0-18 mm)
25	55	summer-fall	–
26	60	summer-summer	–
27	62	summer-summer	–
33	70	summer-summer	–
36	54	summer-summer	–
37	60	spring-summer	–
38	92	summer-summer	–
21	77	summer-fall	–
22	74	summer-fall	spring*-summer*
28	88	summer-summer	spring*-summer
29	87	summer-fall	spring*-summer*
30	80	summer-summer	summer-summer
31	71	summer-summer	spring*-summer
32	85	summer-fall	spring*-summer*
34	77	spring-summer	spring-summer
35	86	summer-summer	summer-summer
39	76	spring-summer	summer*-summer
40	100	summer-fall	spring*-summer*
2	62	spring-summer	summer*-summer
3	50	spring-summer	summer*-summer
4	63	summer-fall	summer-fall
5	45	fall-winter	fall-late fall*
7	65	spring-summer	summer*-summer
10	65	winter-early spring	fall*-late fall*
12	62	fall-early winter	fall-early winter
14	61	winter-winter	fall*-winter
16	66	spring-summer	summer*-fall*
17	67	summer-fall	summer-fall

Note: asterisks indicate where sampling methods led to different seasonality conclusions.

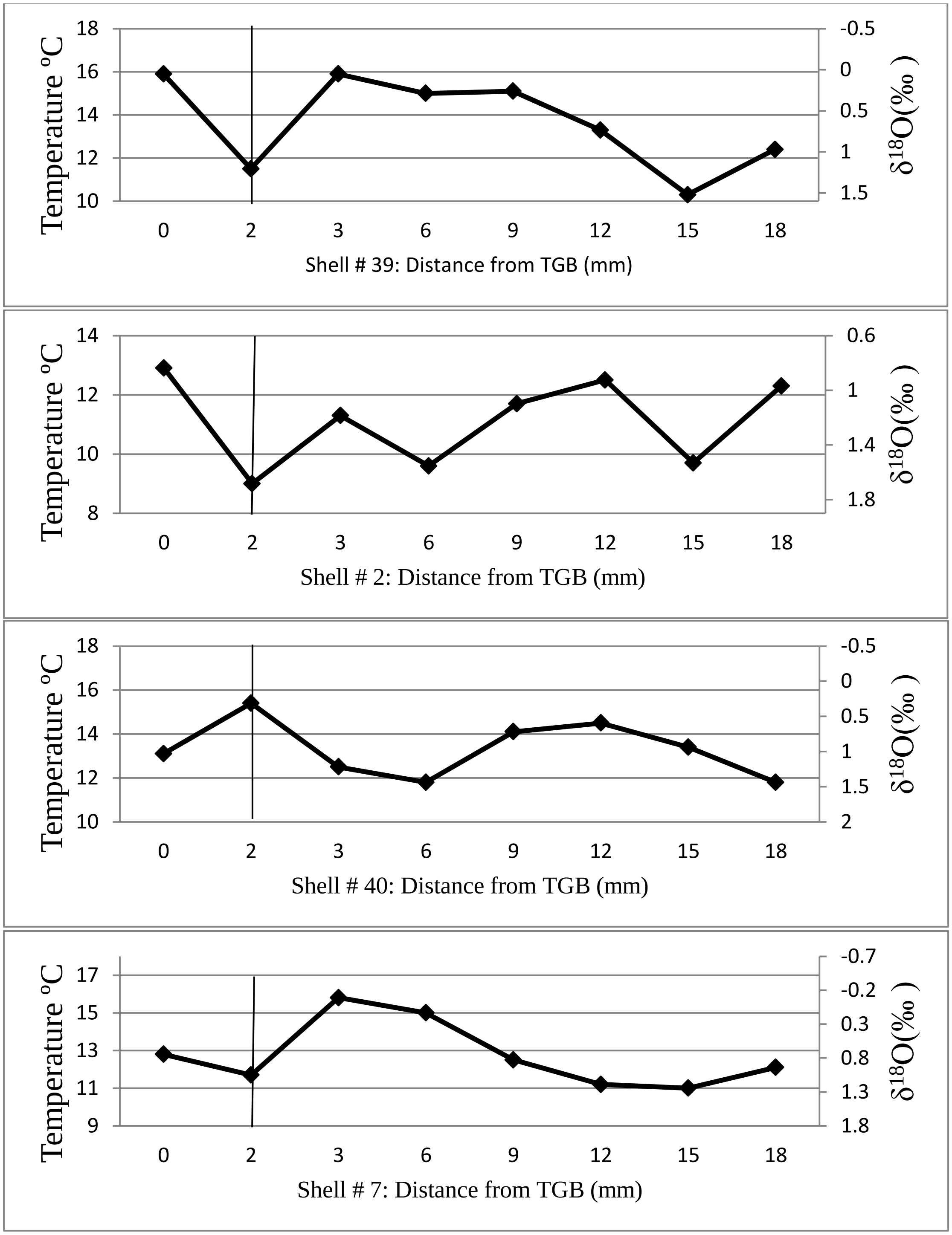

Figure 4.7. Profiled temperature estimates from shells tested using both sampling strategies, illustrating some inconsistencies and seasonal discontinuities. The 2 mm value is represented in each graph by a vertical line through the x-axis. All four shells were harvested in summer based on TGB+6 values.

Discussion

For the 20 California mussel shells from CA-SMI-693 analyzed with both the TGB+1 and TGB+6 methods, our results were substantially different—with the more intensive method changing the estimated season of harvest for 35% of the shells, 40% of those >70 mm long, and 30% of those < 70 long. Assuming that the 18 mm method (TGB+6) is a more accurate measure of the seasons represented at and before harvest, the TGB+1 method appears to be significantly less reliable than our TGB+6 method—at least for western San Miguel Island about 8800 years ago.

The results also significantly narrow the seasonal harvest signature for those 20 shells, with 90% falling within the summer (n=13) or fall (n=5), and just two shells attributed to a winter harvest. In contrast, with the TGB+1 sampling method, just 80% of the shells were identified as being harvested in summer (n=10) or fall (n =6) and 20% were identified as either winter (n=3) or spring (n=1). Applying a 35% error rate to the full sample of 40 shells (Figure 4.8) significantly changes the reconstructed seasonal patterns of mussel harvesting and the inferred season(s) of site occupation. With just 10% of the analyzed shells falling outside of a summer/fall harvest, moreover, it is considerably easier to explain the outliers as resulting from another ecological problem rarely discussed in seasonality analyses for California mussels. This has to do with the typical aggregation of California mussels, human mussel harvesting techniques, and year-round predation on mussels by seastars (*Pisaster ochraeous*) and other non-human predators. If people harvested clusters of intertwined mussels from rocky intertidal areas (see Jones and Richman 1995), occasional shells of dead mussels may have been brought back to the site along with live ones.

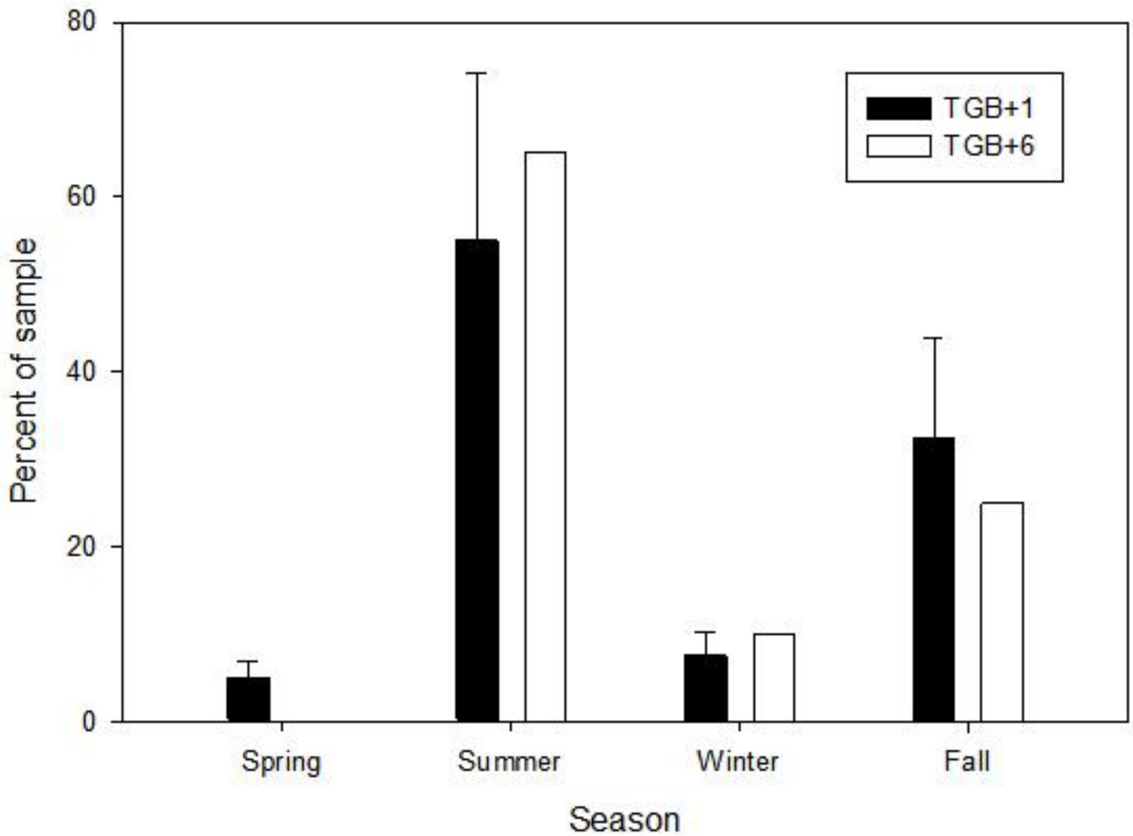

Figure 4.8. Seasonality reconstructions including error bars (whiskers) for 40 analyzed shells, based on an extrapolation from reassignments between the TGB+1 and TGB+6 samples (a 35% error rate for TGB+1 samples was applied to the larger sample).

From a methodological standpoint, if shell growth is ~15-18 mm per season for smaller mussels and ~9-12 mm for larger mussels, then the variation between 0-2 mm of growth represents short-term (intra-seasonal) SST fluctuations rather than broader seasonal signatures prior to harvest. This suggests that for California mussels and other rapidly growing molluscs, archaeologists should carefully consider growth rates—which vary significantly through the life history of many species—in devising $\delta^{18}O$ sampling strategies for isotope analyses. Based on our study, it seems clear that sampling strategies should vary depending on the age and size of the shell being analyzed.

Conclusions

Archaeologists have identified scores of Terminal Pleistocene and Early Holocene sites on California's NCI, but there is still little known about the nature of Paleocoastal settlement in general of the seasonality of specific site occupations. In this paper, we reported the first detailed evidence for the seasonality of a Paleocoastal site based on $\delta^{18}O$ analysis of marine shells. The structure and contents of this 8800 year old shell midden on western San Miguel Island strongly suggested that site occupation was relatively brief, seasonal in nature, and focused on the harvesting of California mussels and other rocky shore shellfish. When initial $\delta^{18}O$ results for 40 California mussel shells seemed at odds with this archaeological evidence, we conducted more intensive isotope sampling for 20 of the same shells. For 35% of the shells, the results were significantly different and produced seasonality data more consistent with a summer-fall occupation of the site. The revised results, when combined with other archaeological evidence, lead us to conclude that CA-SMI-693 was a seasonal camp occupied during the summer and to a lesser extent the fall—possibly a satellite for a larger residential base located elsewhere on San Miguel or Santa Rosa islands. This hypothesis is supported by the isotopic signatures and inferred SST values, the high frequency of California mussels at the site, and near absence of artifacts and vertebrate faunal remains.

More extended profiles for mussel shells from CA-SMI-693 also provided SST estimates that identified several short-term temperature fluctuations suggestive of episodic events potentially related to storm activity, wind-driven upwelling events, or the complexity of ocean currents and microhabitats in the ancient Point Bennett area. Whatever the cause, these short-term fluctuations in SST revised several of the seasonality determinations obtained with the TGB+1 sampling method after more intensive sampling was done. Given the rapid growth of California mussels, particularly in their first year or two of life, we recommend more extensive sampling of shells to obtain higher resolution data on paleo-SSTs, seasonality, site function, and human subsistence and settlement strategies. Ideally, we recommend that more than one whole shell should be fully profiled per assemblage—the more the better—in intervals ranging from 1 to 3 mm along the growth axis to provide a range of SST throughout an annual cycle. The resulting data can be compared to modern water temperatures and seasonal variances to create paleo-SST models that facilitate seasonality studies.

Our study also suggests that growth rates of shellfish should be carefully considered before selecting samples for isotopic analysis (see also Andrus 2011). Rather than a single ‘one size fits all’ methodological approach, sampling strategies should be tailored to the nature of the assemblage being studied, including the primary size range of mussels available for analysis. Since growth rates for many shellfish taxa vary dramatically through their life cycle, the size of each shell analyzed should be reported so other researchers can more effectively estimate the period of growth represented in the sampling of each shell. Finally, although whole shells are not necessarily required (see Schweikhardt et al. 2011), fragments large enough to preserve a terminal growth band and a full season of growth (~15-20 mm in length) prior to harvest are recommended for reliably determining seasonality. Reconstructing the full range of annual variation in paleo-SSTs may require an even longer sequence to insure sampling of one full year of growth.

Stable isotope analysis continues to be a powerful tool in determining paleo-SSTs, the seasonality of shellfish harvest, site occupation, and settlement patterns in many coastal and island settings (Andrus 2011). As numerous studies have shown, however, the ecology and life history of individual taxa should be carefully considered in designing effective sampling strategies. In areas such as Point Bennett, where complex currents and variable oceanic conditions are known to occur, detailed analysis of modern shells and local water temperatures may also help interpret isotopic signatures in ancient shells.

Bridge

Chapter IV discussed fundamental issues concerning sampling strategies, ecology, and growth rates of California mussels for stable oxygen isotope analysis while providing a model for reconstructing PSST at a seasonal campsite (CA-SMI-693) occupied during the Early Holocene. Chapter V, co-authored by Jon Erlandson, Torben Rick, and Leslie Reeder-Myers, builds on those results by exploring paleo-sea surface temperatures, the seasonality of mussel harvest, and human sedentism at CA-SRI-666, a large and complex 8200 year old shell midden located on eastern Santa Rosa Island. This chapter was submitted in March 2013 to *Archaeological and Anthropological Science* for peer review and publication.

In Chapter V, I adapted the template presented in the previous chapter to further explore issues related to effective sampling of mussel shells for $\delta^{18}O$ analysis. The results showed similar error rates for the minimalist sampling method used by most California archaeologists, which often does not adequately control for short-term SST fluctuations recorded in rapidly growing mussels. My results, which suggest that mussels were harvested at CA-SRI-666 during four distinct seasons of the year, were also consistent with other archaeological evidence that the site served as a residential base for relatively sedentary Paleocoastal peoples ~8200 years ago. These results extended the evidence for human sedentism on the NCI by about 700 to 800 years while further supporting the new sampling methods proposed in the previous chapter.

CHAPTER V

$\delta^{18}O$ ANALYSIS OF CALIFORNIA MUSSEL SHELLS: SEASONALITY, SEA SURFACE TEMPERATURE, AND HUMAN SEDENTISM ON EARLY HOLOCENE SANTA ROSA ISLAND

Authors: Jew, Nicholas P.; Jon Erlandson, Torben C. Rick, and Leslie Reeder-Myers, submitted for review in March **2013** to *Anthropological and Archaeological Science*.

Introduction

California's Northern Channel Islands (NCI), first colonized by humans at least 13,000 calendar years ago, contain one of the earliest records of maritime hunter-gatherers in the Americas (see Erlandson et al. 2011, Rick et al. 2005a). The permanence of human occupation during the Paleocoastal period (~13,000-8000 cal BP) has been debated, however, with questions about whether people from the adjacent mainland occupied the islands as part of a seasonal round or other more transitory settlement system (Balter 2011; Erlandson et al. 2008a; Fitzhugh and Kennett 2010; Rick et al. 2005a; Yesner et al. 2004). In the last 20 years, more than 70 Terminal Pleistocene and Early Holocene sites have been identified on the NCI, including a few large middens that contain a diverse array of faunal remains and artifact types (Erlandson et al. 2008a, 2011;

Rick et al. 2005a, 2013). Nonetheless, the ephemeral nature of many early NCI shell middens, the absence of structural features, and the dearth of technology at many sites has led most archaeologists to assume that the islands were seasonally occupied during the Terminal Pleistocene and Early Holocene, with permanent settlements appearing after ~7500 cal BP or later (see Fitzhugh and Kennett 2010:74; Kennett 2005:112-113; Rick et al. 2005a:181; Winterhalder et al. 2010). Complicating our understanding of Paleocoastal settlement patterns is post-glacial sea level rise which has inundated as much as 75% of the NCI land area since the Last Glacial Maximum, including the areas along ancient coastlines that would be the most likely spots to contain early archaeological sites (Erlandson et al. 2011; Kennett et al. 2007; Kinlan et al. 2005).

In this paper, we investigate the seasonality of Paleocoastal occupations on the NCI by analyzing stable oxygen isotope ($\delta^{18}O$) data from a large Early Holocene shell midden (CA-SRI-666) on Santa Rosa Island (Figure 5.1). $\delta^{18}O$ analysis is a well-established method used to address issues related to water temperature, seasonality of shellfish harvest, nearshore ecology, human mobility, and sedentism (see Andrus 2011, 2012; Bailey et al. 1983, 2008; Culleton et al. 2009; Eerkens et al. 2010; Kennett and Voorhies 1994; Killingley 1981; Shackleton 1973). As marine mollusks grow, they precipitate calcium carbonate ($CaCO_3$) in discrete growth bands within their shells that provide a proxy record of fluctuations in sea surface temperature (SST) within their environments (Epstein et al. 1951, 1953; Ford et al. 2010; Glassow et al. 2012; Jones et al. 2008; Kennett and Voorhies 1994; Killingley and Berger 1979; Wanamaker et al.

2007, 2008). Sampling the exterior layers, a shell's growth axis provides a sequential record of temperature changes through a mollusk's lifespan, with the terminal growth band (TGB) providing a proxy record of water temperature at the time of death (Killingley 1981). Comparison of these $\delta^{18}O$ values along a shell's growth axis can be used to identify an approximate season of collection (Andrus 2012; Culleton et al. 2009; Shackleton 1973).

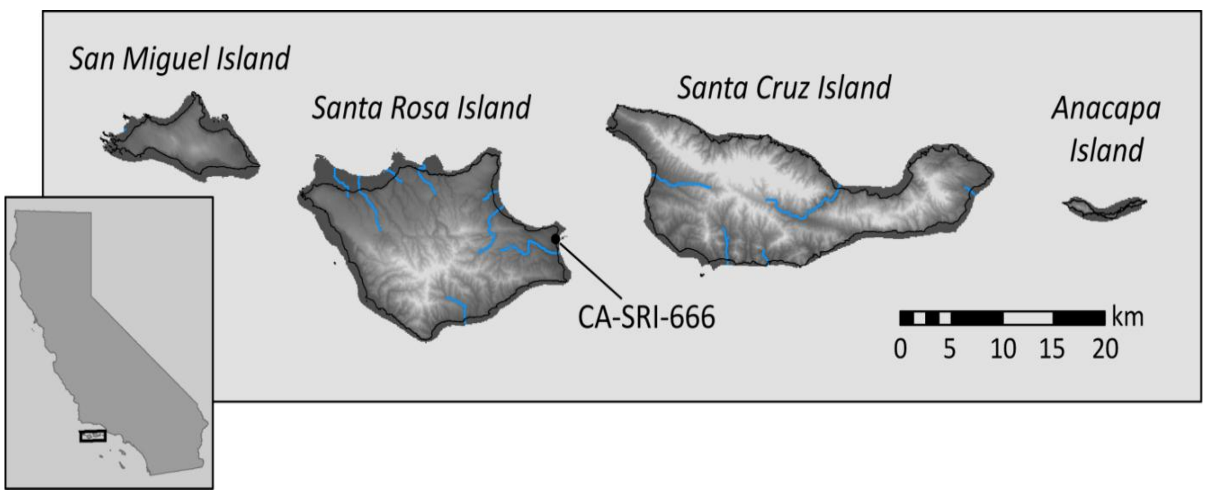

Figure 5.1. Map showing California's Northern Channel Islands and CA-SRI-666. Estimated shoreline location at ~8200 cal BP based on the sea level curve by Muhs et al. (2012) and take into account the impact of uplift on the Northern Channel Islands.

On the NCI, $\delta^{18}O$ analysis has been an important tool for reconstructing SST, paleoecology, and the season of harvest for a variety of mollusks (e.g. Glassow et al. 1994, 2012; Gusick 2012; Jew et al. 2013; Kennett 2005; Kennett and Kennett 2000;

Rick et al. 2006; Robbins 2011; Robbins and Rick 2007). Drilling strategies for California mussels typically include sampling shell calcite in 1 or 2 mm intervals starting with the TGB (Glassow et al. 1994; Robbins and Rick 2007). The total number of calcite samples per shell varies from 2 (including the TGB) to over 15, the latter constituting a shell profile (Killingley 1981; Jones et al. 2008). Jew et al. (2013) examined various calcite sampling strategies and the reliability of assessing seasonality by comparing a shell's TGB to various growth intervals. Although age, water temperature, salinity, available nutrients, and surface exposure will affect the rate of growth, California mussels at the end of their first year of growth (~50-80 mm in length) usually grow 1-5 mm per month in southern California waters (Phillips 2005; see Coe and Fox 1942; 1944; Fox and Coe 1943; Schmidt 1999) equaling an estimated 9 mm per season in intertidal waters between 15 to 19°C (Seed 1976; Seed and Suchanek 1992). Based on these reported growth rates, to adequately capture changes in δ^{18}O beyond a single season requires seven samples at 2 mm intervals or five samples at 3 mm intervals (including the TGB).

Here we evaluate sampling methods for δ^{18}O analysis of California mussel shells where seasonality is assigned based on two approaches (see Jew et al. 2013)—one that compares temperature estimates of the terminal edge with 2 mm of growth (TGB+1) and another that compares the terminal edge with ~15 mm of growth (TGB+5). We also compare SST estimates from a profiled shell from CA-SRI-666 with modern water temperatures near Santa Rosa Island to construct a seasonal paleo-sea surface temperature (PSST) model. This model is used to infer seasonality of mussel shell harvest and evaluate hypotheses proposed for the antiquity of seasonal versus year-round human occupation of Santa Rosa Island.

Background

Santa Rosa Island contains several Terminal Pleistocene archaeological sites, including the Arlington Springs site (Orr 1962; Johnson et al. 2002), CA-SRI-512 (Radio Point, Erlandson et al. 2011), and several recently discovered lithic scatters and middens (see Rick et al. 2013). An Early Holocene component at CA-SRI-666 was identified by Erlandson (1994:192-193) in the early 1990s and consists of the remnants of a large (>10,000 m^2) shell midden and lithic scatter located on eastern Santa Rosa Island, between Skunk Point and the Abalone Rocks Estuary (Figure 5.2). The site is located near the edge of a low coastal plain about 45 m from the current shoreline and 5 to 10 m above modern sea level. Recent sand dunes, grasses, and low-lying vegetation cover the northern part of the site, but other areas have been heavily eroded, deflated by wind action, and trampled by introduced livestock. Today, the site covers an area more than 200 m long and 50 m wide, with patchy and semi-cemented shell midden deposits found in several distinct loci separated by thick vegetation or eroded areas littered with deflated shells and a diverse array of chipped stone tools and tool-making debris.


Figure 5.2. Overview of CA-SRI-666 looking southeast across the site. The lower surface to the right is erosional and littered with deflated artifacts, with a dune ridge at left covering the northern site area (photo by L. Reeder-Myers).

In the late 1990s, D. Kennett obtained a small (5 liter) bulk sample from the southwest site area near deposits radiocarbon (^{14}C) dated by Erlandson. Despite the presence of a variety of rocky intertidal and estuarine shellfish on the site surface, this bulk sample was dominated by California mussel shells which comprised 99% of the assemblage by weight (Kennett 2005; Rick et al. 2005b). In 2010, we returned to CA-SRI-666 to perform additional research and gain a better understanding of its age and function. We excavated samples from three shell midden loci situated ~40 to 50 m apart, aligned along the southern margin of an ancient dune ridge. Each midden locus was between 2 and 5 m across, with dense concentrations of shell and other cultural constituents encased in the remnants of an indurated paleosol 10-20 cm thick. Unit 1 was excavated in the southeast locus, Unit 2 in the central locus, and Unit 3 to the southwest locus. There were dense concentrations of lithic debitage and tools on the site surface, particularly along the heavily eroded southern margin of the site. Faunal remains dominated by relatively large California mussel shells indicate that the site occupants relied heavily on rocky intertidal habitats, but significant amounts of Washington clam (*Saxidomus nuttalli*) and red abalone (*Haliotis rufescens*) shell suggest that estuarine and kelp forest habitats were also important. Chipped stone artifacts were common, consisting of cores, expedient flake tools, and debitage made from materials locally available on the NCI, including Wima and Tuqan Monterey cherts (Erlandson et al. 2008b, 2012). Earlier surveys, conducted when surface visibility was much greater, identified more than a dozen undiagnostic biface fragments on the surface. The size of the site, the density of shell midden exposures, and the number and diversity of stone artifacts observed on the site surface, all suggest the possibility that CA-SRI-666 served as a residential base occupied through a significant portion of the seasonal round.

In 1991, Erlandson (1994) submitted a well-preserved fragment of Washington clam shell from intact midden located in the southeastern site area for conventional ^{14}C dating. The results (Beta-47626) suggested that the site was occupied during the Early Holocene, between ~8170 and 7860 cal BP (2σ). Recently, eight additional shell samples from intertidal, subtidal, and estuarine environments were submitted for acceleratory mass spectrometry (AMS) dating. The results (Table 5.1) range from ~8600 and 7800 cal BP averaging ~8200 cal BP. One reported date on a Washington clam from Unit 3 at ~16 cm in depth produced an early date of 8580 – 8380 cal BP which may represent an early occupation or a statistical outlier. Two other samples from similar depths in Unit 3 produced calibrated ^{14}C ages between ~8050 and 7800 cal BP, overlapping with reported calibrated ages for units 1 and 2.

Table 5.1. ^{14}C dates for CA-SRI-666 including lab number, provenience, material, conventional and calibrated ages. A marine reservoir effect of 225 ± 25 ΔR (see Stuiver and Reimer 1993) was applied for calibrated ages.

Lab #	**Unit #: depth**	**Dated material***	**Measured age**	**Calibrated age range (1-sigma)**	**(2-sigma)**
Beta-47626	SW area 0-20 cm	*S.n*	7780 ± 70	8100-7940	8170-7860
OS-83730	1:15-16 cm	*M.c*	7630 ± 35	7920-7830	7960-7770
OS-96943	1:(base)	*M.c*	7840 ± 35	8130-8020	8170-7970
OS-83732	2:12 cm	*S.n*	7540 ± 35	7720-7830	7890-7670
OS-83731	2:15 cm	*S.n*	7630 ± 30	7920-7830	7950-7780
OS-96944	2:15cm	*M.c*	7980 ± 55	8300-8170	8356-8080
OS-83733	3:15-20 cm	*H.r*	7650 ± 30	7930-7850	7970-7800
OS-96945	3:16 cm	*M.c*	7720 ± 35	8000-7920	8060-7850
OS-83734	3:16 cm	*S.n*	8250 ± 35	8530-8420	8580-8390

***Material abbreviations:** *Saxidomus nuttalli = S.n, Mytilus californianus = M.c, Haliotis rufescens = H.r*

The large size of the site, overlapping radiocarbon dates between loci and large sample pool of California mussels make CA-SRI-666 an excellent candidate for δ^{18}O analysis to determine seasonal patterns of shellfish harvest and investigate early human settlement and mobility on Santa Rosa Island. If the site was occupied seasonally, isotopic values and estimated SST should reflect limited seasonal harvesting. If the site was occupied year-round, shellfish should have been harvested from a range of water temperatures representing multiple seasons.

Methods

For oxygen isotope analysis, California mussels (n=21) were selected from intact midden deposits from Unit 1 (n=11) and Unit 3 (n=10). Mussel shells between 45-76 mm long were selected for analysis because larger mussels slow their growth rate as part of senescence and small mussels prior to sexual maturity grow rapidly over short periods of time (Shaw et al. 1988). Each shell was initially washed in deionized water and inspected under a low powered microscope for an intact TGB and allowed to dry overnight at room temperature. The surface of each shell was etched using hydrochloric acid (0.5 M) to remove foreign substances and diagenetically altered carbonate (see Bailey et al. 1983; Culleton et al. 2006; McCrea 1950; Robbins and Rick 2007), microscopically inspected, and if necessary, re-etched. Calcite samples were removed from shells using a Sherline 5410 Micromill with a carbide (.05 mm) drill bit at low speeds (see Robbins and Rick 2007:29). To avoid cross contamination, carbide drill bits were sonicated in an ethanol bath and allowed to dry between drilling sessions and shells were cleaned with compressed air.

As a baseline, 11 calcite samples were taken at 3 mm intervals from one ~70 cm long mussel shell (666-U1-20), encompassing ~30 mm of growth and providing an extended profile of PSST change spanning roughly 10 months (using 3 mm per month average) of growth for mussels growing off the California coast (see Coe and Fox 1942, 1944; Phillips 2005, Schmidt 1999). Each of the remaining 20 shells was sampled using two methods. For the first sampling method (TGB+1), shells were drilled along the TGB plus one additional sample 2 mm from the terminal edge. In the second sampling method (TGB+5) we added another four samples taken at 3 mm intervals between 6 and 15 mm of shell growth totaling six isotopic measurements for each mussel.

All calcite powder samples were weighed and analyzed in the Department of Geological Sciences Stable Isotope Laboratory at the University of Oregon. Powdered samples were loaded into exetainers which were placed in an autosampler and flushed with helium. Samples were then reacted with several drops of 100% orthophosphoric acid to produce carbon dioxide. $\delta^{18}O$ and $\delta^{13}C$ were measured using a Finnigan MAT253 isotope ratio mass spectrometer with continuous helium flow. Precision of oxygen and carbon isotopic ratios was ±0.1‰ (1σ), calibrated repeatedly against international standard NBS-19. All values are reported in δ-notation in per mil (‰) units relative to the Vienna PeeDee Belemnite (VPDB) standard.

Recent studies have examined sampling, geochemistry, and seasonality of a wide range of shellfish in various environments (see Andrus 2012; Ford et al. 2010; Toro et al. 2004; Wanamaker et al. 2007, 2008). To remain consistent with previous studies in the region (e.g. Glassow et al. 1994; Jones et al. 2008; Kennett 2005; Rick et al. 2006; Robbins and Rick 2007; Robbins 2011) we use the Epstein et al. (1951) formula for converting $\delta^{18}O$ values to temperature estimates as applied to California mussels by Killingley (1981; Killingley and Berger 1979) where:

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

At 8200 cal BP change in reported mean ocean water temperature ($\Delta_{0m}\,\delta^{18}O_{sw}$) in the Pacific is ~0.36‰ (see LaGrande and Schmidt 2009; Martinson et al. 1987:20). Additional adjustments to the ice volume correction ($\delta^{18}O_{water\ (smow)}$) are based on an ocean water sample ($\delta^{18}O$= -0.32‰) collected from the eastern end of Santa Rosa Island, providing a correction of 0.04‰ (Robbins and Rick 2007).

Modeling Paleo-SST and Seasonality

To create PSST estimates at 8200 cal BP for waters in the vicinity of eastern Santa Rosa Island, we compared the isotope profile from shell 666-U1-20 to 10 years of recorded modern SST collected by Engle for Santa Rosa Island (see Kennett 2005:56). Modern SST averages for Santa Rosa Island (Figure 5.3) place the coldest water temperatures around 13.5°C from March to May, increasing from June to September

(~14.5–17.5°C), and returning to cooler temperatures in early October to the end of February. Sea surface temperature reconstructions for CA-SRI-666 shell profile range from 12.6 to 16.8°C averaging 14.9°C.

Modern SST and paleo estimates (Figure 5.4) were compared using Pearson's correlation coefficient and were found to be statistically significant (r = .742, α.05) with a positive correlation. PSST estimates for waters near eastern Santa Rosa Island are statistically similar to the modern SST values using Epstein's (1951, 1953) temperature conversion formula; therefore, estimated seasonal changes are also modeled after modern distributions. Modern $\delta^{18}O$ values reported for California mussels from the Santa Barbara Channel region typically range on average between ~0.8 to -0.6 (VPDB, see Kennett 1998:451-453, 2005:66; Kennett and Kennett 2000:384) where Early Holocene $\delta^{18}O$ values for ~8800 cal BP on eastern Santa Rosa Island fall between ~0.4 and -0.5 (VPDB).

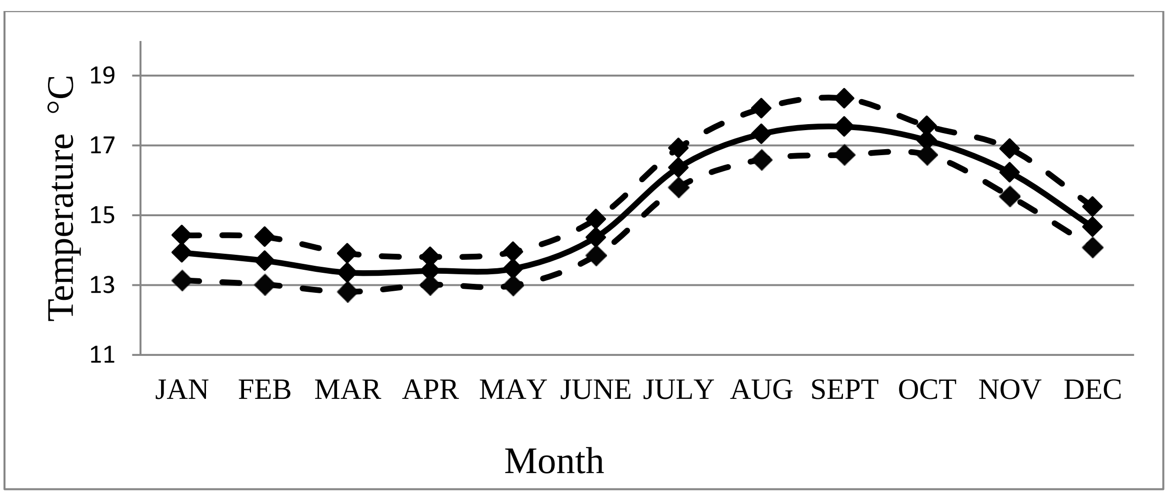

Figure 5.3. Modern SST averages for ten years in the vicinity of Santa Rosa Island (after Kennett, 2005:56) including 95% confidence intervals for one annual cycle.

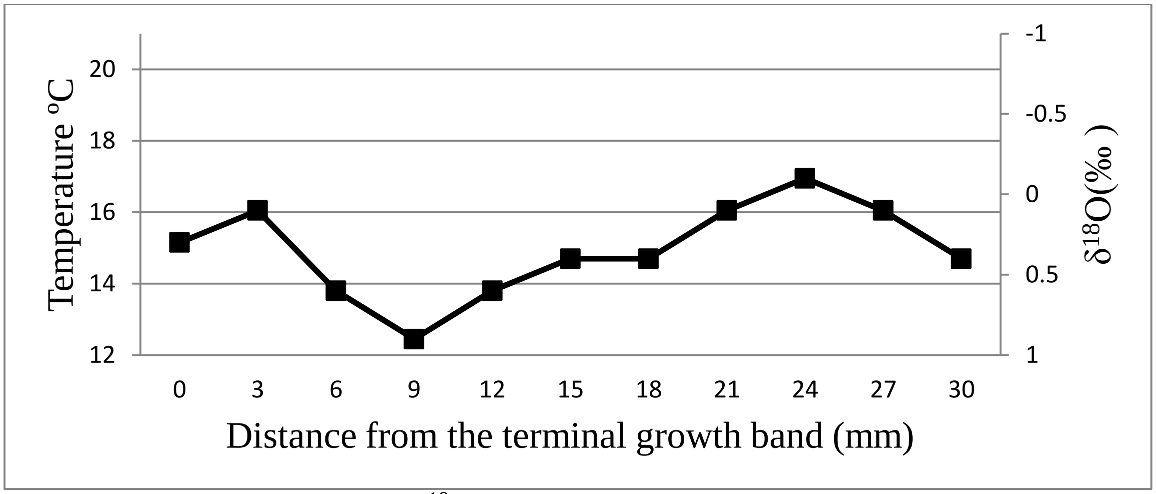

Figure 5.4. Reported PSST and $\delta^{18}O$ for 30 mm of growth from the profiled mussel shell 666-U1-20a-k from Unit 1 CA-SRI-666.

California mussel shells from CA-SRI-666 were assigned to a particular season using the TGB+1 and TGB+5 methods based on the following criteria: *x* equals SST estimated for the TGB (i.e. the season of harvest for each shell) and *y* represents the comparative growth increment(s) (at either 2 mm or for multiple samples from the last 15 mm of growth). Assigned seasonality is determined by the relationship between these values where:

- Fall (*late September to early December*) $x \geq 15$°C and $y > x$ (warmer temperatures for the season prior to harvest)

-Winter (*late December to early March*) $x \leq 15$°C and $y > x$ (warmer temperatures for the season prior to harvest)

-Spring (*late March to early June*) $x \leq 15$°C and $y < x$ (colder temperatures for the season prior to harvest)

-Summer (*late June to early September*) $x \geq 15°C$ and $y < x$ (colder temperatures for the season prior to harvest)

The 15°C seasonal marker has an approximate $\delta^{18}O$ of 0.3‰ (reported in VPBD).When TGB and comparative SST estimates fall within ±0.5°C, they are assigned to a single season. For example, a TGB value of 13°C and a comparative value of 13.5°C was assigned a winter – winter harvest. Seasonal determinations using the TGB+1 method consider temperature values for the terminal edge and 2 mm of growth, which represents temperature change on a shorter time scale (i.e. weekly or monthly). The assigned seasonal signatures for the TGB+5 method include SST changes spanning 15 mm of growth per shell, which increases the probability of identifying PSST changes for at least one full season. Shells that changed their seasonal signatures between methods were identified to compare the effectiveness of the two methods (Table 5.2).

To reconstruct PSST for intertidal zones around eastern Santa Rosa Island ~8200 years ago, the $\delta^{18}O$ data were analyzed using descriptive statistics including the ranges and means for all shells. We also used an independent samples t test to determine whether there were statistically significant differences between estimated mean PSST for units 1 and 3. To illustrate patterns in the estimated PSST data we plotted the maximum, minimum, and midpoints for each shell.

Table 5.2. Inferred pre-harvest and shellfish harvest for TGB+1 and TGB+5 sampling methods, including approximate lengths of mussel shells from units 1 and 3 at CA-SRI-666.

Shell sample (CA-SRI-#)	**Length (mm)**	**Sampling Method**	
		TGB+1	**TGB+5**
Unit 1			
1	63	spring–summer	summer*–summer
3	70	fall–fall	summer*–fall
6	71	spring–summer	summer*–summer
8	50	fall–winter	winter*–winter
9	45	fall–winter	winter*–winter
10	50	fall–winter	summer*–fall**
11	52	spring–summer	spring–summer
12	52	spring–summer	spring–summer
13	63	summer–fall	spring*–summer**
18	60	summer–fall	spring*–spring**
Unit 3			
21	70	summer–fall	fall*–fall
23	70	fall–winter	spring*–spring**
24	76	fall–winter	spring*–spring**
25	70	fall–winter	winter*–winter
27	76	spring–summer	summer*–summer
29	70	summer – fall	winter*–spring**
30	65	spring–summer	spring–summer
31	71	winter–winter	fall*–winter
36	68	fall–winter	winter*–spring**
39	65	spring–summer	spring–summer

*indicates pre-harvest changes between TGB+1 and TGB+5 method **indicates where season of harvest changes between the TGB+1 and TGB+5 method.

Results

The isotopic values and PSST estimates for CA-SRI-666 (see Appendix B) are distributed broadly through a wide range of water temperatures. The estimated temperature distributions for all 131 isotopic determinations range between 10°C and 18.6°C with a mean of 14.7°C (Figure 5.5). PSST estimates for Unit 1 (southeast locus) range from 11.7°C and 18.6°C with a mean of 15°C. Mussels from Unit 3 (southwest locus) range from 10°C and 17.5°C with a mean of 14.4°C. Shells from Unit 3 were harvested in slightly cooler waters and show greater variation than shells sampled from Unit 1. However, the results from our independent samples t test found no significant differences ($t= 2.026$, $df= 118$, α .05) in mean PSST estimates for units 1 and 3 suggesting that PSST averages recorded in shells from the two units are statistically similar.

Seasonal designations by sampling method and unit are reported for each individual shell (Table 5.2). The maximum variation in PSST between the TGB and 2 mm growth band is 6.5°C (666-U2-30a-b) with a minimum temperature change of 0.5°C (666-U1-3a-b). The inferred season of harvest for California mussels using the TGB+1 method are winter (n=8), summer (n=7), and fall (n=5). Unit 1 is distributed into summer (n=4), fall (n=3), and winter (n=3). Unit 3 contains mussels harvested during winter (n=5), summer (n=3), and fall (n=2). Based on the TGB+1 method and assigned seasonality, mussel harvesting occurred most frequently during winter and summer, less often during the fall, and is not represented in the spring. Nonetheless, the results suggest that CA-SRI-666 was occupied during at least three seasons of an annual cycle.

The difference in PSST between the TGB and 15 mm of growth showed a minimum of 0.1°C (666-U2-27a-f) and a maximum of 4.8°C (666-U2-39a-f). The seasonal distribution of mussels for both units using the TGB+5 method are summer (n=8), spring (n=5), winter (n=4), and fall (n=3). Shellfish harvesting for Unit 1 occurred during summer (n=5), winter (n=2), fall (n=2), and spring (n=1). For Unit 3, mussels were harvested in the spring (n=4), summer (n=3), winter (n=2), and fall (n=1). Seasonal determinations using the TGB+5 method suggest that shellfish harvesting (and site occupation) occurred year-round at CA-SRI-666 and that the site occupants were relatively sedentary. Significantly, 35% (n=7) of the analyzed mussel shells were assigned a different season of capture using the TGB+5 method instead of TGB+1.

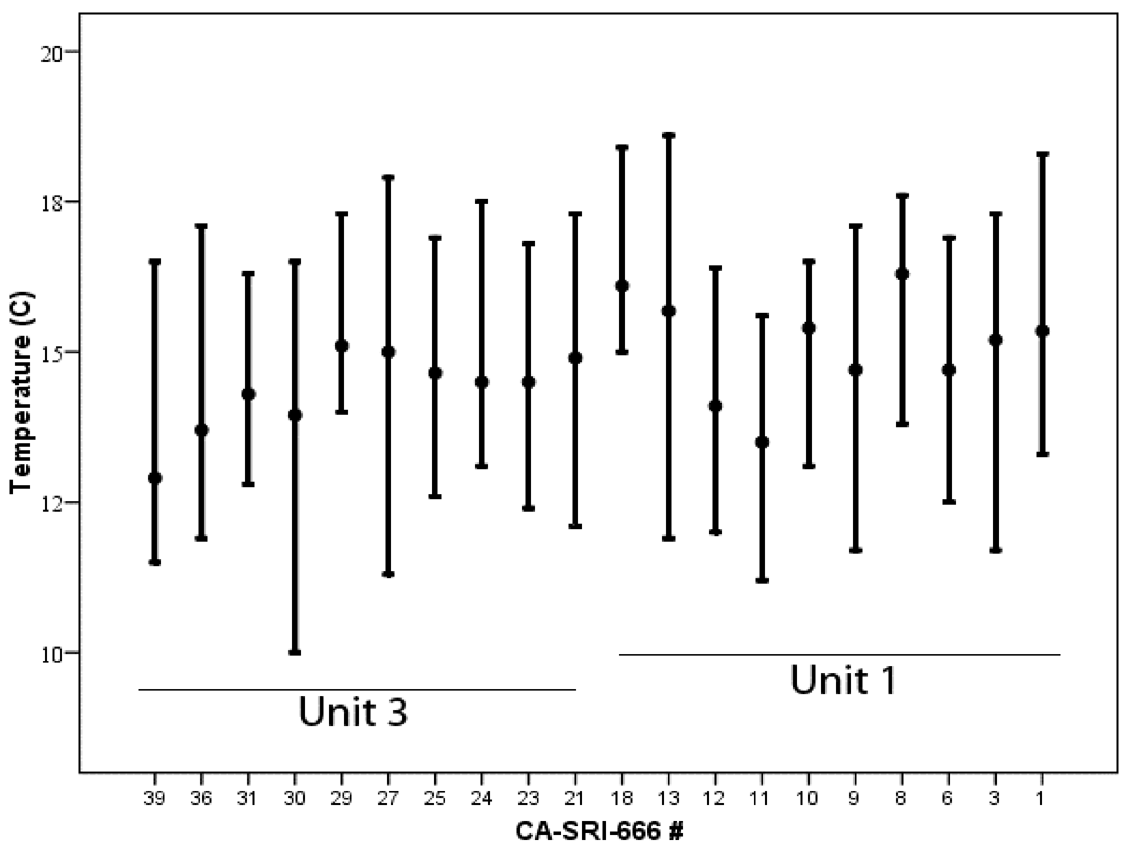

Figure 5.5. Temperature ranges and means for sampled CA-SRI-666 mussel shells.

Discussion and Conclusions

Previous research has suggested a high degree of SST oscillation during the Early Holocene in the Santa Barbara Basin with a shift from cooler to warmer SSTs from 8500 to 7500 cal BP (Kennett 2005; Kennett et al. 2007). Our results indicate that seasonal variation, enriched and depleted $\delta^{18}O$ values, and overall distribution of PSST closely resemble modern water temperatures near Santa Rosa Island, suggesting that nearshore ecology and abundance of California mussels and other rocky intertidal shellfish may have been comparable to modern intertidal water conditions. Our data confirm that CA-SRI-666 was occupied during a time in the Early Holocene (~8200-7800 cal BP) when PSST was in a warming phase. In contrast to CA-SRI-666, where the average inferred temperature from 131 samples was 14.7ºC, average PSST for an 8800 cal BP shell midden (CA-SMI-693) on western San Miguel Island was ~12°C, with most of the shells harvested during warmer summer and fall months. This suggests that the earlier San Miguel Island site was occupied during a period of cooler PSST or was situated in an area with greater upwelling (Jew et al. 2013). Both of these explanations may contribute to the different water temperatures, but the relative estimates for mean PSST values and ranges for both sites are consistent with reported warming and cooling trends reconstructed from foraminifera from varved sediments in the Santa Barbara Basin (Kennett 2005:66). Although there are several temperature conversions for interpreting oxygen isotope data, our current reported estimates of PSST for the Santa Barbara Channel and Santa Rosa Island are consistent with other studies in the region.

Both methods show multi-seasonal shellfish harvesting near eastern Santa Rosa Island (Table 5.3), but there is an absence of a spring harvest from the TGB+1 method while the TGB+5 method shows harvest during all four seasons—including 25 percent of the shells identified as having been harvested in spring. In evaluating our two sampling methods (TGB+1 vs. TGB+5) for reconstructing the seasonality of California mussel harvesting at two separate Early Holocene sites on the NCI, we found that similar percentages (35%) of shells were assigned different season-of-capture values using the more intensive TGB+5 method. This more intensive sampling method, which encompasses a full season of growth and PSST fluctuation, is less likely to be affected by weekly or monthly perturbations in local SST (Jew et al. 2013).

If average growth rates of California mussels in southern California waters are between 1-5 mm per month then observed PSST variability from the TGB and 2 mm of growth in medium size (~45-76 mm) California mussels represents variation on the scale of weeks or days. These variations are much more likely to be the result of episodic events such as tidal or storm cycles, variations in upwelling or surficial currents, or other factors. In contrast, ~15 mm of growth provides an extended sequence of water temperature variability and a more reliable indicator of conditions during the season prior to harvest. Comparative isotopic sampling strategies for San Miguel and Santa Rosa islands illustrate the importance of considering growth rates when designing sampling methods for identifying seasonality of shellfish harvest, especially for mollusks that grow at different rates through their life cycle. Given the variation of mollusk growth by species and geographic area, the incremental sampling strategy and number of carbonate samples from a shell will vary by research questions and the mollusk under study (Andrus 2011). For CA-SRI-666, the evidence of year-round harvesting based on the seasonal signatures from the TGB+5 method suggests that some NCI sites were occupied during all seasons by at least 8200 years ago.

Table 5.3. Summary showing the season of harvest by units and combined totals for the terminal growth band and 2 mm increment (TGB+1) versus the terminal growth band and 15 mm growth band (TGB+5).

	Fall	Winter	Spring	Summer	**Total**
(TGB+5)					
Unit 1	2 (20%)	2 (20%)	1 (10%)	5 (50%)	10 (100%)
Unit 3	1 (10%)	2 (20%)	4 (40%)	3 (30%)	10 (100%)
Combined	3 (15%)	4 (20%)	5 (25%)	8 (40%)	20 (100%)
(TGB+1)					
Unit 1	3 (30%)	3 (30%)	0 (0%)	4 (40%)	10 (100%)
Unit 3	2 (20%)	5 (50%)	0 (0%)	3 (30%)	10 (100%)
Combined	5 (25%)	8 (40%)	0 (0%)	7 (35%)	20 (100%)

Two explanations could account for the seasonal pattern of shellfish harvest on eastern Santa Rosa during the Early Holocene. Current evidence suggests that the three loci at CA-SRI-666 were at one time part of a larger site that has been dissected by erosion. Reconnaissance in the 1990s (see Erlandson 1994), which documented more extensive areas of intact shell midden, supports this hypothesis. In this scenario, these remnant midden loci represent a continuous year-round occupation of Santa Rosa Island by early Channel Island populations, with California mussels being harvested during the summer, spring, winter, and to a lesser extent fall, supplemented by other rocky intertidal, subtidal, and estuarine shellfish.

Alternatively, the remnants of CA-SRI-666 could result from multiple and spatially overlapping site occupations, possibly by mainland peoples utilizing the site during various seasons over a century or more. It seems unlikely that mainlanders would only seasonally visit the islands for shellfish, however, as California mussels and other shellfish species are widely distributed along mainland coast of California (see Bayne 1976; Erlandson 1994; Killingley and Berger 1979) and a wider variety of terrestrial resources were also available on the mainland.

Considering the size, structure, and contents of CA-SRI-666, we argue that the $\delta^{18}O$ data presented here support a more permanent and probably year-round occupation of CA-SRI-666 around 8200 years ago. Similarities in midden density, thickness, and stratigraphy between the three loci deposited in similar soil concretions suggest contemporaneous occupations, supported by the overlapping ranges of eight ^{14}C dates. Finally, the range and mean PSST estimates for units 1 and 3 suggest that humans were harvesting California mussels from similar water temperatures and possibly the same intertidal zones. The interpretation of CA-SRI-666 as a year-round habitation site is supported by work at CA-SRI-3 on northwest Santa Rosa Island, where a large cemetery dated to ~7400 cal BP also suggests a sustained Early Holocene occupation (Erlandson 1994:188-189; Kennett 2005:123; Orr 1962). Recent excavations at CA-SRI-512, an ~11,750 year old site on Santa Rosa Island, also recovered numerous bones of migratory waterfowl that suggest a late fall or winter occupation (Erlandson et al. 2011). When placed in the context of other Terminal Pleistocene and Early Holocene sites, it seems increasingly likely that the NCI were occupied by Paleocoastal people on a relatively permanent basis, a hypothesis that will be tested with additional research.

For identifying seasonality of shellfish harvest or reconstructing past water temperatures for intertidal or subtidal areas around the Channel Islands, a number of studies have shown that a variety of sampling techniques and mollusk species can provide baseline isotopic data for reconstructing PSST (e.g. Glassow et al. 1994; 2012; Gusick 2012; Kennett 2005; Kennett and Kennett 2000; Rick et al. 2006; Robbins and Rick 2007). The research questions, available funds, and species represented in an assemblage are all considerations in designing appropriate sampling strategies, but mollusk growth rates and ecology should also be carefully considered. This is important when addressing issues of shellfish harvest because the rate of growth influences the number of samples required to extend beyond the season of harvest and correctly identify inter-seasonal changes in water temperature. Given the average growth rates of mid-size California mussels (~3 mm per month) in southern California waters, at least 12 mm (approximately four months of growth) should be sampled to increase the likelihood of accurately modeling the season of harvest, particularly in warmer seasons where mussels grow rapidly. Our current isotopic data and seasonality inferences provide evidence for early year-round shellfish harvest on the NCI during a time when some researchers have suggested the islands were only seasonally occupied by mainlanders. Stable oxygen isotope analysis of shellfish from other Paleocoastal sites on the NCI can help further understand seasonal or year-round harvesting of shellfish and contribute greatly to ongoing debate about the antiquity of human commitment to island and maritime lifeways.

Bridge

The previous two chapters focused on stable oxygen isotope analyses from Early Holocene sites on San Miguel and Santa Rosa islands, examining sampling strategies and interpretive issues for $\delta^{18}O$ analysis designed to reconstruct seasonality of shellfish harvest. In these chapters, I evaluated the efficacy of assigning seasonality to shellfish harvest using an extended sampling method and proposed year-round shellfish harvesting and human sedentism ~8200 years ago on Santa Rosa Island.

Chapter VI is a larger isotopic study of marine shells from four Early Holocene assemblages on San Miguel Island dating between ~10,000–8600 cal BP. In this chapter, I use archaeological data from each site including the size, depth, density, and diversity of artifacts and faunal remains to predict whether each site was occupied seasonally or year-round. Stable oxygen isotope data were then rigorously analyzed to test my predictions. The results supported my hypotheses, suggesting that two large and/or dense shell midden sites on western San Miguel were occupied year-round, one about 9000 years ago and the other 10,000 years ago. Two other sites, whose contexts and contents suggest shorter term or less intense occupations, provided shellfish harvest signatures restricted to fewer seasons, suggesting that they served as seasonal camps rather than residential bases. Chapter VI, which has been submitted in April 2013 to the peer-reviewed *Journal of Pacific Archaeology*, was co-authored by Jon Erlandson, Torben Rick, and Jack Watts.

CHAPTER VI

SHELLFISH, SEASONALITY, AND SEDENTISM: $\delta^{18}O$ ANALYSIS OF CALIFORNIA MUSSEL FROM EARLY HOLOCENE SHELL MIDDENS ON SAN MIGUEL ISLAND, CALIFORNIA

Authors: Jew, Nicholas P., Jon M. Erlandson, Torben C. Rick, and Jack Watts, submitted for review in April **2013** to the *Journal of Pacific Archaeology*.

Introduction

Researcher interest is growing 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 and Hunt 1997; O'Connor et al. 2011; Yesner 1980). California's Northern Channel Islands (NCI), colonized by Paleocoastal peoples at least 13,000 calendar years (cal BP) ago, have produced some of the earliest evidence for maritime adaptations and seafaring in the Americas (see Erlandson et al. 2011). 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 has increased global sea levels 100-120 meters on the NCI (Muhs et al. 2012), submerging paleoshorelines and restructuring nearshore ecosystems, with the islands approaching their modern configuration approximately 7500 cal BP (see Glassow et al. 2010; Kennett et al. 2008). Despite landscape changes and loss of ~75% of island mass since the LGM, over 75 Paleocoastal sites (~13,000 to 7800 cal BP) have been identified (Erlandson et al. 2008, 2011; Rick et al. 2005, 2013). The lack of structural features and dearth of tools at many of these early sites led archaeologists to believe that humans only permanently occupied the islands after ~7500 cal BP (see Fitzhugh and 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 cal BP 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-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 and Voorhies 1995; Killingley 1981; Kimball et al. 2009; Rick et al. 2006; Schweikhardt et al. 2011; Shackleton 1973). On the NCI, $\delta^{18}O$ analysis has provided a wealth of information for reconstructing paleo-SST (PSST) and identifying seasonality of shellfish harvest and site occupation (e.g. Glassow et al. 2012, Gusick 2012; Jew et al. 2013a, b; Kennett 2005, Rick et al. 2006, Robbins and 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. Jew et al. (2013a, b) examined seasonality of mussel harvest 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 (see Jew et al. 2013a). In contrast, analysis of mussel shells from a large and dense 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.

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 cal BP. Our results build on earlier work at CA-SRI-666 by providing evidence for year-round shellfish harvest and early human sedentism on San Miguel Island. First, we describe the sites investigated and establish baseline predictions about the seasonal versus year-round occupation of each site. Second, we 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. Analyzing 449 calcite samples from 84 California mussels from four Early Holocene components, we assign seasonality for each shell using PSST models and calculate seasonal harvest percentages for each component. From these data, we identify shellfish harvest patterns, and discuss human mobility and sedentism on San Miguel Island during the Early Holocene.

<u>Paleocoastal Sites on San Miguel Island</u>

From east to west, the NCI include Anacapa, Santa Cruz, Santa Rosa, and San Miguel (Figure 6.1). Today, the islands lie ~20 to 42 kilometers off the California Coast and range in size from the smallest (Anacapa) at ~2.6 km^2 to the largest (Santa Cruz) at ~249 km^2. 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 colonized by humans on a permanent or year-round basis.

For this study, we selected four Early Holocene shell middens on San Miguel Island (Figure 6.1) for detailed $\delta^{18}O$ analysis: CA-SMI-261, CA-SMI-507, CA-SMI-522, and CA-SMI-604. 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 cal BP (Table 6.1). 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 (see Erlandson et al. 2008; Rick et al. 2005, 2013). Despite this, 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.

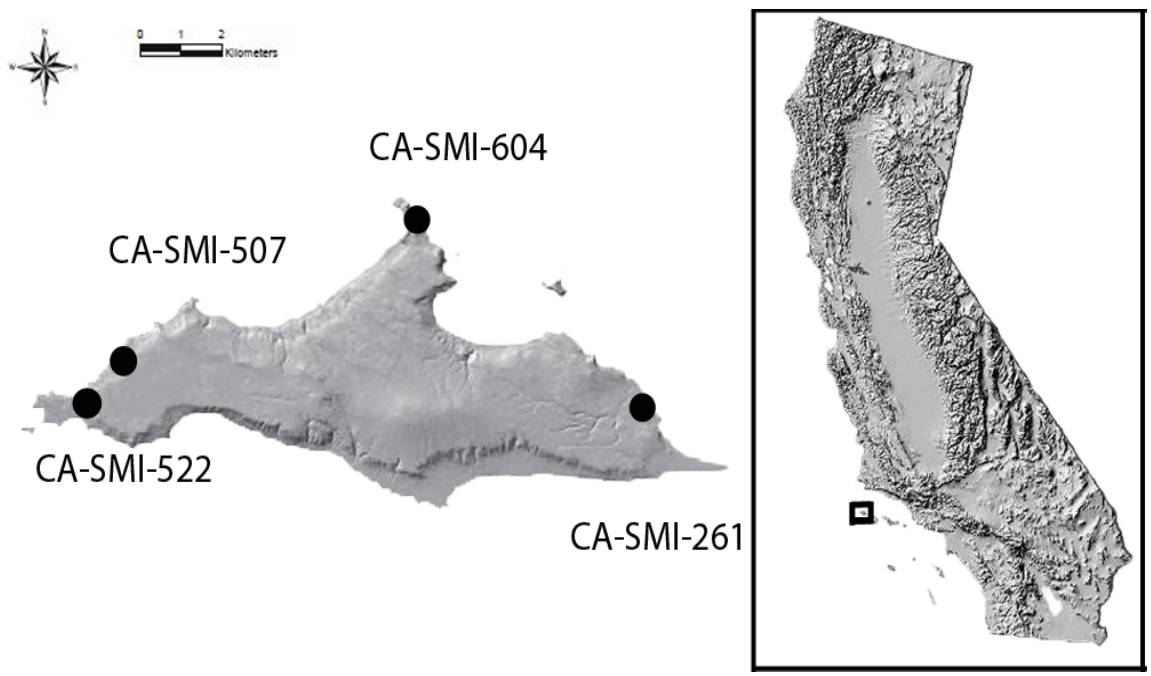

Figure 6.1. Map of San Miguel Island including the approximate locations of Paleocoastal sites selected for $\delta^{18}O$ analysis.

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 cal BP (Erlandson et al. 1996). Cordage and basketry (Connolly et al. 1995), sea mammal hunting and fishing technologies (Rick et al. 2001), and chipped stone bifaces (see Erlandson and Jew 2009) have been found in the Early Holocene strata E and F, dated between about 10,000 and 8600 cal BP (Erlandson et al. 1996:365-366). California mussels were selected for $\delta^{18}O$ analysis from stratum E1, dated to ~8600 cal BP. 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; Walker and Snethkamp 1984).

Table 6.1. Descriptions of Four Early Holocene Shell Middens on San Miguel Island

Site Name (CA-SMI-)	Location (SMI)	General site description	Age (cal BP)	References
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
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
SMI-522	Northwest coast; Point Bennett area	Large and dense shell midden containing rocky shore shellfish and diverse artifacts technologies.	~10,000	Erlandson & Rick 2002; Watts 2013
604 (Seal Cave)	North-central coast at 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

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 cal BP, 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 8 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 cal BP 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 and 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 cal BP 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 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 δ^{18}O analysis on several whole black abalone shells from the site.

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 δ^{18}O analysis. To minimize the effects of variation in mollusk growth rates (see Glassow et al. 2012; Jew et al. 2013a, b) we selected mid-size mussel shells between ~50-85 mm long. In their first year, mussels grow between 1 to 5 mm per month, averaging approximately 9 to 12 mm per season (Coe and Fox 1942:60, 1944; Richards 1946; Phillips 2005; Schmidt 1999). Our selection and sampling methods were adapted from several studies (see Glassow et al. 2012; Kennett 2005; Jew et al. 2013a, b; 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. 2013a).

Prior to submission, shells were inspected for intact terminal growth band (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 and Rick 2007). Calcite samples were removed from shells using a Sherline 5410 Micromrill. 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:

$$\delta^{18}O = ((R_{sample} - R_{standard}) / R_{standard}) \times 1000$$

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 and 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 and Rick 2007; Watts 2012) 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 Δ0m $\delta^{18}O_{sw(‰)}$ 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 -.32‰ taken from waters near Old Ranch Canyon on eastern Santa Rosa Island (see Robbins and 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 -.02‰ from 0.3‰ (adding -.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 6.2.) place the coldest 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.

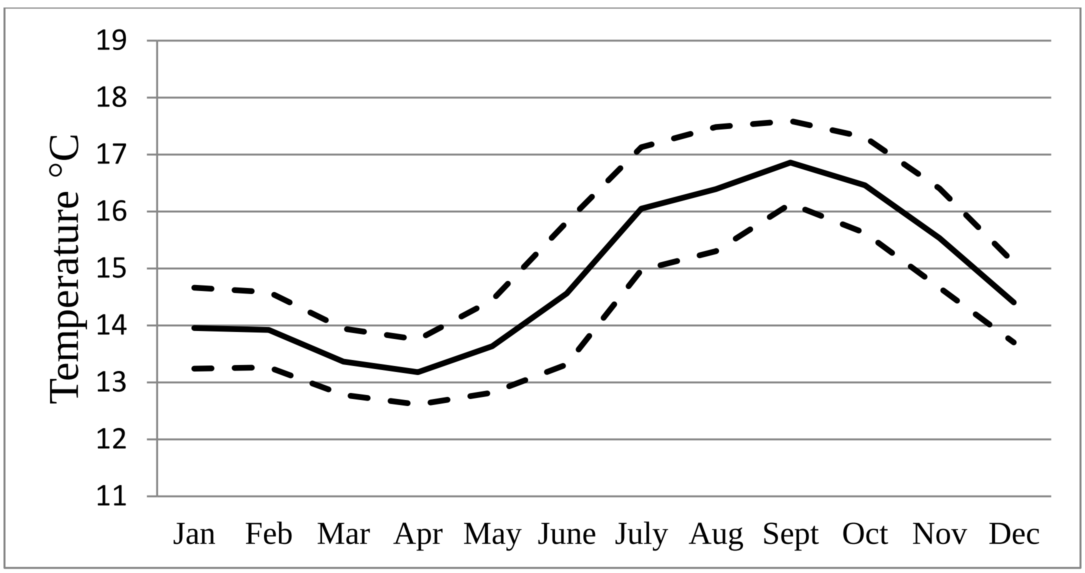

Figure 6.2. Modern SST averages for ten years (1981-1991, see Kennett 2005:56) near waters around San Miguel Island, including upper and lower confidence intervals (95%).

$\delta^{18}O$ 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 (see Appendix C; Figure 6.3.). 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) (see 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 6.4.).

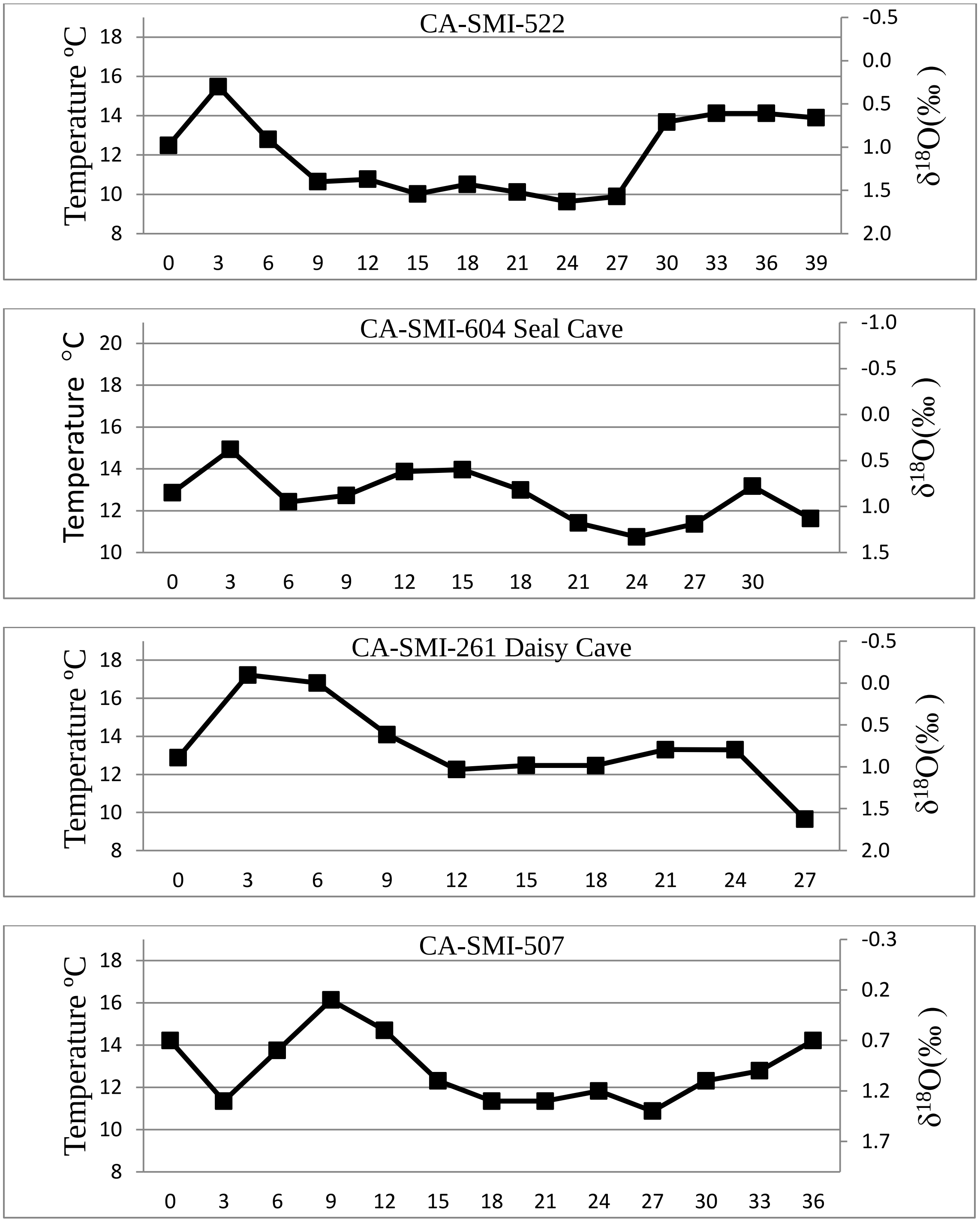

Figure 6.3. Isotopic profiles and inferred temperatures for each component showing seasonal variation. Mussel profiles include: CA-SMI-522#21(a-n), CA-SMI-604#21(a-l), CA-SMI-261#21(a-j), and CA-SMI-507#21(a-m). The x axis represents the distance from the TGB in mm.

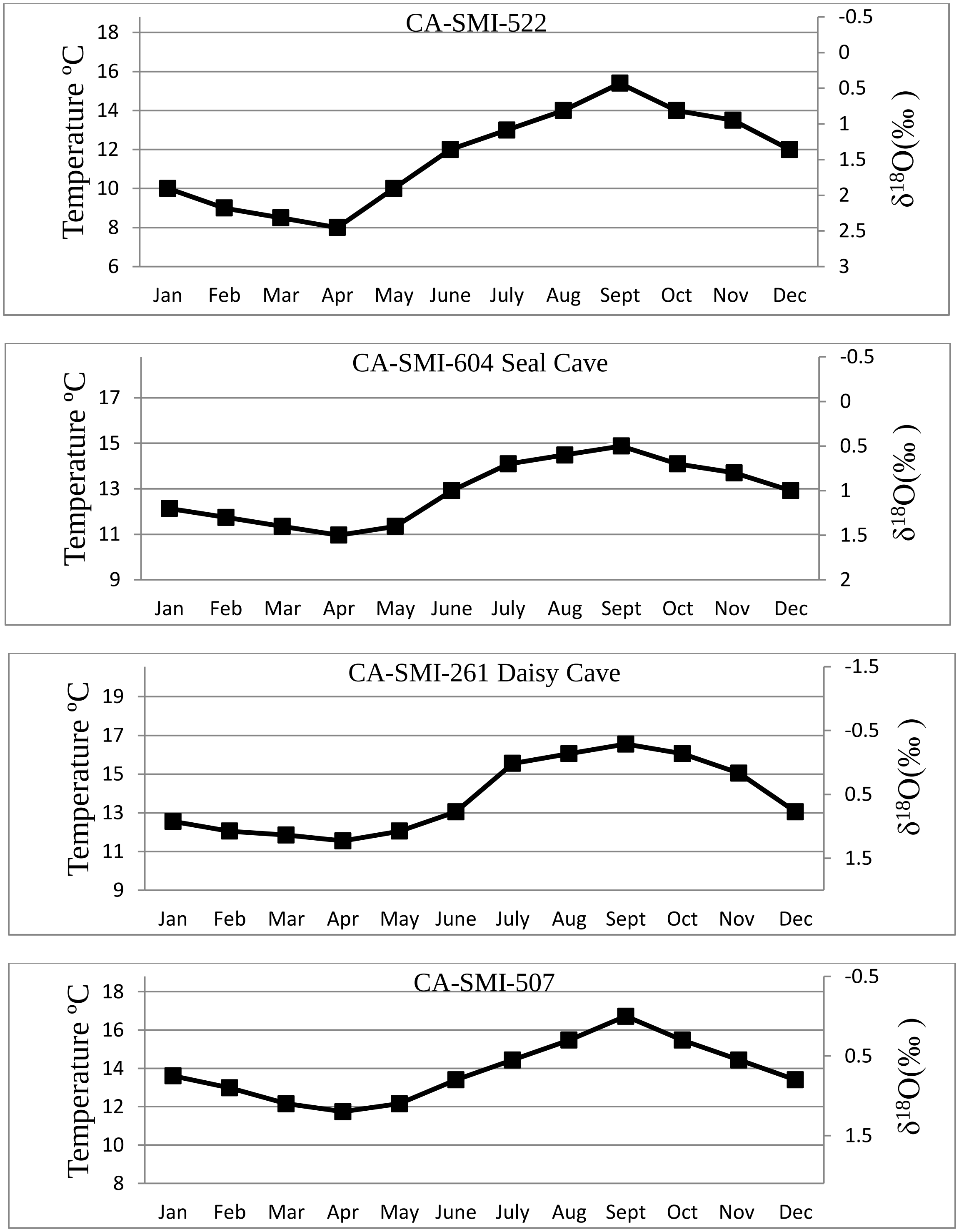

Figure 6.4. Paleo-SST estimates for CA-SMI-522, CA-SMI-604, CA-SMI-261, and CA-SMI-507 based on inferred temperatures ranges for profiled California mussel for each Early Holocene site adjusted to modern seasonal temperature distributions.

Seasonal PSST distributions for each component (Table 6.2) reflect estimated annual water temperature where the warmest temperatures are late summer to early fall and coldest are late winter to early spring. 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 least one full season of growth (Jew et al. 2013a). 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 summarized 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 variances (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

On San Miguel Island between 10,000 and 8600 cal BP, shellfish harvest occurred during all four seasons, although the seasonality signatures varied between sites (Table 6.3). At CA-SMI-522, the oldest site sampled at ~10,000 cal BP, 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 cal BP, 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, data suggest that mussels were harvested 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.

Table 6.2. 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	$x \leq 13.5°C$	$x \leq 13.5°C$	$x \geq 13.5°C$	$x \geq 13.5°C$
CA-SMI-507	$x \leq 13.4°C$	$x \leq 13.4°C$	$x \geq 13.4°C$	$x \geq 13.4°C$
CA-SMI-604	$x \leq 13°C$	$x \leq 13°C$	$x \geq 13°C$	$x \geq 13°C$
CA-SMI-522	$x \leq 12.8°C$	$x \leq 12.8°C$	$x \geq 12.8°C$	$x \geq 12.8°C$
TGB and 3-12mm comparison	$x < y$	$x > y$	$x > y$	$x < y$

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

Table 6.3. Seasonal distribution and percentages of harvested California Mussel Shells from Early Holocene Sites on San Miguel Island.

Site (SMI-)	**Component**	**Age (cal BP)**	**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%)

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 6.5, 6.6, 6.7, and 6.8), 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 most recent component at ~8600 cal BP and is located furthest east, where modern average SSTs 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 components analyzed, and appears to have been occupied during four distinct seasons.

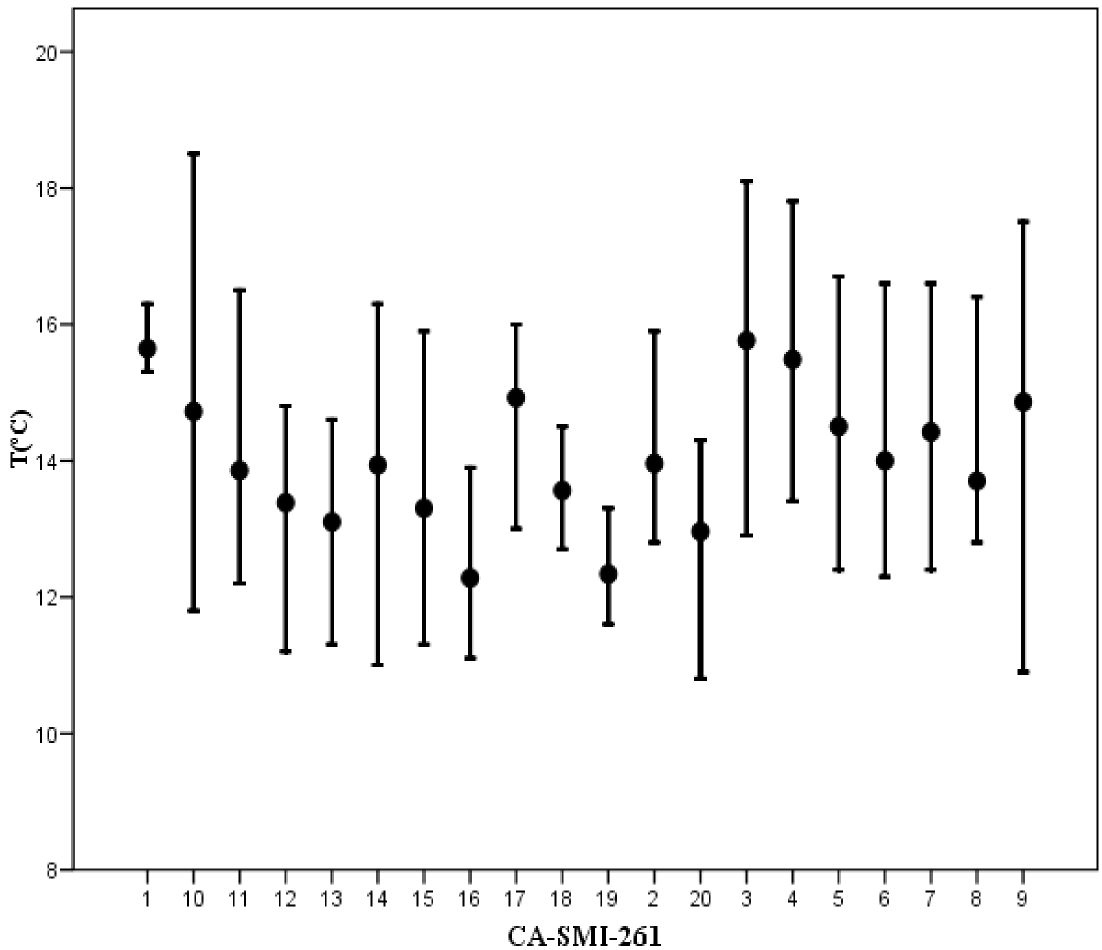

Figure 6.5. Maximum, minimum and means for sampled mussel shells from CA-SMI-261 (Daisy Cave) Unit D stratum E1 radiocarbon dated to ~8600 cal BP. Sample ID #s are presented along the x-axis.

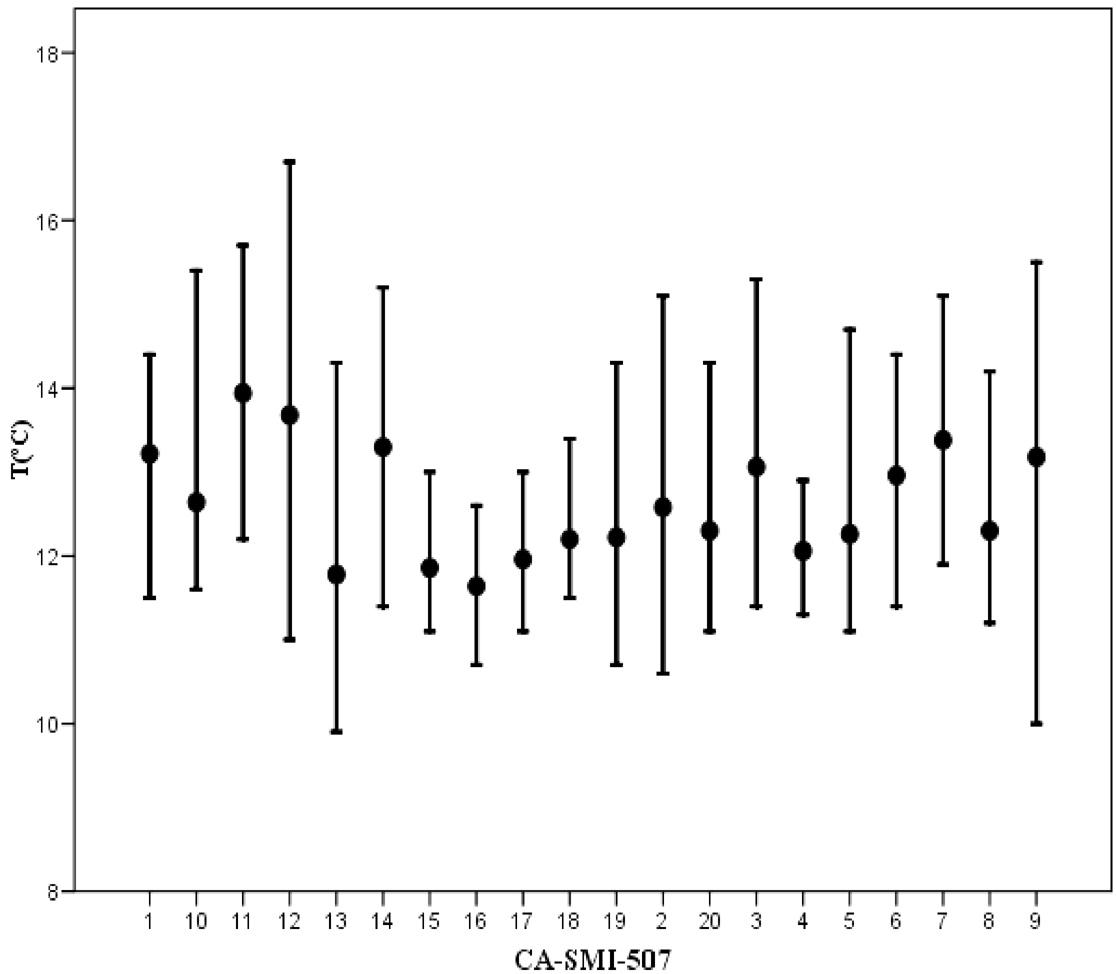

Figure 6.6. Maximum, minimum and means for sampled shells from CA-SMI-507 Unit 1 level 1 radiocarbon dated to ~9000 cal BP. Sample ID #s are presented along the x-axis.

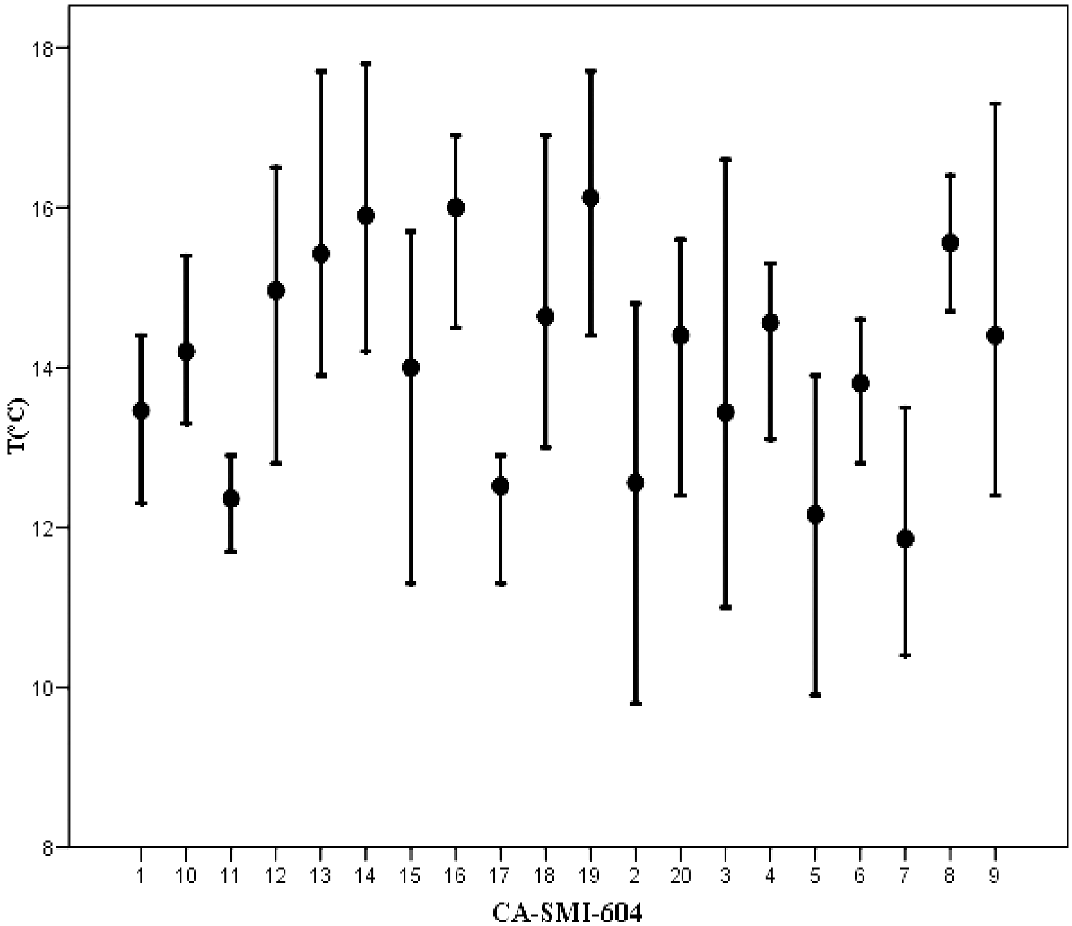

Figure 6.7. Maximum, minimum and means for sampled shells from CA-SMI-604 (Seal Cave) Unit 1 levels III and IV radiocarbon dated between ~9300-10,000 cal BP. Sample ID #s are presented along the x-axis.

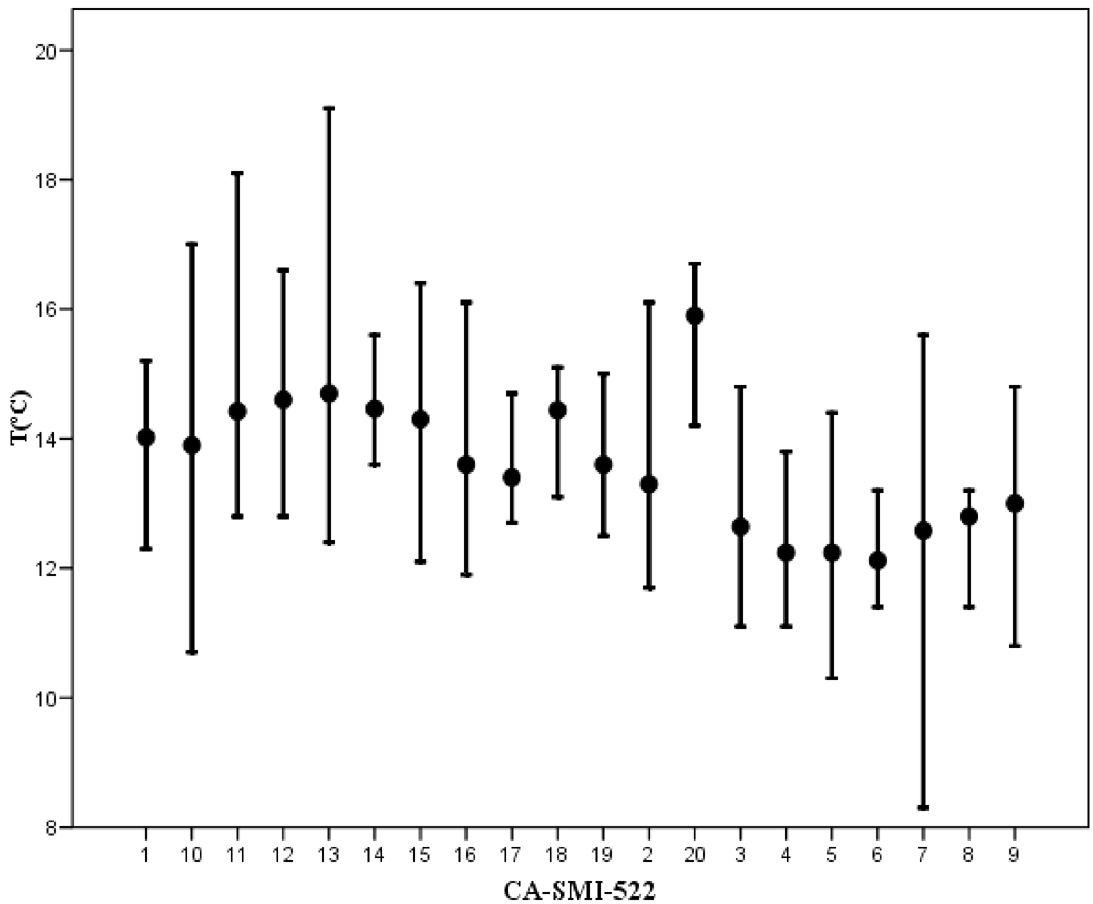

Figure 6.8. Maximum, minimum and means for sampled shells from CA-SMI-522 Unit 2 levels I and II radiocarbon dated to ~10,000 cal BP. Sample ID #s are presented along the x-axis.

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 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.

Discussions and Conclusions

Inferred 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 PSSTs 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 ~10,000-9000 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. Overall, however, compared to modern SST around San Miguel Island, mean water temperatures at various locations during the Early Holocene appear to have been slightly cooler. On the western end of San Miguel ~10,000 cal BP, for instance, $\delta^{18}O$ values are overall enriched and estimated SST is slightly cooler, on the northern tip between ~10,000-9200 cal BP and along the northeast coast at ~8600 cal BP, 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 water temperatures may be attributed to predominately a 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 stratum E1 seasonally during the summer and fall, consistent with earlier predictions by Erlandson et al. (1996:64). Interestingly, the two shells (CA-SMI-261# 5, 7) assigned winter harvest 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. To remain consistent in assigning seasonality, however, we left these as winter harvest because of the relatively low TGB PSST values –although given the 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. Cave sites are ideal locations to return 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. At CA-SMI-507, 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 limpets, 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, which is also located in proximity to a freshwater source, contains a diverse faunal assemblage of marine shell, some fish and marine mammal remains, and a variety of bone, shell, and stone artifacts. Based on isotopic results, mussels were collected throughout the year with decreased harvest 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 limpets 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 basecamp.

Several lines of evidence suggest that Paleocoastal peoples were more sedentary than previously believed and held a stronger commitment to the NCI well before 7500 cal BP. A large cemetery at CA-SRI-3 on the northwest coast of Santa Rosa Island, radiocarbon dated to ~7400 cal BP, 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. 2011). Recent analysis of California mussels shells from a large shell midden (CA-SRI-666) located on eastern Santa Rosa has provided evidence of year-round shellfish harvest and probable sedentism at ~8200 cal BP (Jew et al. 2013b). The remains of migratory geese at CA-SRI-512 at ~11,750 cal BP suggest a late fall or winter occupation of western Santa Rosa (Erlandson et al. 2011). Winter shellfish harvest at CA-SMI-507, CA-SMI-604, and CA-SMI-522 also documents winter occupations on San Miguel Island. Evidence of year-round shellfish harvest at CA-SMI-507 and CA-SMI-522, combined with archaeological evidence suggests that these sites were probably residential basecamps ~10,000-9000 years ago. Distinctive Paleocoastal chipped stone tool technologies consisting of Channel Island Barbed (CIB) and Channel Island Amol (CIA) projectile points (see Erlandson 2013; Erlandson et al. 2011; Glassow et al. 2008) that are relatively common on the NCI, but rare on the California mainland, also support the idea that islanders and mainlanders had only limited interaction during the Paleocoastal period.

As we synthesize archaeological and archaeometric data sets from Paleocoastal assemblages on the NCI, it seems increasingly likely that humans were occupying 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. For now, we can no longer assume that the islands were inhabited only on a seasonal basis before 7500 cal BP. Considering that much of the landscape Paleocoastal 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 human effects on island ecosystems.

Bridge

In previous chapters, I documented a relatively intensive and year-round occupation of the NCI by Paleocoastal peoples, Chapter VII, summarizes these findings, connects early human use of local cherts and shellfish on the NCI, and returns to the larger contextual issues presented in my introduction. In particular, I address the human use of continental island resources, human mobility and sedentism in island environments, and present hypotheses related to Paleocoastal people's settlement of the NCI and their commitment to maritime lifeways. Finally, I discuss research issues raised by my results that may direct future archaeological research on the NCI or in similar island archipelagos.

CHAPTER VII

SUMMARY AND CONCLUSIONS

In this dissertation, I have presented a collection of studies of Paleocoastal assemblages on California's Northern Channel Islands (NCI). I examined the paleoecology of island nearshore waters, early human use of island lithic resources, seasonality of shellfish harvest, and sedentism between about 12,200 and 7000 cal BP. My goal was to explore whether Paleocoastal inhabitants of the NCI relied primarily on island rather than mainland resources during the Terminal Pleistocene and Early Holocene and whether their occupations were seasonal and transitory or largely year-round and relatively permanent. My results indicate an emphasis on local island cherts available on western Santarosae, with heat treatment systematically utilized to improve lithic knappability. The lithic evidence suggests the possibility of a permanent occupation of the islands by Paleocoastal peoples.

In examining Paleocoastal chipped stone, I documented a strong preference for island cherts in stone tool manufacture, with an emphasis on Tuqan/Monterey cherts that are abundant on western Santarosae. The importance and use of island cherts is evident during the Terminal Pleistocene and persists throughout the Early Holocene, although a ~7000 year old assemblage shows an increase in the use of local Cico cherts on San Miguel Island, consistent with a similar shift documented in a ~6500 year old component at Daisy Cave (Erlandson et al. 1997). In comparing experimentally heat-treated island cherts with several Paleocoastal artifact assemblages, I documented that island cherts were regularly exposed to controlled and high temperature heat treatment to facilitate the manufacture of chipped stone tools, especially the delicate and finely-crafted projectile points and crescents that Heye (1921) described as among the finest examples of Native American flint knapping in North America. Using a combination of macroscopic, microscopic, and quantitative glossmeter analyses, I found that a high proportion of chert artifacts from Paleocoastal assemblages showed evidence of heat fractures and measurably increased luster (gloss) characteristic of heat treated cherts.

In examining seasonality of shellfish harvest on San Miguel and Santa Rosa Islands, I analyzed over 140 California mussel shells from six Paleocoastal sites dating between about 10,000 and 8200 cal BP. To interpret the resulting stable oxygen isotope ($\delta^{18}O$) data, I reconstructed paleo-sea surface temperature (PSST) curves for each area by fully profiling at least one whole mussel shell from each site. Multiple sampling strategies were then tested statistically to explore the reliability of seasonality studies on California mussels of different sizes. I found that the number of samples analyzed (the TGB+1 versus TGB+5) and the size of the mussel shells sampled significantly affected the interpretations. The limited sampling method (TGB+1) often used by Channel Island and California archaeologists was found problematic for two assemblages, producing erroneous seasonal signatures in ~35 percent of the shells analyzed more intensively. It appears that the rapid growth of California mussels during the first 12-18 months of their life cycle makes the TGB+1 sampling method especially susceptible to short-term fluctuations in local SST.

Using the more intensive TGB+5 sampling method, my analysis of California mussel shells from six Paleocoastal sites identified a series of seasonal and year-round occupations that are consistent with expectations generated from independent data sets such as site size, depth, and density of sites, as well as the diversity of artifacts and faunal remains present. Three sites produced mussel shells harvested in all four seasons of the year, suggesting that they were occupied more-or-less continuously through the course of an annual period. When combined with other data from these sites, it appears some island groups were sedentary on the NCI by 10,000 (CA-SMI-522), 9000 (CA-SMI-507), and 8200 (CA-SRI-666) years ago. The oxygen isotope results from California mussels from the oldest of these sites (CA-SMI-522) are consistent with $\delta^{18}O$ data obtained from black abalone shells from the same midden (Watts 2013).

All of these studies were part of a larger attempt to identify the extent of Paleocoastal reliance on island resources when in close proximity to the mainland. My methods included archaeological excavation, survey, and artifact recovery along with lithic and shell analyses, experimental archaeology, glossmeter analysis, stable oxygen isotope analysis, and a variety of statistics. A part of my dissertation research involved developing analytical techniques and experimental methods to efficiently and accurately examine data. Some of these methods and results can be applied to island and coastal settings elsewhere in California and around the world. For instance, experimentally heating and documenting the changes in island cherts provided visual characteristics for identifying thermally altered Wima, Cico, and Tuqan Monterey cherts. The use of glossmeters, which are relatively inexpensive and widely available, also provides a means to quantify differences in luster and glossiness characteristic of heat treated and unheated cherts. In evaluating different sampling strategies for $\delta^{18}O$ analyses of California mussels, I emphasized the importance of recognizing mollusk growth, ecology, and diversity when sampling calcite from shells to infer seasonality of harvest. My results on California mussels recovered from two Paleocoastal sites provided a sampling protocol for more reliable analysis of seasonality data for California mussel shells widely recovered in middens along the Pacific Coast of North America. A reliance on more intensive sampling of marine and estuarine shells may also be relevant for other mollusc species around the world.

Throughout my dissertation I have provided evidence for intensive resource use of NCI terrestrial and marine resources by Paleocoastal peoples, raising questions about the supposed marginality of the islands when compared to the adjacent mainland. The identification of year-round mussel harvest and occupation of the NCI, including three sites that may have served as residential bases between 10,000 and 8200 years ago, also establishes a sustained human presence on the islands more than two millennia earlier than previously believed (Fitzhugh and Kennett 2010:74; Kennett 2005:1; Rick et al. 2005:181; Winterhalder et al. 2010).

Based on my experimental, archaeometric, paleoecological, and more traditional archaeological analyses, I have concluded that:

(1) Paleocoastal peoples on the NCI had a strong commitment to island lifeways and utilized marine resources year-round while relying predominantly on island cherts for stone tool manufacture. While shellfish remains dominate many Terminal Pleistocene and Early Holocene middens, Paleocoastal assemblages and sites such as CA-SRI-512 clearly establish a balanced hunting, fishing, and foraging economy.

(2) Early inhabitants of San Miguel and Santa Rosa islands consistently used high quality Tuqan, Cico, and Wima cherts, in the production of formal artifacts such as projectile points and many more expedient tools. Metavolcanic rocks, quartzites, and other coarser-grained rocks were also utilized, primarily for expedient tools. These trends persisted from the Terminal Pleistocene through the Early Holocene, although many sites show some preference for locally abundant toolstone.

(3) Paleocoastal peoples systematically improved the quality of island cherts using sophisticated annealing strategies for stone tool manufacture instead of relying exclusively on high quality Santa Cruz Island cherts or mainland

Monterey and Franciscan cherts. Heat treating island cherts was probably essential to producing the delicate and finely made crescents and CIA/CIB points used by Paleocoastal peoples.

(4) San Miguel Island and Santa Rosa Island (western Santarosae) were occupied more or less permanently and year-round by at least 10,000 years ago, including a semi-sedentary settlement system that included some residential bases occupied during all four seasons of an annual cycle. Evidence for a late fall or winter occupation at the 11,700 year old CA-SRI-512 (Erlandson et al. 2011), along with the growing number of Terminal Pleistocene sites documented on the NCI suggests that the permanent occupation of the islands may have even greater antiquity.

(5) $\delta^{18}O$ analysis and PSST reconstruction indicate that the nearshore ecology and water temperatures around San Miguel and Santa Rosa islands varied through the Early Holocene by geographic location but were generally comparable to modern sea-surface temperatures or slightly cooler. Faunal evidence from the Cardwell Bluffs sites, where red abalone and other cool-water shellfish are abundant but black abalone is virtually absent, suggests that PSSTs were cooler during the Terminal Pleistocene Younger Dryas period. Preliminary results of $\delta^{18}O$ analysis support this idea (Watts 2013), but these data require confirmation and have not been discussed in detail in this dissertation.

Further research is necessary to more thoroughly evaluate these conclusions, but I have demonstrated that Paleocoastal human occupation on the NCI is more complex than the traditional view that mainlanders only seasonally or occasionally visited the islands until around 7500 cal BP. PSSTs around the San Miguel and Santa Rosa islands were within seasonal temperature ranges that supported a variety of shellfish, kelp forests, and other marine resources, which were available year-round. Recent research is showing that plant foods were more abundant than previously thought on the NCI and that Paleocoastal peoples collected a variety of geophyte and seed resources (Reddy and Erlandson 2012). Thus, it seems increasingly likely that the NCI were optimal rather than marginal habitats for maritime Paleocoastal peoples.

Without clearly defined structural features at NCI Paleocoastal sites, some archaeologists may argue that the islands were only visited by mainlanders each season. It remains conceivable that mainlanders used the islands for short periods during each season, utilizing local island resources then returning to their primary mainland residences. Indeed, based on the cruder and mostly leaf-shaped bifaces the site produced, Erlandson et al. (2009) suggested the possibility that a 9000 year old occupation at CA-SMI-507 on western San Miguel may have been by mainland Millingstone peoples. California mussels, limpets, chitons, red and black abalones, crabs, turban snails, and estuarine clams are abundant and widely accessible along the California Coast, however, and it is not clear why mainland peoples would travel to the Channel Islands to obtain them. Some have argued that there are higher quality chert sources on Santa Cruz Island

and the mainland (see Arnold 1987, 1992), but the characteristics and types of cherts I examined resemble chert sources similar in composition to those identified on San Miguel and Santa Rosa islands (see Erlandson et al. 1997, 2008, 2012). Given the wide distribution and availability of shellfish and lithic sources on the mainland, island resources alone cannot explain why mainlanders might have returned each season—particularly during harsh winter seasons with severe storms, high waves, and especially dangerous seas. If mainlanders traveled to the islands periodically to hunt pinnipeds, we should expect to see higher frequencies of mainland cherts and for CIA and CIB points to be found in early sites along the mainland coast, but so far none have been documented.

If the NCI were remote oceanic islands hundreds of kilometers from the mainland then year-round shellfish harvest and heavy reliance on local lithics would strongly support permanent island colonization. The NCI are continental islands where the shortest distance to the mainland from Santarosae (the closest point is the eastern end of Anacapa) has changed over time (Table 7.1). In such close proximity to the mainland, it is more difficult to demonstrate permanent and year-round occupation, especially if seafaring mainland peoples were regularly moving between the mainland and the islands. In this sense, general theories related to isolation, colonization, and resource use on remote oceanic islands are inadequate for explaining similar phenomena on the NCI and other continental islands (see Moss 2004:180).

The patterns of resource use on the NCI during the Paleocoastal period are more consistent with an alternate hypothesis where people inhabited the islands year-round, subsisting on island resources, and manufacturing distinct Paleocoastal tools (see Erlandson et al. 2011) using locally (island) heat treated cherts. This hypothesis does not preclude the possibility of mainlanders traveling to the islands as part of their seasonal rounds, but the evidence presented in this dissertation is more consistent with sedentary human groups living on the NCI prior to about 9,000 to 10,000 years ago. On Haida Gwaii in British Columbia, for instance, Early Holocene assemblages from Richardson Island and Kilgii Gwaay have produced a variety of stone tools including leaf-shaped bifaces, hammerstones, scrapers, and expedient flake tools—all of which derive from local sources (Fedje and Mackie 2005). Fedje and Mackie (2005:158) argue that the use of island sources "suggests limited or no contact with mainland groups" around 10,000 cal BP. After 10,000 cal BP during the Early Moresby Tradition bifacial tools are replaced by microblades (Fedje et al. 2005:239). The inhabitants of Haida Gwaii manufactured microblades from local lithic sources but the introduction of microblade technologies to the islands suggests regional interactions (Fedje and Mackie 2005:159). The Paleocoastal period on the NCI also possess unique bifacial tools manufactured from local sources and microblade technologies appear on the NCI much later than on Haida Gwaii, although the absence of these tools during the Paleocoastal period does not preclude regional contact with mainland groups.

Table 7.1. NCI total area and distance to California mainland from 13,000-9000 cal BP. (adjusted from Kennett et al. 2008)

Years ago (cal BP)	**Approximate NCI area (mi^2)**	**Approximate distance to California mainland***
13,000	1430 km^2 / 890 mi^2	8.5 km / 5.2 mi
12,500	1350 km^2 / 840 mi^2	9.5 km / 5.9 mi
12,000	1275 km^2 / 790 mi^2	9.5 km / 5.9 mi
11,500	1200 km^2 / 745 mi^2	10 km / 6.2 mi
11,000	1150 km^2 / 715 mi^2	10.75 km / 6.7 mi
10,500	1080 km^2 / 670 mi^2	11.5 km / 7.1 mi
10,000	1000 km^2 / 620 mi^2	11.8 km / 7.3 mi
9500	925 km^2 / 575 mi^2	12 km / 7.4 mi
9000	820 km^2 / 510 mi^2	13 km / 8 mi

*****Estimated distance from eastern Anacapa Island to the adjacent Ventura Coast.

My studies are part of larger effort by archaeologists (e.g. Erlandson et al. 2011, Rick et al. 2013) to better understand long-term cultural trajectories on the Channel Islands which humans have occupied for at least 13,000 calendar years. The methods, data, and conclusions presented in this dissertation should be further researched and refined in efforts to better understand variability in human technologies, resource use, and settlement on the NCI and the adjacent mainland coast during this time period. In the meantime, the presence of maritime Paleocoastal peoples on the NCI expands our understanding of the diversity evident in Paleoindian lifeways in the Americas (Erlandson et al. 2011).

The studies presented here are the beginning of a broader pursuit in my career of understanding early human resource use, settlement, and mobility in island and coastal environments. The Channel Islands, in particular, have a rich archaeological record spanning thousands of years which has attracted archaeologists and other researchers for over a century. I combined archaeometric techniques with more traditional archaeological methods to examine a range of resources commonly found on islands and in coastal assemblages. A range of archaeological materials (e.g. shellfish, lithics, faunal remains) provide information related to the use of resources whether aquatic, terrestrial, or mineral.

Archaeologists must continue to shed illusions that islands are closed and isolated laboratories because continental islands are not geographically circumscribed, isolated, and distance or connectivity between islands and mainland change through time (see Erlandson 2001; Fitzpatrick 2004; Moss 2004, 2008). To determine the extent of human presence in island environments, archaeologists should compare the availability of both mainland and island resources. This will help evaluate the marginality of island environments and the need, if any, for resource procurement from the mainland. In my dissertation, I presented a bottom-to-top approach as discussed by Curet (2004:199) identifying diversity in Paleocoastal assemblages to better understand human mobility, sedentism, and commitment to island lifeways–all aspects of past human behavior. Before archaeologists can construct theories specifically tailored to continental islands, we must develop an understanding of the variation and diversity of resources that exist between continental islands and the adjacent mainland.

Models developed for island biogeography (e.g. MacArthur and Wilson 1967; Renfrew 2004) or long-distance exchange and trade (Renfrew 1977, 1984) can be revised for continental island settings. MacArthur and Wilson’s (1967) model for identifying species immigrations and extinctions on islands may be adapted to accommodate relatively stationary resources (e.g. cherts and other minerals), widely available species (mussels and other shellfish), or translocated plants and animals to serve as proxies to infer the degree of human presence on continental islands. For instance, *The Distance Effect*, where the farther an island is from a source of colonists the fewer species it holds, can be modified to evaluate resources on continental islands.

If we substitute ‘species’ with a restricted resource (e.g. Franciscan chert) we can predict the abundance of that resource in an assemblage based on the distance from the source or origin (substituted in place of ‘colonist’) providing a proxy for the extent of human presence. Theoretically, we would expect to see a decrease in the presence of Franciscan chert in an assemblage as distance from the source increases. Models such as MacArthur and Wilson's are based on rates of immigrations, emigrations, and extinctions that vary with distance and size of the destination (island) only, therefore, deviations in data from those predicted by their model would imply highly intentional and directed movements as might be expected of human populations with shared knowledge of destinations and resources.

Modeling the geographic distance between geologic sources and archaeological sites of known age allows us to determine the temporal and spatial distribution of artifacts such as lithic materials. Hughes (1994, 2011; Hughes and Milliken 2007) noted that knowing a material's point of origin and its archaeological context (destination) permits an understanding of *material conveyance* or the transport and movement of goods. Specific contextual data such as site type (e.g. village, camp, or quarry) is necessary to create inferences specifically related to human motivations for trade, exchange, interaction, or direct procurement of materials and goods (Hughes and Milliken 2007).

In my studies of NCI Terminal Pleistocene and Early Holocene lithic assemblages, despite the fact that mainland chert sources were probably less distant during Paleocoastal times, Franciscan chert is virtually absent (less than .01%). The limited distribution of a rare lithic material in an archaeological assemblage and known source of origin provides spatial data to identify material conveyance from a source to an archaeological site. Additional contextual data, including similarities and differences in tools (mainland or island traditions), subsistence economies, and lifeways between mainland and island groups, is necessary to create hypotheses to examine trade, exchange, or direct procurement. For instance, the absence of Franciscan chert in Paleocoastal assemblages may reflect (a) an isolated human group on the islands who limited their interactions with mainland populations; (b) seasonal rounds by mainlanders who relied almost exclusively on local island lithic materials; or (c) islanders who adapted their own lithic manufacturing techniques of local cherts instead of using high-quality Franciscan cherts. Before archaeologists can explore the motivations which may explain how materials were conveyed, it is necessary to have a firm understanding of the location, availability, and distribution of transferred goods such as lithic materials or other resources (Eerkens 2011). If future studies support permanent Paleocoastal human occupations on the NCI, then we can synthesize additional contextual site data to begin to generate and evaluate hypotheses related to isolation, interaction, and trade or exchange.

Future Research

To further understand the use, availability, and distribution of lithic sources on the Channel Islands, archaeologists need to conduct comprehensive surveys on all the islands to identify lithic sources or quarries then document detailed lithologies for all known sources. This will provide the geographic distribution and microscopic characteristics identifying clast inclusions and size, mineralogy, fabric, texture, and color to determine the intra- and inter-source variability within island cherts and other rock types. By creating and sharing comparative collections of lithic materials from the NCI and adjacent mainland, archaeologists working in the area may gain a much better understanding of variation in lithic resource use on the NCI through time and space. As Erlandson and Braje (2008:6) noted:

> After 130 years of archaeological research, we should know the basic distribution of the major economic minerals on California's Channel Islands. For Native American peoples, these included local sources of rock used to manufacture chipped stone tools (e.g., chert, quartzite, meta-volcanics) and ground stone tools (steatite, sandstone, etc.), as well as ochres and other minerals used for pigments and medicines, asphaltum used as an adhesive or sealant, and other geological materials. We do know many major sources of valued minerals on the islands and the adjacent mainland, including Santa Cruz Island chert, Santa Catalina steatite, Grimes Canyon fused shale, Franciscan cherts, and exotic obsidians. Unfortunately, despite more than 100 years of organized archaeological research, there has been no comprehensive inventory of such mineral resources on the Channel Islands or the adjacent mainland.

Five years later, we have made some progress but there is still no comprehensive inventory of rock and mineral resources on the NCI. Since 2008 at least two high quality chert types (Tuqan and Wima) have been identified on San Miguel and Santa Rosa islands, however, and a lower quality source has also been identified on Anacapa Island (Rick 2006).

Variability within the new chert sources complicates the identification of raw materials because some of the artifacts are made from materials that macroscopically overlap. Distinguishing NCI and mainland chert types may benefit from geochemical or other discrimination techniques such as wavelength/energy dispersive x-ray fluorescence or Fourier transform infrared reflectance micro-spectroscopy to determine whether the chemical composition or other geo-signatures can quantitatively discriminate between island-island and island-mainland cherts. It would also be beneficial to expand lithic analysis in assemblages beyond cherts to include a more systematic examination of the use of quartzite, basalts, metavolcanics, siliceous shales, and other lithic materials. Finally, future researchers can conduct a broader analysis of lithic use including evidence for intentional heat treatment at multiple sites across the islands to identify changes in preference, manufacturing techniques, and use through space and time. It would be interesting to know if heat treatment practices continued through the Holocene, including the specialized microblade production centered on Santa Cruz Island during the Late Holocene (Arnold 1987).

There are several ways researchers can further evaluate hypotheses related to the permanence of Paleocoastal people on the NCI. Increasing sample sizes and additional isotopic analysis of mussels from Paleocoastal assemblages may further support year-round shellfish harvesting, but it may also help flesh out settlement patterns that clearly included both sedentism and mobility. Other shellfish taxa commonly found in early assemblages–red and black abalones, limpets, giant chitons, and estuarine clams—should be studied to reconstruct changes in paleoecology, water temperatures, and if possible the seasonality of harvest. It is possible that some of these shellfish may have been harvested during more restricted seasons than California mussels, which would add significantly to our understanding of shellfish use by Paleocoastal peoples.

I expect that we will find many more Terminal Pleistocene and Early Holocene sites on California's Channel Islands. Since I began my doctoral studies on the NCI, over two dozen Paleocoastal sites have been identified and ^{14}C dated, including several in the last three years (see Erlandson et al. 2011; Rick et al. 2013). The sheer number of Paleocoastal sites on the NCI, despite the effects of sea-level rise, overgrazing and heavy soil erosion, extensive dune building, pinniped trampling, and other destructive processes, further supports conclusions proposed in this dissertation. Given the data presented herein, we know that the islands were an important source for toolstone and subsistence resources for Paleocoastal peoples since the Terminal Pleistocene at least ~12,000 years ago and that there was a more-or-less permanent and year-round human presence by at least ~10,000 years ago.

APPENDIX A

REPORTED $\delta^{13}C$, $\delta^{18}O$, AND INFERRED TEMPERATURE VALUES FOR ALL ISOTOPIC DETERMINATIONS FROM FORTY ANALYZED CALIFORNIA MUSSEL SHELLS FROM CA-SMI-693

Sample ID	Distance (mm)	$\delta^{13}C$ (VPBD)	$\delta^{18}O$ (VPBD)	Temp °C
Mc1a	0	0.7	1.4	10.2
Mc1b	2	0.1	1.2	11.3
Mc2a	0	0.3	0.8	12.9
Mc2b	2	0.1	1.7	9
Mc3a	0	0.4	0.8	12.7
Mc3b	2	-0.2	1.1	11.7
Mc4a	0	0.4	1.4	10.4
Mc4b	2	0.4	1	11.9
Mc5a	0	0.5	1.5	9.9
Mc5b	2	0.1	0.9	12.4
Mc6a	0	0.3	1.2	11.3
Mc6b	2	-0.3	0.8	12.8
Mc7a	0	0.1	0.8	12.8
Mc7b	2	0	1.1	11.7
Mc8a	0	-0.1	0.9	12.4
Mc8b	2	-0.1	1.1	11.3
Mc9a	0	0.2	0.7	13.2
Mc9b	2	0.3	2	7.8
Mc10a	0	1.2	1.5	9.8
Mc10b	2	0.2	1.1	11.4

Sample ID	Distance (mm)	$\delta^{13}C$ (VPBD)	$\delta^{18}O$ (VPBD)	Temp °C
Mc11a	0	0.5	0.4	14.6
Mc11b	2	0.2	1.9	8.2
Mc12a	0	0.7	1.7	9
Mc12b	2	-0.3	0.5	13.8
Mc13a	0	0.5	0.9	12.3
Mc13b	2	0.4	1.5	9.9
Mc14a	0	0.8	1.7	9
Mc14b	2	0.4	1.6	9.5
Mc15a	0	1.3	1.7	9.2
Mc15b	2	0	0.4	14.6
Mc16a	0	1	0.8	12.8
Mc16b	2	0.4	1.5	10
Mc17a	0	0.7	1.3	10.6
Mc17b	2	0.2	0.5	14
Mc18a	0	0.1	1.1	11.7
Mc18b	2	0.2	0.7	13.1
Mc19a	0	1	1.1	11.5
Mc19b	2	0.4	0.9	12.5
Mc20a	0	0	0.9	12.4
Mc20b	2	0.1	1.4	10.2
Mc21a	0	0.2	1.2	11.3

Sample ID	Distance (mm)	$\delta^{13}C$ (VPBD)	$\delta^{18}O$ (VPBD)	Temp °C
Mc21b	3	-0.2	0.5	13.9
Mc21c	6	-0.8	1	11.8
Mc21d	9	-0.6	1.7	9.2
Mc21e	12	0	1.6	9.6
Mc21f	15	-0.1	1.5	9.8
Mc21g	18	0.2	1.1	11.5
Mc21h	21	0.5	1.3	10.7
Mc21i	24	0.6	1.3	10.5
Mc21j	27	0.6	1.5	10.1
Mc21k	30	0.2	0.9	12.5
Mc21l	33	0	0.7	13.3
Mc21m	36	0.2	1.1	11.4
Mc21n	39	-0.1	1.3	10.7
Mc21o	42	-0.3	0.9	12.4
Mc21p	45	-0.3	1.3	10.9
Mc21q	48	-0.1	1.4	10.3
Mc22a	0	-0.2	0.5	14
Mc22b	2	-0.3	0.3	14.7
Mc23a	0	-0.2	0.1	15.8
Mc23b	2	-0.3	0.3	14.9
Mc24a	0	0.2	0.4	14.4

Sample ID	Distance (mm)	$\delta^{13}C$ (VPBD)	$\delta^{18}O$ (VPBD)	Temp °C
Mc24b	2	0.1	0	16.2
Mc25a	0	-0.2	0.4	14.4
Mc25b	2	-0.8	0.2	15.4
Mc26a	0	0.1	0.5	13.8
Mc26b	2	0.5	0.6	13.7
Mc27a	0	0.1	0.5	14.2
Mc27b	2	0.1	0.6	13.6
Mc28a	0	-0.1	0.3	14.7
Mc28b	2	-0.6	0.6	13.6
Mc29a	0	-0.1	0.5	13.9
Mc29b	2	0.1	0.3	14.7
Mc30a	0	0.1	0.3	14.8
Mc30b	2	0	0.7	13.2
Mc31a	0	-0.4	0.1	15.6
Mc31b	2	-0.7	0.2	15.2
Mc32a	0	0.5	0.6	13.5
Mc32b	2	-0.6	0.2	15
Mc33a	0	1.4	0.5	14.1
Mc33b	2	0.8	0.4	14.5
Mc34a	0	-0.1	0.4	14.3
Mc34b	2	0.4	0.8	12.6

Sample ID	Distance (mm)	$\delta^{13}C$ (VPBD)	$\delta^{18}O$ (VPBD)	Temp °C
Mc35a	0	0.8	0.8	12.7
Mc35b	2	-0.6	0.9	12.6
Mc36a	0	0.2	0.4	14.6
Mc36b	2	-0.9	0.7	13.1
Mc37a	0	-0.2	0.6	13.5
Mc37b	2	-0.6	0.9	12.4
Mc38a	0	-0.1	0.4	14.5
Mc38b	2	0	0.2	15.3
Mc39a	0	-0.2	0.1	15.9
Mc39b	2	0.6	1.1	11.5
Mc40a	0	0.3	0.7	13.1
Mc40b	2	0	0.2	15.4
22Mc2a	3	-0.8	0.1	15.9
22Mc2b	6	-1.3	0.3	14.6
22Mc2c	9	-0.4	1.2	11
22Mc2d	12	-0.1	1.8	8.9
22Mc2e	15	0	1.5	10.1
22Mc2f	18	0.1	1.1	11.4
28Mc2a	3	-1.1	0.2	15.4
28Mc2b	6	-0.5	1.4	10.5
28Mc2c	9	0.6	2.1	7.5

Sample ID	Distance (mm)	$\delta^{13}C$ (VPBD)	$\delta^{18}O$ (VPBD)	Temp °C
28Mc2d	12	0	0.5	14.1
28Mc2e	15	0	0.7	13.2
28Mc2f	18	0	1.8	8.8
29Mc2a	3	0	2.4	6.4
29Mc2b	6	0	2.4	6.5
29Mc2c	9	-0.8	0.7	13
29Mc2d	12	-0.1	0.1	15.5
29Mc2e	15	0	1.2	11.2
29Mc2f	18	-0.1	1.6	9.3
30Mc2a	3	0.1	1.7	9.3
30Mc2b	6	0.7	2.6	5.5
30Mc2c	9	0.8	2.2	7
30Mc2d	12	0.9	1.5	9.7
30Mc2e	15	0.1	-0.3	17.5
30Mc2f	18	0.3	0.6	13.7
31Mc2a	3	-1.1	-0.1	17
31Mc2b	6	-1	0.9	12.4
31Mc2c	9	-0.1	2.1	7.5
31Mc2d	12	0	2.1	7.7
31Mc2e	15	0	1.3	10.5
31Mc2f	18	0.3	1.7	9.3

Sample ID	Distance (mm)	$\delta^{13}C$ (VPBD)	$\delta^{18}O$ (VPBD)	Temp °C
32Mc2a	3	-0.5	1.6	9.7
32Mc2b	6	-0.2	1.3	10.8
32Mc2c	9	0.6	2.5	5.9
32Mc2d	12	0.1	1.1	11.4
32Mc2e	15	0.4	1.1	11.6
32Mc2f	18	0.4	1.6	9.4
34Mc2a	3	0.4	2.3	6.8
34Mc2b	6	0.7	2.4	6.1
34Mc2c	9	0.6	0.6	13.7
34Mc2d	12	0.6	0.9	12.4
34Mc2e	15	0.3	1	11.8
34Mc2f	18	-0.2	1.1	11.7
35Mc2a	3	0	1.4	10.2
35Mc2b	6	0.5	0.4	14.3
35Mc2c	9	0.2	0.6	13.5
35Mc2d	12	-0.3	–0.3	17.5
35Mc2e	15	0	0.4	14.4
35Mc2f	18	0	0.8	12.7
39Mc2a	3	-0.5	0.1	15.9
39Mc2b	6	-0.9	0.2	15
39Mc2c	9	-1.1	0.2	15.1

Sample ID	Distance (mm)	$\delta^{13}C$ (VPBD)	$\delta^{18}O$ (VPBD)	Temp °C
39Mc2d	12	-0.6	0.7	13.3
39Mc2e	15	-0.1	1.4	10.3
39Mc2f	18	0.1	0.9	12.4
40Mc2a	3	-0.2	0.9	12.5
40Mc2b	6	0.2	1	11.8
40Mc2c	9	0.3	0.5	14.1
40Mc2d	12	0.8	0.4	14.5
40Mc2e	15	0.2	0.6	13.4
40Mc2f	18	0.2	1	11.8
2Mc2a	3	0.7	1.1	11.3
2Mc2b	6	0.3	1.6	9.6
2Mc2c	9	1	1.1	11.7
2Mc2d	12	1	0.9	12.5
2Mc2e	15	0.3	1.6	9.7
2Mc2f	18	0.9	0.9	12.3
3Mc2a	3	-0.5	1.1	11.5
3Mc2b	6	-0.2	1.5	10
3Mc2c	9	0.5	2.4	6.2
3Mc2d	12	0.6	1.9	8.4
3Mc2e	15	0.2	1.1	11.7
3Mc2f	18	0.8	0.8	12.7

Sample ID	Distance (mm)	$\delta^{13}C$ (VPBD)	$\delta^{18}O$ (VPBD)	Temp °C
4Mc2a	3	0	0.6	13.8
4Mc2b	6	0	1.4	10.4
4Mc2c	9	0.3	1.3	10.6
4Mc2d	12	0.7	1.1	11.5
4Mc2e	15	0.7	0.9	12.3
4Mc2f	18	0.8	0.8	12.7
5Mc2a	3	-0.4	0.3	14.8
5Mc2b	6	-0.7	0.6	13.5
5Mc2c	9	-0.7	1.1	11.7
5Mc2d	12	-0.8	1	11.8
5Mc2e	15	-0.5	1.3	10.7
5Mc2f	18	0	0.7	13
7Mc2a	3	-0.2	0.1	15.8
7Mc2b	6	-0.7	0.3	15
7Mc2c	9	-0.6	0.9	12.5
7Mc2d	12	-0.3	1.2	11.2
7Mc2e	15	-0.4	1.2	11
7Mc2f	18	0	1	12.1
10Mc2a	3	0.2	1.2	11.2
10Mc2b	6	0.5	1.1	11.4
10Mc2c	9	0.9	0.6	13.4

Sample ID	Distance (mm)	$\delta^{13}C$ (VPBD)	$\delta^{18}O$ (VPBD)	Temp °C
10Mc2d	12	0.8	0.3	14.7
10Mc2e	15	0.9	0.6	13.5
10Mc2f	18	0.1	0.5	14.1
12Mc2a	3	-0.4	0.9	12.6
12Mc2b	6	-0.7	1.1	11.5
12Mc2c	9	-0.4	1.3	10.7
12Mc2d	12	-0.1	1.6	9.4
12Mc2e	15	0	1.3	10.6
12Mc2f	18	0.2	1.3	10.7
14Mc2a	3	0.4	0.7	13.2
14Mc2b	6	0.8	1.3	10.9
14Mc2c	9	0.8	0.8	12.8
14Mc2d	12	0.4	0.6	13.5
14Mc2e	15	0.5	1.8	8.9
14Mc2f	18	0.3	1.1	11.7
16Mc2a	3	0.8	0.8	12.7
16Mc2b	6	1.1	0.4	14.2
16Mc2c	9	1	0.6	13.8
16Mc2d	12	0.5	1.2	11
16Mc2e	15	0.7	0.9	12.4
16Mc2f	18	1	0.6	13.6

Sample ID	Distance (mm)	$\delta^{13}C$ (VPBD)	$\delta^{18}O$ (VPBD)	Temp °C
17Mc2a	3	-0.1	0.8	12.7
17Mc2b	6	0	1.4	10.3
17Mc2c	9	0	1.3	10.8
17Mc2d	12	0.5	1.2	11.1
17Mc2e	15	1.2	1.8	8.6
17Mc2f	18	0.6	0.3	14.8

APPENDIX B

REPORTED ISOTOPIC VALUES AND INFERRED TEMPERATURES FOR CALIFORNIA MUSSEL SHELLS FROM CA-SRI-666

Sample ID	Distance (mm)	$\delta^{13}C$ (VPDB)	$\delta^{18}O$ (VPDB)	T °C
666-U1-1a	0	0.1	-0.5	18.3
666-U1-1b	2	-0.9	0.7	13.7
666-U1-1c	6	-0.4	-0.1	16.8
666-U1-1d	9	-0.7	0.7	13.6
666-U1-1e	12	-0.4	0.8	13.3
666-U1-1f	15	0.4	0	16.4
666-U1-3a	0	0.8	0.3	15.3
666-U1-3b	2	0.6	0.2	15.8
666-U1-3c	6	0.9	1.2	11.7
666-U1-3d	9	1.1	0.4	14.9
666-U1-3e	12	0.9	0	16.3
666-U1-3f	15	0.8	-0.2	17.3
666-U1-6a	0	1.1	-0.1	16.9
666-U1-6b	2	0.2	0.9	12.8
666-U1-6c	6	0.4	1	12.5
666-U1-6d	9	0.5	0.6	14.1
666-U1-6e	12	0.3	0.2	15.6
666-U1-6f	15	0.3	0	16.4
666-U1-8a	0	0.7	0.6	13.8
666-U1-8b	2	0.5	-0.3	17.6
666-U1-8c	6	0.3	-0.2	17.3

Sample ID	Distance (mm)	$\delta^{13}C$ (VPBD)	$\delta^{18}O$ (VPBD)	Temp °C
666-U1-8d	9	0	-0.1	16.9
666-U1-8e	12	-0.2	-0.1	16.8
666-U1-8f	15	-0.5	0.3	15.4
666-U1-9a	0	0	1.2	11.7
666-U1-9b	2	0	0.1	16
666-U1-9c	6	-1	-0.2	17.1
666-U1-9d	9	-1.1	0	16.3
666-U1-9e	12	-1	0.7	13.5
666-U1-9f	15	-1	0.7	13.6
666-U1-10a	0	0.7	0.8	13.1
666-U1-10b	2	0.5	0.5	14.5
666-U1-10c	6	0	0.2	15.7
666-U1-10d	9	0.2	0	16.3
666-U1-10e	12	0.1	0	16.5
666-U1-10f	15	-0.1	0	16.3
666-U1-11a	0	0.5	0.2	15.6
666-U1-11b	2	-0.1	1.3	11.2
666-U1-11c	6	0.5	0.7	13.8
666-U1-11d	9	0.8	1.1	12.1
666-U1-11e	12	0.6	0.5	14.3
666-U1-11f	15	0.8	0.8	13.1

Sample ID	Distance (mm)	$\delta^{13}C$ (VPBD)	$\delta^{18}O$ (VPBD)	Temp °C
666-U1-12a	0	0.8	0	16.4
666-U1-12b	2	0.5	0.4	14.8
666-U1-12c	6	0.6	0.6	14.2
666-U1-12d	9	0.8	1	12.4
666-U1-12e	12	0.2	0.4	14.8
666-U1-12f	15	0.6	1.1	12
666-U1-13a	0	0.5	0.1	16.1
666-U1-13b	2	0.5	-0.2	17.5
666-U1-13c	6	0.1	-0.5	18.6
666-U1-13d	9	-0.1	-0.1	16.7
666-U1-13e	12	-0.4	0.8	13.3
666-U1-13f	15	-0.3	1.1	11.9
666-U1-18a	0	1	0.3	15
666-U1-18b	2	1.1	-0.4	17.9
666-U1-18c	6	0.8	-0.5	18.4
666-U1-18d	9	0.3	-0.4	17.9
666-U1-18e	12	0.2	0.2	15.5
666-U1-18f	15	0.7	1.1	11.9
666-U1-20a	0	1	0.3	14.9
666-U1-20b	3	0.5	0.1	15.7
666-U1-20c	6	0.7	0.6	13.9

Sample ID	Distance (mm)	$\delta^{13}C$ (VPBD)	$\delta^{18}O$ (VPBD)	Temp °C
666-U1-20d	9	1	0.9	12.6
666-U1-20e	12	0.9	0.6	13.7
666-U1-20f	15	0.7	0.4	14.5
666-U1-20g	18	0.4	0.4	14.7
666-U1-20h	21	0.5	0.1	16
666-U1-20i	24	0.4	-0.1	16.9
666-U1-20j	27	0.3	0.1	16.1
666-U1-20k	30	-0.4	0.4	14.6
666-U3-21a	0	0.2	0.2	15.5
666-U3-21b	2	-0.7	-0.2	17.3
666-U3-21c	6	-0.5	1	12.2
666-U3-21d	9	-0.1	1.1	12.1
666-U3-21e	12	-0.2	0.1	16
666-U3-21f	15	0	0	16.3
666-U3-23a	0	1	0.5	14.4
666-U3-23b	2	0.5	-0.1	16.8
666-U3-23c	6	-0.4	0.4	14.8
666-U3-23d	9	-0.6	0.6	14.1
666-U3-23e	12	0.5	1	12.4
666-U3-23f	15	0.6	0.5	14.5
666-U3-24a	0	1.2	0.7	13.5

Sample ID	Distance (mm)	$\delta^{13}C$ (VPBD)	$\delta^{18}O$ (VPBD)	Temp °C
666-U3-24b	2	1.6	0.5	14.4
666-U3-24c	6	0.2	-0.3	17.5
666-U3-24d	9	-0.5	0.6	14
666-U3-24e	12	0.5	0.5	14.3
666-U3-24f	15	0.6	0.8	13.1
666-U3-25a	0	1	0.3	15.2
666-U3-25b	2	0.8	-0.1	16.9
666-U3-25c	6	0.4	0.5	14.5
666-U3-25d	9	0.4	0.9	12.6
666-U3-25e	12	0.7	0.6	13.8
666-U3-25f	15	0.8	0.4	14.9
666-U3-27a	0	0.7	0.1	15.9
666-U3-27b	2	0.3	1.3	11.3
666-U3-27c	6	0.5	-0.1	16.7
666-U3-27d	9	0	1	12.5
666-U3-27e	12	1	-0.4	17.9
666-U3-27f	15	0.2	0.1	15.8
666-U3-29a	0	2	0.6	14
666-U3-29b	2	0.9	0	16.3
666-U3-29c	6	0.4	-0.2	17.3
666-U3-29d	9	0.1	0.2	15.6

Sample ID	Distance (mm)	$\delta^{13}C$ (VPBD)	$\delta^{18}O$ (VPBD)	Temp °C
666-U3-29e	12	-0.1	0.4	15
666-U3-29f	15	0.1	0.9	12.9
666-U3-30a	0	1.3	0	16.5
666-U3-30b	2	0.8	1.6	10
666-U3-30c	6	0.6	0.7	13.7
666-U3-30d	9	0.1	0.2	15.7
666-U3-30e	12	0	0.1	16
666-U3-30f	15	-0.4	1.1	11.8
666-U3-31a	0	2	0.5	14.4
666-U3-31b	2	0.7	0.5	14.3
666-U3-31c	6	0.9	0.9	13
666-U3-31d	9	1.1	0.9	12.8
666-U3-31e	12	1	0.3	15.2
666-U3-31f	15	0.7	0	16.3
666-U3-36a	0	1	0.5	14.3
666-U3-36b	2	1	-0.2	17.1
666-U3-36c	6	-0.1	1.1	11.9
666-U3-36d	9	0.4	1	12.3
666-U3-36e	12	0.4	0.8	13.1
666-U3-36f	15	0.6	0.6	13.9
666-U3-39a	0	0.2	0	16.5

Sample ID	Distance (mm)	$\delta^{13}C$ (VPBD)	$\delta^{18}O$ (VPBD)	Temp °C
666-U3-39b	2	0.5	1.4	10.8
666-U3-39c	6	0.4	1	12.2
666-U3-39d	9	-0.1	0.3	15.1
666-U3-39e	12	0.1	1.2	11.5
666-U3-39f	15	0.6	1.2	11.7

APPENDIX C

REPORTED $\delta^{13}C$, $\delta^{18}O$, AND INFERRED TEMPERATURE VALUES INCLUDING SHELL LENGTH FOR ISOTOPIC DETERMINATIONS FROM CALIFORNIA MUSSEL SHELLS FROM CA-SMI-261, 522, 604, AND 507

Sample ID	Distance (mm)	$\delta^{13}C$ (VPDB)	$\delta^{18}O$ (VPDB)	T °Cs	Shell length (mm)
604-21a	0	0.9	0.3	13.1	70
604-21b	3	0.3	1	15	
604-21c	6	0.3	0.9	12.6	
604-21d	9	0.2	0.4	12.9	
604-21e	12	0.5	1	14	
604-21f	15	0.8	0.9	14.1	
604-21g	18	0.4	0.6	13.2	
604-21h	21	-0.4	0.6	11.7	
604-21i	24	-0.7	0.8	11.1	
604-21j	27	-0.4	1.2	11.7	
604-21k	30	0	1.3	13.3	
604-21l	33	0.4	1.2	11.9	
522-21a	0	0	1	12.6	65
522-21b	3	0.3	0.3	15.4	
522-21c	6	0.2	0.9	12.9	
522-21d	9	-0.5	1.4	10.9	
522-21e	12	-0.8	1.4	11	
522-21h	21	-1.1	1.5	10.3	
522-21i	24	-0.6	1.4	10.8	
522-21j	27	-0.2	1.5	10.4	
522-21k	30	-0.2	1.6	10	

Sample ID	Distance (mm)	$\delta^{13}C$ (VPDB)	$\delta^{18}O$ (VPDB)	T °Cs	Shell length (mm)
522-21l	33	-0.2	1.6	10.2	
522-21m	36	0.2	0.7	13.7	
522-21n	39	0.2	0.6	14.1	
522-21o	42	-0.2	0.6	14.1	
522-21p	45	0.1	0.7	13.9	
261-21a	3	0.8	0.9	12.8	71
261-21b	6	0.3	-0.1	16.9	
261-21c	9	1	0	16.5	
261-21d	12	-0.3	0.6	13.9	
261-21e	15	-0.5	1	12.3	
261-21f	18	-0.6	1	12.5	
261-21g	21	-1	1	12.5	
261-21h	24	-0.7	0.8	13.2	
261-21i	27	-0.5	0.8	13.2	
261-21j	30	-0.8	1.6	10	
507-21a	0	-0.6	0.7	13.7	74
507-21b	3	-0.3	1.3	11.4	
507-21c	6	0.5	0.8	13.5	
507-21d	9	0.6	0.3	15.6	
507-21e	12	0.5	0.6	14.4	
507-21f	15	0.2	1.1	12.4	

Sample ID	Distance (mm)	$\delta^{13}C$ (VPDB)	$\delta^{18}O$ (VPDB)	T °Cs	Shell length (mm)
507-21g	18	0.3	1.3	11.6	
507-21h	21	0.1	1.3	11.7	
507-21i	24	0.3	1.2	11.7	
507-21j	27	0.3	1.4	11.2	
507-21k	30	0.6	1.1	12.4	
507-21l	33	0.8	1	12.8	
507-21m	36	0.8	0.7	14	
522-1a	0	1.2	0.8	14.1	63
522-1b	3	0.7	1.3	12.3	
522-1c	6	0.8	0.8	14.4	
522-1d	9	0.5	0.6	15.2	
522-1e	12	0	0.8	14.1	
522-2a	0	0.4	1.4	11.7	61
522-2b	3	0	0.3	16.1	
522-2c	6	-0.3	0.9	14	
522-2d	9	-0.4	1.2	12.8	
522-2e	12	-0.6	1.4	11.9	
522-3a	0	0.9	1.3	12.2	73
522-3b	3	0.4	0.7	14.8	
522-3c	6	0.2	1.1	12.9	
522-3d	9	0.2	1.6	11.1	

Sample ID	Distance (mm)	$\delta^{13}C$ (VPDB)	$\delta^{18}O$ (VPDB)	T °Cs	Shell length (mm)
522-3e	12	0.4	1.3	12.2	
522-4a	0	1	1.3	12.4	61
522-4b	3	0.8	0.9	13.8	
522-4c	6	0.5	1.6	11.1	
522-4d	9	0.8	1.5	11.6	
522-4e	12	0.9	1.3	12.3	
522-5a	0	0.2	1.2	12.5	71
522-5b	3	-0.2	1.4	12	
522-5c	6	-0.3	1.8	10.3	
522-5d	9	0.1	1.4	12	
522-5e	12	0.2	0.8	14.4	
522-6a	0	0.4	1.2	12.8	67
522-6b	3	0.3	1.1	13.2	
522-6c	6	0.3	1.5	11.4	
522-6d	9	0.1	1.5	11.7	
522-6e	12	0.4	1.5	11.5	
522-7a	0	-0.8	0.5	15.6	68
522-7b	3	1	1.3	12.4	
522-7c	6	1.8	2.3	8.3	
522-7d	9	0.3	1.6	11.2	
522-7e	12	1	0.5	15.4	

Sample ID	Distance (mm)	$\delta^{13}C$ (VPDB)	$\delta^{18}O$ (VPDB)	T °Cs	Shell length (mm)
522-8a	0	1.4	1.1	13.1	69
522-8b	3	0.4	1.5	11.4	
522-8c	6	1.3	1.1	13.2	
522-8d	9	0.7	1.1	13.1	
522-8e	12	1	1.1	13.2	
522-9a	0	0.9	1.2	12.8	78
522-9b	3	0.9	1.7	10.8	
522-9c	6	-0.1	1.3	12.4	
522-9d	9	-0.8	0.8	14.2	
522-9e	12	-1.5	0.7	14.8	
522-10a	0	0.1	0.1	17	73
522-10b	3	0.2	0.9	14	
522-10c	6	1	1.4	12	
522-10d	9	1.4	1.7	10.7	
522-10e	12	1.1	0.4	16	
522-11a	0	0.8	1	13.3	67
522-11b	3	1.4	1	13.4	
522-11c	6	-1.1	-0.1	18.1	
522-11d	9	0.1	0.7	14.5	
522-11e	12	0.8	1.2	12.8	
522-12a	0	0.1	0.5	15.4	74

Sample ID	Distance (mm)	$\delta^{13}C$ (VPDB)	$\delta^{18}O$ (VPDB)	T °Cs	Shell length (mm)
522-12b	3	0.9	0.6	15	
522-12c	6	-0.6	0.2	16.6	
522-12d	9	0.6	1.1	12.8	
522-12e	12	1.1	1.1	13.2	
522-13a	0	-0.5	0.6	15.2	69
522-13b	3	-0.9	-0.4	19.1	
522-13c	6	0.2	0.8	14.3	
522-13d	9	0.9	1.2	12.5	
522-13e	12	0.6	1.3	12.4	
522-14a	0	0.7	0.8	14.2	73
522-14b	3	0.4	0.8	14.4	
522-14c	6	0.3	0.5	15.6	
522-14d	9	-0.3	0.7	14.5	
522-14e	12	-0.3	1	13.6	
522-15a	0	0.6	0.7	14.5	79
522-15b	3	0.9	0.3	16.4	
522-15c	6	0.9	0.8	14.4	
522-15d	9	0.6	0.9	14	
522-15e	12	0.7	1.3	12.1	
522-16a	0	0.1	1.4	11.9	62
522-16b	3	0.2	0.8	14.2	

Sample ID	Distance (mm)	$\delta^{13}C$ (VPDB)	$\delta^{18}O$ (VPDB)	T °Cs	Shell length (mm)
522-16c	6	-0.3	1.2	12.7	
522-16d	9	0.4	1.1	13.1	
522-16e	12	1.1	0.3	16.1	
522-17a	0	-0.1	0.7	14.7	74
522-17b	3	-0.6	1.1	12.9	
522-17c	6	-0.2	1	13.6	
522-17d	9	-0.1	1.2	12.7	
522-17e	12	-0.5	1.1	13.1	
522-18a	0	-0.3	1.1	13.1	61
522-18b	3	-0.3	0.6	14.9	
522-18c	6	0.1	0.6	15	
522-18d	9	-1	0.6	15.1	
522-18e	12	-0.7	0.8	14.1	
522-19a	0	0.1	0.6	15	66
522-19b	3	0.3	0.8	14.3	
522-19c	6	-0.5	1	13.3	
522-19d	9	-0.1	1.2	12.5	
522-19e	12	-0.1	1.1	12.9	
522-20a	0	0.5	0.8	14.2	63
522-20b	3	0.5	0.1	17	
522-20c	6	0.4	0.3	16.3	

Sample ID	Distance (mm)	$\delta^{13}C$ (VPDB)	$\delta^{18}O$ (VPDB)	T °Cs	Shell length (mm)
522-20d	9	0.1	0.2	16.7	
522-20e	12	-0.2	0.5	15.5	
604-1a	0	0.4	1	13	59
604-1b	3	0.9	0.6	14.4	
604-1c	6	0.2	0.6	14.4	
604-1d	9	0	0.9	13.2	
604-1e	12	0.6	1.1	12.3	
604-2a	0	0.5	1.8	9.8	61
604-2b	3	0.9	0.8	13.8	
604-2c	6	0.8	0.5	14.8	
604-2d	9	0.1	1	13	
604-2e	12	0.5	1.4	11.4	
604-3a	0	0.3	1.5	11	57
604-3b	3	0.1	1.2	12.1	
604-3c	6	0.4	1.4	11.3	
604-3d	9	0.3	0.2	16.2	
604-3e	12	0	0.1	16.6	
604-4a	0	0.5	0.9	13.1	55
604-4b	3	0.9	0.4	15.1	
604-4c	6	0.5	0.4	15.3	
604-4d	9	0.1	0.5	14.8	

Sample ID	Distance (mm)	$\delta^{13}C$ (VPDB)	$\delta^{18}O$ (VPDB)	T °Cs	Shell length (mm)
604-4e	12	0	0.6	14.5	
604-5a	0	0.4	1.7	9.9	66
604-5b	3	0.6	0.7	13.9	
604-5c	6	0.5	0.8	13.6	
604-5d	9	0	1.5	10.8	
604-5e	12	-0.4	1.1	12.6	
604-6a	0	0.3	0.7	14.1	61
604-6b	3	0	0.8	13.5	
604-6c	6	0	0.7	14	
604-6d	9	-0.5	1	12.8	
604-6e	12	0.2	0.6	14.6	
604-7a	0	0.1	1.6	10.4	65
604-7b	3	-0.2	0.8	13.5	
604-7c	6	-0.1	1.1	12.4	
604-7d	9	0.2	1.5	10.8	
604-7e	12	0.2	1.2	12.2	
604-8a	0	1.3	0.4	15.3	58
604-8b	3	1.1	0.4	15.3	
604-8c	6	0.8	0.1	16.4	
604-8d	9	0	0.2	16.1	
604-8e	12	0	0.5	14.7	

Sample ID	Distance (mm)	$\delta^{13}C$ (VPDB)	$\delta^{18}O$ (VPDB)	T °Cs	Shell length (mm)
604-9a	0	1	0.7	14.1	70
604-9b	3	0.7	1.1	12.4	
604-9c	6	0.8	0.4	15.2	
604-9d	9	0.6	-0.1	17.3	
604-9e	12	-1	1	13	
604-10a	0	1	0.5	14.8	85
604-10b	3	0.5	0.9	13.3	
604-10c	6	0.7	0.8	13.7	
604-10d	9	0.6	0.7	14	
604-10e	12	0.6	0.4	15.4	
604-11a	0	0	1.3	11.7	75
604-11b	3	-0.5	1	12.9	
604-11c	6	-0.4	1.1	12.4	
604-11d	9	-0.4	1.1	12.5	
604-11e	12	0	1.1	12.3	
604-12a	0	0.8	0.7	14.2	58
604-12b	3	1	0.1	16.5	
604-12c	6	0.4	0.5	15	
604-12d	9	-0.5	1	12.8	
604-12e	12	1.2	0.2	16.3	
604-13a	0	1.5	0.7	13.9	80

Sample ID	Distance (mm)	$\delta^{13}C$ (VPDB)	$\delta^{18}O$ (VPDB)	T °Cs	Shell length (mm)
604-13b	3	1.6	-0.2	17.7	
604-13c	6	1.2	0	17	
604-13d	9	0.8	0.6	14.5	
604-13e	12	0.2	0.7	14	
604-14a	0	1	0.7	14.2	80
604-14b	3	1.5	-0.2	17.8	
604-14c	6	1.1	0	17	
604-14d	9	0.7	0.4	15.1	
604-14e	12	1	0.4	15.4	
604-15a	0	0.4	0.4	15.4	77
604-15b	3	0.1	0.3	15.7	
604-15c	6	-0.5	0.6	14.6	
604-15d	9	0.1	1.4	11.3	
604-15e	12	0.2	0.9	13	
604-16a	0	1.1	0.6	14.5	79
604-16b	3	1	0.3	15.6	
604-16c	6	0.5	0.1	16.7	
604-16d	9	0.4	0	16.9	
604-16e	12	0.4	0.2	16.3	
604-17a	0	0.3	1.2	12.2	75
604-17b	3	0.5	1.2	12.2	

Sample ID	Distance (mm)	$\delta^{13}C$ (VPDB)	$\delta^{18}O$ (VPDB)	T °Cs	Shell length (mm)
604-17c	6	0.3	1.4	11.3	
604-17d	9	0.1	0.7	14	
604-17e	12	-0.1	1	12.9	
604-18a	0	0.3	0.5	14.8	79
604-18b	3	0.4	0.5	14.8	
604-18c	6	0.1	1	13	
604-18d	9	0.6	0.8	13.7	
604-18e	12	1	0	16.9	
604-19a	0	0.6	0.6	14.4	63
604-19b	3	0.6	0.4	15.2	
604-19c	6	0.8	0.2	16.2	
604-19d	9	0.7	-0.2	17.7	
604-19e	12	0.6	0	17.1	
604-20a	0	1.1	0.3	15.8	73
604-20b	3	0.6	0.3	15.6	
604-20c	6	0.1	1.1	12.4	
604-20d	9	0.5	0.6	14.3	
604-20e	12	0.7	0.7	13.9	
261-1a	0	0.3	0.2	15.6	60
261-1b	3	0.3	0.2	15.6	
261-1c	6	-0.3	0.3	15.3	

Sample ID	Distance (mm)	$\delta^{13}C$ (VPDB)	$\delta^{18}O$ (VPDB)	T °Cs	Shell length (mm)
261-1d	9	-0.5	0.3	15.4	
261-1e	12	-0.2	0	16.3	
261-2a	0	1.2	0.1	15.9	70
261-2b	3	0.7	0.7	13.5	
261-2c	6	1.1	0.9	12.8	
261-2d	9	0.9	0.5	14.3	
261-2e	12	0.6	0.8	13.3	
261-3a	0	1	0.8	13.3	55
261-3b	3	0.7	0.9	12.9	
261-3c	6	0.7	-0.1	16.7	
261-3d	9	0.9	-0.4	18.1	
261-3e	12	0.5	-0.3	17.8	
261-4a	0	-0.5	0.7	13.4	67
261-4b	3	0.2	0.3	15.2	
261-4c	6	0.3	-0.3	17.8	
261-4d	9	-0.1	0	16.3	
261-4e	12	-0.7	0.4	14.7	
261-5a	0	-0.1	1	12.4	68
261-5b	3	-0.3	0.6	14	
261-5c	6	0.6	0.8	13.1	
261-5d	9	1.2	-0.1	16.7	

Sample ID	Distance (mm)	$\delta^{13}C$ (VPDB)	$\delta^{18}O$ (VPDB)	T °Cs	Shell length (mm)
261-5e	12	-0.2	0.1	16.3	
261-6a	0	0	0	16.6	66
261-6b	3	0.4	0.7	13.4	
261-6c	6	0.6	1	12.4	
261-6d	9	0.3	0.8	13.2	
261-6e	12	0.4	0.5	14.4	
261-7a	0	0.3	1	12.4	67
261-7b	3	0.7	0.8	13.3	
261-7c	6	1.3	0	16.6	
261-7d	9	1	0.1	15.9	
261-7e	12	0.4	0.6	13.9	
261-8a	0	0.2	0.8	13.1	70
261-8b	3	0.5	0	16.4	
261-8c	6	0.5	0.5	14.5	
261-8d	9	-0.2	0.9	12.8	
261-8e	12	0.5	1.2	11.7	
261-9a	0	0.6	0.6	14.2	80
261-9b	3	0.5	-0.3	17.5	
261-9c	6	0.4	-0.1	16.8	
261-9d	9	0.2	0.4	14.9	
261-9e	12	1	1.4	10.9	

Sample ID	Distance (mm)	$\delta^{13}C$ (VPDB)	$\delta^{18}O$ (VPDB)	T °Cs	Shell length (mm)
261-10a	0	0.7	1.2	11.8	40
261-10b	3	0.7	1	12.3	
261-10c	6	1.1	0.5	14.3	
261-10d	9	1.4	-0.5	18.5	
261-10e	12	0.8	0	16.7	
261-11a	0	1.2	0.9	12.6	53
261-11b	3	0.5	0.5	14.5	
261-11c	6	1	1.1	12.2	
261-11d	9	1.2	0.7	13.5	
261-11e	12	0.5	0	16.5	
261-12a	0	0.4	0.7	13.5	60
261-12b	3	0.7	0.6	14.1	
261-12c	6	-0.8	0.4	14.8	
261-12d	9	-0.9	0.8	13.3	
261-12e	12	-0.2	1.3	11.2	
261-13a	0	-0.2	0.5	14.6	50
261-13b	3	0.1	0.5	14.6	
261-13c	6	0.3	1.2	11.7	
261-13d	9	0.4	1.3	11.3	
261-13e	12	0.1	0.8	13.2	
261-14a	0	0.9	0.2	15.6	60

Sample ID	Distance (mm)	$\delta^{13}C$ (VPDB)	$\delta^{18}O$ (VPDB)	T °Cs	Shell length (mm)
261-14b	3	0.9	0	16.3	
261-14c	6	0.7	0.4	14.8	
261-14d	9	0.3	1.1	12	
261-14e	12	0.4	1.4	11	
261-15a	0	0.9	0.2	15.9	65
261-15b	3	0.8	0.5	14.6	
261-15c	6	0.9	1.2	11.8	
261-15d	9	1.3	1.3	11.3	
261-15e	12	1.3	0.9	12.9	
261-16a	0	0.4	0.6	13.9	50
261-16b	3	0.3	0.8	13.2	
261-16c	6	0.5	1.1	11.9	
261-16d	9	0.6	1.3	11.1	
261-16e	12	0.6	1.3	11.3	
261-17a	0	1.4	0.9	13	55
261-17b	3	1.1	0.4	14.8	
261-17c	6	1.3	0.1	16	
261-17d	9	1.1	0.1	15.9	
261-17e	12	0.8	0.4	14.9	
261-18a	0	0.6	0.9	12.7	65
261-18b	3	0.4	0.8	13.1	

Sample ID	Distance (mm)	$\delta^{13}C$ (VPDB)	$\delta^{18}O$ (VPDB)	T °Cs	Shell length (mm)
261-18c	6	0.9	0.5	14.3	
261-18d	9	0.5	0.5	14.5	
261-18e	12	0.1	0.8	13.2	
261-19a	0	0.4	0.8	13.3	70
261-19b	3	-0.3	1	12.2	
261-19c	6	-0.1	1.2	11.8	
261-19d	9	0.4	0.9	12.8	
261-19e	12	0.2	1.2	11.6	
261-20a	0	0.5	0.6	14	64
261-20b	3	0.5	0.5	14.3	
261-20c	6	0.7	0.7	13.6	
261-20d	9	0.3	1.1	12	
261-20e	12	0.3	1.4	10.9	
507-1a	0	1.2	0.8	13.3	73
507-1b	3	0.7	1.3	11.5	
507-1c	6	0.8	0.8	13.6	
507-1d	9	0.5	0.6	14.4	
507-1e	12	0	0.8	13.3	
507-2a	0	0.6	0.9	13.2	70
507-2b	3	0.3	0.4	15.1	
507-2c	6	0.1	1.5	10.6	

Sample ID	Distance (mm)	$\delta^{13}C$ (VPDB)	$\delta^{18}O$ (VPDB)	T °Cs	Shell length (mm)
507-2d	9	0.1	1.2	11.9	
507-2e	12	0.5	1.1	12.1	
507-3a	0	0.9	1.3	11.4	72
507-3b	3	0.4	0.7	13.9	
507-3c	6	0.3	1.3	11.4	
507-3d	9	0.2	0.8	13.3	
507-3e	12	-0.1	0.3	15.3	
507-4a	0	-0.3	0.9	12.9	63
507-4b	3	0.1	1.3	11.3	
507-4c	6	-0.1	1.3	11.7	
507-4d	9	0.1	1.2	12	
507-4e	12	0.3	1.1	12.4	
507-5a	0	0.6	1.2	11.8	79
507-5b	3	0.5	1.2	11.7	
507-5c	6	0.4	0.5	14.7	
507-5d	9	0.3	1.4	11.1	
507-5e	12	0.7	1.2	12	
507-6a	0	-0.1	1	12.6	71
507-6b	3	0.3	1.1	12.4	
507-6c	6	0.3	0.7	14	
507-6d	9	-0.2	0.6	14.4	

Sample ID	Distance (mm)	$\delta^{13}C$ (VPDB)	$\delta^{18}O$ (VPDB)	T °Cs	Shell length (mm)
507-6e	12	-0.5	1.3	11.4	
507-7a	0	0.4	1.2	11.9	65
507-7b	3	0.3	0.6	14.3	
507-7c	6	0.5	1.1	12.1	
507-7d	9	0.3	0.8	13.5	
507-7e	12	0.2	0.4	15.1	
507-8a	0	0.4	0.6	14.2	70
507-8b	3	0	1.4	11.2	
507-8c	6	0.3	1.3	11.3	
507-8d	9	0.1	0.8	13.4	
507-8e	12	0.1	1.3	11.4	
507-9a	0	0.2	1.1	12.3	59
507-9b	3	0.3	0.4	15.2	
507-9c	6	-0.4	0.3	15.5	
507-9d	9	-0.4	0.9	12.9	
507-9e	12	-0.1	1.7	10	
507-10a	0	1.1	1	12.6	61
507-10b	3	0.5	0.5	14.6	
507-10c	6	0.6	0.3	15.4	
507-10d	9	0.3	0.4	15.2	
507-10e	12	0.4	1.3	11.6	

Sample ID	Distance (mm)	$\delta^{13}C$ (VPDB)	$\delta^{18}O$ (VPDB)	T °Cs	Shell length (mm)
507-11a	0	0.7	0.9	12.9	68
507-11b	3	0.8	0.5	14.6	
507-11c	6	1	0.6	14.3	
507-11d	9	0.5	0.2	15.7	
507-11e	12	0.3	1.1	12.2	
507-12a	0	1	0.6	14.3	75
507-12b	3	0.8	0.8	13.3	
507-12c	6	1.1	0	16.7	
507-12d	9	0.8	0.9	13.1	
507-12e	12	1.1	1.4	11	
507-13a	0	0.3	0.7	13.9	72
507-13b	3	0	1.7	9.9	
507-13c	6	0.2	1.5	10.6	
507-13d	9	0.5	1.6	10.2	
507-13e	12	0.4	0.6	14.3	
507-14a	0	0.2	0.8	13.6	63
507-14b	3	0.3	0.7	13.9	
507-14c	6	0.4	0.4	15.2	
507-14d	9	-0.2	1.1	12.4	
507-14e	12	0.2	1.3	11.4	
507-15a	0	0.5	1	12.5	75

Sample ID	**Distance (mm)**	**δ^{13}C (VPDB)**	**δ^{18}O (VPDB)**	**T °Cs**	**Shell length (mm)**
507-15b	3	0.4	1.3	11.6	
507-15c	6	0.1	1.4	11.1	
507-15d	9	0.6	1.4	11.1	
507-15e	12	0.8	0.9	13	
507-16a	0	0.7	1	12.6	71
507-16b	3	0	1.5	10.7	
507-16c	6	0.2	1.3	11.5	
507-16d	9	0.7	1.4	11.1	
507-16e	12	0.7	1.1	12.3	
507-17a	0	-0.4	0.9	13	69
507-17b	3	-0.2	1.4	11.1	
507-17c	6	-0.3	1.2	11.9	
507-17d	9	-0.1	1.2	11.9	
507-17e	12	0.3	1.2	11.9	
507-18a	0	0.2	0.8	13.4	70
507-18b	3	-0.4	1.2	11.9	
507-18c	6	-0.4	1.3	11.5	
507-18d	9	0	1.1	12.3	
507-18e	12	0.3	1.2	11.9	
507-19a	0	1.8	1.1	12.3	73
507-19b	3	1	1.1	12.3	

Sample ID	Distance (mm)	$\delta^{13}C$ (VPDB)	$\delta^{18}O$ (VPDB)	T °Cs	Shell length (mm)
507-19c	6	1	1.3	11.5	
507-19d	9	1.1	1.5	10.7	
507-19e	12	1.1	0.6	14.3	
507-20a	0	-0.1	1.4	11.1	71
507-20b	3	0	1.1	12.3	
507-20c	6	0.1	1.2	11.9	
507-20d	9	0.9	0.6	14.3	
507-20e	12	0.4	1.2	11.9	

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