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Past Small-Scale Ecological and Oceanographic Variability around Santa Cruz Island, California. Implications for Human Foraging on *M. californianus* Beds during the Late Holocene (2200-500 cal B.P.)

A dissertation submitted in partial satisfaction of the
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in Anthropology

by

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ABSTRACT

Past Small-Scale Ecological and Oceanographic Variability around Santa Cruz Island, California. Implications for Human Foraging on *M. californianus* Beds during the Late Holocene (2200-500 cal B.P.)

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Archaeologists working on the northern Channel Islands of California have proposed that during the Late Holocene, foraging decisions of the islands' prehistoric occupants were progressively less affected by environmental changes as increasing human exploitation pressure shaped abundance and size of intertidal shellfish species. This proposal, although supported by archaeological data from habitation sites, does not incorporate past small-scale ecological and oceanographic variability around the islands nor the effect of this variability on *Mytilus californianus* (California mussel), the main intertidal shellfish species exploited through prehistory. Consequently, the lessening influence of environmental conditions on shellfish harvesting during the Late Holocene has not been definitively demonstrated. This study evaluates this proposal through the study of archeological, ecological and stable isotopic data from two shell midden sites, SCRI-195 and SCRI-496, on the coast of Santa Cruz Island, both occupied during the Late Holocene (2200-500 cal B.P.). The correlation between changes in abundance and size of *M. californianus* and past sea surface temperature (SST) through the chronological sequences at each archaeological site was statistically evaluated, regional and local SST records spanning the Late Holocene were compared, and modern data concerning ecological and oceanographic factors affecting *M. californianus* productivity around Santa Cruz Island were used to interpret past natural conditions of this shellfish species. The results of this study show that fluctuation in regional and local past SST does not explain variation in abundance or length of collected *M. californianus* through the occupation of SCRI-195 and SCRI-496. Instead, the factors determining this variation are the intensity of human occupation at the archaeological sites, together with past productivity of *M. californianus* beds near the human settlements. Differing intensities of human occupation at SCRI-195 and SCRI-496 defined harvesting pressure on *M. californianus* beds, and the frequency and intensity of upwelling conditions (cooler SST) influenced past productivity of *M. californianus* during the Late Holocene at each site location. This study reached the conclusion that the factors of site occupation dynamics and upwelling occurrence together influenced human foraging on *M. californianus* during the Late Holocene around Santa Cruz Island and explain variation in archaeological shellfish assemblages.

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Chapter 1. Introduction

A rich archaeological record and biological diversity makes Santa Cruz Island an ideal setting to answer research questions about interactions between human adaptation and coastal environment in prehistory and marine resource use through time. Santa Cruz island has experienced decades of study of prehistoric human occupation and intertidal shellfish communities. Hundreds of archaeological sites cover the island's coastline, primarily identified by dense shell midden deposits, that date from the Terminal Pleistocene to Historic times (Glassow 2010) and high-resolution ecological datasets have been compiled over more than 10 years from intertidal study sites. These datasets include nearshore oceanographic conditions and intertidal ecological characteristics (SWAT http://cbsurveys.ucsc.edu/index.html).

Santa Cruz Island is 38 km long and 16 km wide, the largest of the four northern Channel Islands and the one with the greatest marine and terrestrial biological diversity (Figure 2). Productive nearshore littoral habitats influenced by the cold California Current and seasonal upwelling enhance the diversity of natural resources available around the island (Hickey 1992; Hickey, et al. 2003). These resources, although distributed around the whole perimeter of the island, exhibit small-scale ecological and oceanographic variability (e.g., Blanchette, et al. 2006; 2009; Broitman, et al. 2005), which may have had important implications for human foraging on *Mytilus californianus* beds during the Late Holocene (2200-500 cal B.P.) around Santa Cruz Island.

The Late Holocene (3000-200 B.P.) on the northern Channel Islands is a period of important cultural development, technological innovation, intensification of fishing, increased territoriality, craft specialization, expansion of trade networks, and higher sociopolitical complexity (Arnold 2001b; Kennett 2005; Munns and Arnold 2002). The archaeological record during this time around Santa Cruz Island provides evidence of population growth, with larger numbers of archaeological sites and the establishment of primary villages on the island's coast (e.g., Arnold 2001b; Erlandson and Jones 2002; Kennett 2005). This period is also described as an epoch of environmental instability, with episodes of extremely dry conditions (Kennett and Kennett 2000). Within this environmental context, a decrease in residential mobility and an overall reduction in foraging range has been identified, which put more pressure on the exploitation of particular resources as people filled the coastal landscape and competed for nearshore resources (see Glassow 1993; Kennett 2005).

Molluscan resources are densely distributed around the island and are temporally and spatially predictable. Due to the highest potential net gain, intertidal habitats around Santa Cruz Island, especially because of the abundance of *M. californianus*, were highly attractive. Despite the increasing reliance on fishing through the Late Holocene, mussels were still intensively collected (Braje, et al. 2011), and the decreasing shell size and the increasing importance of other lower ranked species over time have been interpreted as evidence of the effect of human harvesting on mussel beds (Braje, et al. 2007a; Braje, et al. 2012; Erlandson, et al. 2008).

How much of the observed variation in archaeological shellfish assemblages and by inference in shellfish harvesting decisions are due to environmental factors rather than human predation? Various research projects on the northern Channel Islands have addressed this topic directly or indirectly (Arnold 2001b; Braje, et al. 2012; Glassow, et al. 2012; Kennett and Kennett 2000; Kennett, et al. 2007). It has been proposed that during the Late Holocene, shellfish harvesting decisions were progressively less affected by environmental changes (sea surface temperature fluctuations) as the human-driven decrease in size and abundance of high-ranked species (mainly *M. californianus*) was compensated by exploiting a wider range of shellfish species and increasing fishing activities (Braje, et al. 2012). This proposal, supported by a regional approach to the relationship though time between changes in archaeological shellfish assemblages and past sea surface temperature (SST), is an important contribution to the understanding of general patterns of human-environment interactions along the California coast and beyond, and it lays the foundation for the development of more detailed hypotheses. Nonetheless, the complexity of environmental dynamics and their effect on *M. californianus*, the main intertidal shellfish species exploited through prehistory along the coast of California, have not yet been addressed. The main weaknesses are: 1) the use of regional past SST records as the only proxy for interpreting marine productivity, 2) the omission of small-scale oceanographic variability for understanding the structure of archaeological shellfish assemblages, 3) the absence of statistical tests of significance to evaluate correlations between environmental and archaeological shellfish assemblage variation, and 4) a failure to take advantage of published data on small-scale interactions between oceanographic patterns and intertidal community structure.

The proposal of lessening influence of environmental conditions on shellfish harvesting around the northern Channel Islands during the Late Holocene is based on a rich body of archaeological data but has never been evaluated using small-scale oceanographic and ecological data to assess past intertidal habitat productivity and to evaluate human impact on these habitats. The study presented here evaluates this proposal, based on archeological, ecological and stable isotopic data from two shell midden sites on the coast of Santa Cruz Island dated to the Middle and Late Periods (2200-500 cal B.P.) (Arnold 1992; Kennett 2005:83; King 1990). Not much information is available concerning the ecological articulation between humans and shellfish communities and this study reveals the dynamic aspect and complexity of this articulation.

This study is meant to stimulate researchers around the world to construct more explicit models of how hunter-gatherer populations adapted to the complexities of the habitats in which they lived. Even though the research presented here is limited in geographic scope to Santa Cruz Island, the topic of long-term dynamics between humans and past marine ecosystems is of broad interest (Ono, et al. 2013; Rick and Erlandson 2008), and methodological approaches developed by Braje and colleagues (e.g. Braje, et al. 2012; Erlandson, et al. 2008; Glassow, et al. 1994; Glassow, et al. 2012; Kennett, et al. 2007; Rick, et al. 2006) have demonstrated to be a guide for studies around California and beyond (e.g. Baisre 2010; Faulkner 2009; Gutiérrez-Zugasti 2011). By evaluating Braje et al. (2012) arguments and methodology, the research presented here demonstrates the importance of small-scale variability in past nearshore oceanography and ecology for understanding the archaeological evidence of prehistoric human foraging on important intertidal shellfish species.

Chapter 2. Research Background

The following paragraphs describe the aspects that structure the present study. First to be considered are the theoretical frameworks of Optimal Foraging models, including Ideal Free Distribution, Prey Choice and Patch Choice, which have been applied around the world to understand past resource use through space and time (e.g. Bettinger 1991:83; Kaplan and Hill 1992; Kelly 1995:65), and also to define and describe the sequence of circumstances under which human impact would be expected on particular coastal resources such as intertidal shellfish species around the northern Channel Islands (e.g., Braje, et al. 2007a; Kennett 2005; Raab 1992; Winterhalder, et al. 2010). Of particular significance are expectations derived from Optimal Foraging models regarding human resource exploitation and habitat suitability. Second, in order to evaluate the influence of human harvesting and environmental fluctuations on past shellfish communities and subsequently on observed changes in archaeological shellfish assemblages, it is important to define the multiple lines of evidence of the effect of human harvesting and of small-scale ecological and oceanographic variability on modern and past intertidal shellfish species. Given that stable isotope analysis is used to reconstruct past sea surface temperature (SST), the methods of this analysis are discussed together with the link between SST and intertidal community dynamics. The final topic to be discussed is the nature of current archeological approaches to determine how much of the observed variation in archaeological shellfish assemblages are due to environmental factors rather than human predation around the northern Channel Islands during the Late Holocene.

Optimal Foraging Models

Within optimal foraging models, people’s decisions about diet (diet breadth), foraging time (patch choice), settlement and foraging locations are expected to maximize energy intake considering natural resource distribution and abundance (Bettinger 1991; Bird and Bird 1997; Boer, et al. 2002; Kennett and Winterhalder 2006; Raab 1992; Stephens and Krebs 1986). The ideal free distribution (IFD) model, for example, specifies that foraging locations are ranked by habitat suitability, or overall productivity, and therefore the highest-ranked habitats are predicted to be occupied and exploited first and most persistently through time, with secondary and tertiary habitats settled later in time, and perhaps less frequently or for shorter periods of time. As habitat suitability or productivity is density-dependent, the IFD model also predicts that patch quality declines as the number of individuals increases, due to competition for resources with other group members (Hildebrandt and Jones 1992; Kennett, et al. 2009; Smith and Winterhalder 1992; Tregenza 1995; Winterhalder, et al. 2010). The Prey Choice model describes how habitat productivity is expected to decline as the number of human predators increases. Following optimization expectations, the prey type with the highest return rate should be pursued over prey types with lower return rates (Kelly 1995; Smith and Winterhalder 1992). Intensive collection of a high-ranked prey would reduce their abundance, and consequently would increase search time and decrease the overall return rate of the prey (Broughton 1994; Grayson 2001; Raab 1992). The decrease in encounter rates of these high-ranked species could generate an expansion in diet breadth by including lower ranked resources and/or increasing the number of patches used in order to compensate for the decrease in the main prey (Bettinger 1991; Broughton 1994; Nagaoka 2002; Smith and Winterhalder 1992).

Finally, the patch choice model predicts how long a forager would remain in a patch before moving to a new one. Linked to prey choice model predictions, foragers are expected to use a resource patch to maximize their average foraging return rates. As human predation increases within a patch, productivity decreases and therefore a forager group would move to another patch when the expected returns of foraging time in the patch are lower than expected returns of foraging other patches (Bettinger 1991; Bird and Bird 1997; MacArthur and Pianka 1966; Smith and Winterhalder 1992; Stephens and Krebs 1986).

Ideal free distribution, Prey choice and Patch choice models together define and describe the sequence of circumstances under which human impact would be expected on mussel beds around Santa Cruz Island, starting from the time people initially settled on the selected habitat until they are forced to move to another place with higher productivity. Following the density-dependent characteristic of habitat productivity described in the models above, a decrease in productivity of the patches exploited (intertidal mussel beds) next to the archaeological sites under study is expected during the Late Holocene. This, as a result of relatively high and growing human population and space circumscription during the Late Holocene along the coasts of Santa Cruz Island, which would have increased human pressure on intertidal resources (Arnold 2001b; Glassow 1993; e.g. Kennett 2005; Kennett, et al. 2009; Winterhalder, et al. 2010).

Human Impact

M. californianus is a competitive dominant species that defines the entire intertidal zone and provides food and shelter for a variety of organisms (Blanchette, et al. 2006; Blanchette and Gaines 2007; Broitman, et al. 2005; Coe and Fox 1944; Phillips 2005).

Increasing human harvesting of mussels can affect growth rate, size and abundance of other non-harvested species, changing the structure of the whole community (Keough, et al. 1993; Lasiak and Field 1995; Roy, et al. 2003).

Evidence of the effects of human harvesting on modern intertidal shellfish species comes from ecological studies comparing areas protected and unprotected from human exploitation (Castilla 1999; Duran and Castilla 1989; Fenberg and Roy 2007; Hockey and Bosman 1986; Hockey, et al. 1988; Keough, et al. 1993; Kingsford, et al. 1991; Roy, et al. 2003). When comparing species size distribution of exploited and unexploited areas, human access to intertidal sites has been strongly correlated with reductions in number of large shellfish individuals (Castilla and Duran 1985; Keough, et al. 1993; Sagarin, et al. 2007). In archaeological deposits, decrease in abundance and size of high-ranked shellfish species and increase in abundance of low-ranked ones through time are interpreted as evidence of the effect of human harvesting on shellfish resources (Alvarez-Fernandez, et al. 2011; Braje, et al. 2007a; Braje, et al. 2012; Broughton 1994; Erlandson, et al. 2008; Erlandson, et al. 2011; Glassow, et al. 2008; Jerardino 1997, 2012a; Jerardino, et al. 1992; Mannino and Thomas 2002; Sealy and Galimberti 2011). Reduction in shellfish size has been explained by the fact that recurrent extraction of large individuals leads to a decreasing probability of survival into adulthood, dropping the average age of natural shellfish populations and therefore the size of the shell (Castilla and Duran 1985; Keough, et al. 1993; Sagarin, et al. 2007). The intermediate disturbance hypothesis, though, proposes that species richness is greater and natural competitive elimination is lower under conditions of intermittent or moderate disturbance or predation (Connell 1978). For the specific case of mussel beds, the removal of larger individuals may relieve intraspecific competition within beds, enhance growth rate of the remaining mussels, and increase the overall productivity of mussel populations (Hockey and Bosman 1986; Whitaker 2008; Yamada and Peters 1988).

When considering the effect of human exploitation on size and abundance of mollusk-targeted species, species size seems to be more responsive than abundance (Hockey and Bosman 1986; Lasiak 1991; Lasiak and Field 1995). This is due to the fact that in cases where exploited species have long-range larval dispersal and successful recruitment, they could maintain their abundance but not reach large sizes before harvesting by humans (Hockey and Bosman 1986).

Multiple lines of evidence are necessary to support or discard human harvesting as the main causal agent of change in archaeological shellfish assemblages. Harvesting pressure can be potentially confounded by environmental variability, which has a well-known influence on abundance, distribution and body size of shellfish species but might be difficult to detect in the archeological record (Claassen 1999; Jerardino 1997; Lupo 2007; Mannino and Thomas 2002). Fluctuations in sea surface temperature, for example, can affect recruitment and growth rate of *M. californianus*, which can change their age structure and abundance (Blanchette and Gaines 2007; Blanchette, et al. 2009; Broitman, et al. 2005; Hobday and Tegner 2002).

Stable Isotope Analysis and Past Oceanographic Characteristics

Several studies have shown that marine shells provide useful records of past oceanographic conditions (Epstein, et al. 1953; Killingley 1981; Killingley and Berger 1979). Oxygen isotopic analyses of *M. californianus* is a well established technique for reconstructing past sea surface temperature of the water where they grew (Bailey, et al. 1983;

Epstein, et al. 1953; Glassow, et al. 1994; Killingley 1981; Killingley and Berger 1979). During growth, mollusks deposit new layers of shell which precipitates in chemical equilibrium (δ^{13}C and δ^{18}O isotope values) with the ocean water temperature in which they grew (Wefer and Berger 1991).

Past and Present SST

Biological and ecological research have shown that long-term mean SST provides a reasonable index of oceanographic conditions (Blanchette, et al. 2006; Broitman, et al. 2005) and studies around the world support the strong relationship between coastal oceanography (water temperature) and nearshore community structure, particularly in regions of strong upwelling and oceanographic variability (Broitman, et al. 2001; Bustamante, et al. 1995; Menge, et al. 1997). In archaeology, past SST (from oxygen isotope on shell and foraminifera) is widely used to infer past marine productivity and to interpret fluctuations in collected shellfish abundance and size (e.g. Braje., et al. 2011; Erlandson, et al. 2008; Glassow, et al. 2012; Jerardino 1995a; Kennett 2005; Kennett, et al. 2007; Rick, et al. 2006; Robbins, et al. 2013).

In the present study, past SST values from oxygen isotope analysis of archaeological mussel shell and modern SST values from satellite imagery (Advanced Very High Resolution Radiometer (AVHRR)) are compared in order to evaluate possible changes in nearshore oceanographic conditions through time and interpret past characteristics of mussel beds. However, a recent archaeological study questions the use of satellite SST as a reference for modern intertidal water temperature and also the use of SST from modern shells as a baseline to evaluate changes in nearshore oceanographic conditions through time (Glassow, et al.

2012). Glassow et al (2012) compared SST values between oxygen isotopes from modern intertidal mussel shells (16.8.ºC), oxygen isotopes from archaeological mussel shells (13.2ºC) and modern satellite imagery (14.6.ºC) (AVHRR) at the west coast of Santa Cruz Island (Glassow, et al. 2012:2580). Cooler SST from satellite imagery compared to modern shells is interpreted as differences between subtidal and intertidal water temperatures, and considerably warmer SST reflected in the oxygen-isotope values derived from modern shells compared to archaeological shells is interpreted as the result of global warming over the last 100 years. Regarding the first interpretation, it is important to clarify that satellite imagery does not show subtidal temperatures; it shows sea surface temperature around 1-5 kilometers from the coast, which in upwelling areas could be even warmer than inshore sea surface temperatures (e.g. Lagos, et al. 2005; Navarrete, et al. 2005). Cooler satellite SST in Glassow et al. (2012) may be then reflecting horizontal rather than vertical difference in nearshore water temperature. Regarding the second interpretation, the last 100 years of global warming should not be a problem in explaining the large difference between SST from past and present intertidal mussel shells, this since the drastic warming is part of long-term fluctuations in nearshore oceanographic conditions. The reasons for cooler SST from satellite imagery compared to water temperatures recorded through oxygen-isotope values from modern intertidal mussels in an area of strong upwelling is not clear, and small-scale coastal features related to the location of the sampled mussels could be a factor to explore. Until new research and results come to clarify this issue, satellite-derived SSTs and their link to modern nearshore natural conditions is the best bridge to past oceanographic and ecological conditions at shorelines exploited by humans in prehistory. In addition, for the specific case of the Channel Islands, SST values from satellite imagery and water temperatures derived from modern intertidal mussel will both reflect the differences in water temperature present around Santa Cruz Island and will fluctuate together under changing oceanographic conditions.

Prehistoric Human Impact around the Northern Channel Islands.

Scholars have argued that the increase in human population and space circumscription on the northern Channel Islands during the Late Holocene (3000-200 B.P.) had some effect on intertidal habitat suitability. (Arnold 2001b, 2004; Erlandson and Jones 2002; Kennett, et al. 2009; Winterhalder, et al. 2010). In fact, it has been proposed that during the Late Holocene, shellfish harvesting decisions were progressively less influenced by environmental conditions and more influenced by foraging pressure (Braje, et al. 2012). Several sources of evidence have been used to infer this decreasing environmental influence (Braje, et al. 2007a; 2011; Erlandson, et al. 2008; Glassow 1993)**;** a general decline through time in size and abundance of *M. californianus* shells, the declining abundance of other high-ranked shellfish species such as *Haliotis rufescens and Haliotis cracherodii* (red and black abalone), the increase in abundance of lower-ranked shellfish species, and finally the decreasing correlation through time between these observed changes in archaeological shellfish assemblages and fluctuations in regional past SST and marine productivity recorded in a Santa Barbara Basin marine sediment core (Kennett and Kennett 2000; Kennett, et al. 2007). The research done by Braje et al. and others (Braje, et al. 2007a; 2012; Erlandson, et al. 2008; Kennett, et al. 2007; Rick, et al. 2006) is significant in that it has revealed important spatial and temporal patterns in shellfish harvesting around the northern Channel Islands.

However, the interpretation about the role of natural factors on these patterns has three main shortcomings that need to be evaluated and clarified.

The first shortcoming is that although regional SST records are an important reference for general oceanographic and climatic conditions, these records do not necessarily represent local nearshore SST and their effect on intertidal shellfish species. Unless records of past SST from regional cores and archaeological data (oxygen isotopic data from mussel shells) are demonstrated to be similar or to show similar fluctuations and trends, regional paleo-oceanographic conditions should not be used as the single proxy for local past intertidal productivity. Some archaeological studies around the Channel Islands correlate regional SST records with local ones based on stable isotope data from archaeological sites (Arnold 2001a; Glassow, et al. 1994; Kennett, et al. 2007; Rick, et al. 2006). In other cases, when local SST records are not available for an archaeological site under study, local records from other nearby sites are used as reference and are correlated with regional ones to estimate past oceanographic conditions (Glassow, et al. 2008).

The use of regional past SST records neglects the complex oceanographic dynamic around the northern Channel Islands and the implications of this complexity for availability of nearshore resources in the past. Two different oceanographic circulation systems encompass the northern Channel Islands: the cold California Current moves southward along the California coast with a portion of it passing through the Santa Barbara Channel influencing waters off the northwest coasts of Santa Cruz, Santa Rosa and San Miguel islands, while the main part of it passes along the southwest coasts of San Miguel and Santa Rosa Island (Figure 1). The southern California Countercurrent moves northwestward between the southern Channel Islands and encounters the southeast coasts of the northern

Channel Islands (Figure 1). In addition, mean ocean temperatures are cooler in the northwestern sector of the Santa Barbara Channel due not only to the California Current but also to coastal upwelling, and ocean temperatures are warmer in the southeastern sector due to seasonal poleward advection of subtropical waters (Harms and Winant 1998; Hickey 1992; Hickey, et al. 2003). As Anacapa, Santa Cruz, Santa Rosa and San Miguel islands are located in this southeast-northwest oceanographic gradient, Anacapa Island on the east is surrounded by warmer SSTs than is San Miguel Island. Additionally, eastern shores of each island have warmer SSTs than western shores (Blanchette, et al. 2006; Blanchette, et al. 2009; Hickey 1992) (Figure 36). Studies of spatial distribution and abundance of intertidal species along the mainland coast of southern California, have found strong relationships between the described intra-regional nearshore SST variability and intertidal community patterns (2006; Blanchette, et al. 2008; 2009; Broitman, et al. 2005). These studies emphasize the importance of local features of coastal areas and how they may prevail over large-scale processes to define regional intertidal habitats characteristics. The mentioned relationship between variation in intertidal community patterns and small scale oceanographic differences can be observed across the Channel Islands: warmer water temperatures are associated with sites with high invertebrate recruitment, abundance, and growth rate, whereas cooler water temperatures are associated with sites with high algal growth and productivity and reduced invertebrate growth (Blanchette and Gaines 2007; Blanchette, et al. 2007; Blanchette, et al. 2009; Broitman, et al. 2005).

Consequently, the exclusive use of regional paleoclimatic records to estimate past intertidal habitat productivity and environmental influence on past shellfish harvesting under-represents the effect of small-scale oceanographic and ecological variability on nearshore resources and on human decisions related to their collection. For example, when past SST and marine productivity derived from regional cores do not correlate with fluctuations in size of *M. californianus* shells from a shell midden site, it does not immediately mean absence of an environmental effect on archaeological shellfish assemblages, but only the absence of regional environmental influence. Local SST from archaeological shells must be included in a study in order to discard environmental influence. As an example, Braje et al. (2007a) did not find clear correlations between *M. californianus* overall size reduction through time from a site on the south coast of Santa Rosa Island and SST and productivity recorded in the Santa Barbara Basin core. Because these investigators used only a regional SST record, they did not account for local differences in nearshore SST and marine productivity through time. In contrast, a recent study included a local SST sequence based on *M. californianus* shells from the same archaeological site published in Braje et al. (2007a) and did find correlations between fluctuations in this local SST sequence and shellfish assemblage variation through time (Robbins, et al. 2013).

In addition, the complex oceanographic dynamic around the northern Channel Islands implies that past SST records from a location, for example, along the west coast of Santa Rosa Island cannot be used as a reference for SST conditions in a location with warmer waters such as the southeast coast of the same island. Similarly, a past SST record from the west coast of Santa Rosa cannot be used to explain shellfish species variation at an archaeological site on the southeast coast of the island. If past SST conditions are posited to be a determinant of archaeological shellfish species variation, past local SST data must be derived from the same place where the archaeological site is located or from a location with similar past SST records (e.g., oxygen isotopic data on archaeological mussel shells) and therefore similar intertidal habitat characteristics.

Variation in oceanographic characteristics around the Channel Islands also highlight the problem of combining archaeological shellfish components from different sites into a single shellfish harvesting chronological sequence (as done in Braje, et al. 2012; Erlandson, et al. 2008). Even in a regional perspective, combining archaeological shellfish data from locations with different past SST is to combine shellfish harvesting events while ignoring geographic and ecological characteristics of the exploited intertidal habitats. For example, if the mean size of *M. californianus* shells at a Middle Holocene archaeological site on a warmer-water coast is larger than the mean size at a Late Holocene site on a cooler-water coast, could be not only due to the overall higher human predation pressure on *M. californianus* beds during the Late Holocene, but also due to the less optimal natural conditions for mussel growth in cooler waters. *M. californianus* grow at much higher rates in sites with warmer waters where upwelling events are less frequent or weaker and therefore nutrients from cool waters stay nearshore and available for benthic filter-feeders (e.g., barnacles and mussel). Warmer coastal locations have also thicker and more extensive mussel beds, with bigger mussel specimens than cooler coastal locations (Blanchette and Gaines 2007; Blanchette, et al. 2007).

The last but not the least implication of the complex oceanographic dynamic around the northern Channel Islands concerns the construction of chronological sequences of past local SST, and the problem of combining in a single sequence, SST values obtained from archaeological shells taken from locations with different nearshore oceanographic conditions (e.g. Kennett and Kennett 2000). Fluctuations observed in such a composite SST sequence could be the effect of mixing SST values from cooler and warmer shores within one chronological sequence and not the effect of seawater temperature fluctuations through time. Such a composite SST sequence is not taking into account how the observed differences in SST can be the effect of the geographic location of the archaeological site where SST values were taken. A more appropriate approach to generate a regional sequence of the effect of past nearshore water temperature on intertidal shellfish species would be to compare SST values from contemporaneous archaeological assemblages along the east-west Channel Islands' oceanographic gradient. This would provide information about changes in SST through time at these different cooler and warmer coastal locations. Any other combination will ignore past small geographic scale oceanographic variability and will provide a distorted picture on how this variability shaped the characteristics of the intertidal habitats exploited by humans.

The second shortcoming of current interpretations about the role of natural factors on the observed patterns in prehistoric shellfish harvesting around the northern Channel Islands is that with few exceptions (Braje, et al. 2007a), observations about correlations between archaeological shellfish assemblages and past SST and marine productivity fluctuations through time do not provide statistical values of significance (e.g Braje, et al. 2012; Kennett, et al. 2007; Rick 2011; Robbins, et al. 2013). This lack of significance tests risks transforming conclusions about the influence of environmental conditions on shellfish harvesting around the northern Channel Islands through time into mere qualitative observations.

Finally, published data about small-scale interactions between oceanographic patterns and *M. californianus* beds' dynamics from around the southern California Coast have not been properly considered in interpretations about natural and human foraging effects on past shellfish resources. Despite previous applications of ecological data to understand general past characteristics of marine resources and human use of them (e.g. Erlandson, et al. 2005; Jerardino 2012b; Kinlan, et al. 2005; Rick, et al. 2006), further considerations are needed regarding how these data may be applied. It is especially important to consider the way past marine productivity has been reconstructed and used to interpret its effect on past changes in shellfish species abundance and size. Although several biological studies have shown that coastal locations with cooler waters have higher marine productivity than coasts with warmer waters (Blanchette and Gaines 2007; Blanchette, et al. 2009; Broitman, et al. 2005; Hobday and Tegner 2002), this higher productivity does not apply to all intertidal species. High nutrients in cool upwelled waters can stimulate phytoplankton productivity, which when delivered to benthic filter-feeders (e.g., barnacle and mussels), due to weak upwelling favorable winds (offshore) known as relaxation events, result in higher mussel abundance and growth (Phillips 2005). In the California oceanographic system, however, relaxation events are infrequent, and upwelled nutrients are advected offshore, and therefore the enhanced phytoplankton production rarely becomes available to coastal benthic organisms (Blanchette and Gaines 2007; Blanchette, et al. 2007). In addition, it has been shown that in coastal locations with cool, nutrient-rich upwelled waters, algae and surfgrass dominate intertidal habitats over filter-feeders (for example *M. californianus*) (Blanchette and Gaines 2007; Blanchette, et al. 2007).

Also, many studies have been undertaken on the sources of variation in abundance, recruitment, and growth of specific shellfish species. *M. californianus* for example, have been studied by researchers at different locations around southern California (Blanchette, et al. 2006; Blanchette and Gaines 2007; Broitman, et al. 2005; Coe and Fox 1944; Phillips

2005; Smith, et al. 2006, 2009). These studies have shown that *M. californianus* is affected by upwelling and water temperature, specifically weak seasonal upwelling and warm water conditions (from 15°C to 20°C) favoring mussel growth rate (more rapid), biomass (larger individuals), abundance (more extensive mussel beds), and recruitment (more larvae) (Blanchette, et al. 2006; Broitman, et al. 2005; Coe and Fox 1944; Morris, et al. 1980; Phillips 2005).

Like *M. californianus*, abalone species abundance and size are related to SST patterns. Warm temperatures reduce growth and reproduction of *Haliotis rufescens* (red abalone), and higher abundance and faster growth occurs in places with cool upwelling waters between 13° C and 19°C (Hobday and Tegner 2002; Leighton 1974; Tissot 1988; Vilchis, et al. 2005). Unlike *M. californianus*, literature on *Haliotis rufescens* does not directly mention the effect of upwelling dynamics on their abundance and size, but considering that these marine gastropods feed on kelp, which depend upon upwelling sources of cool nutrient-rich waters (Vilchis, et al. 2005), it could be inferred that *H. rufescens* abundance and size is positively correlated to cooler waters and high marine productivity. Conversely, *Haliotis cracherodii* (black abalone) is almost exclusively located in the intertidal zone and grows faster in warmer waters between 16-20°C (Arnold and Tissot 1993, Hamm and Burton 2000, Tissot 1988).

Based on these differences, cooler nearshore waters and higher marine productivity create better natural conditions for *H. rufescens*, but not for *M. californianus*. Consequently, it is not correct to link cold past SST with expected high abundance and large size of *M. californianus*, and therefore it is wrong to use the presence or absence of this relationship to interpret environmental influence on mussel beds (e.g. Braje, et al. 2007a).

The differential effect of marine productivity on intertidal shellfish species abundance and shell size highlights the necessity of being extremely careful when estimating the influence of past paleoceanographic conditions on shellfish harvesting and emphasizes the importance of local SST records to estimate past abundance and size of shellfish species such as for example *M. californianus*.

Also, the differential effect of marine productivity on *H. rufescens* and *M. californianus* warns us, again, about the problem of combining archaeological shellfish assemblages from sites at locations with cool (higher abundance of algae and herbivores such as abalone, urchin and turban snail) and warm sea waters (higher abundance of filter-feeders such as mussel and barnacle) into single chronological sequences. Fluctuation in abundance and size of *H. rufescens* and *M. californianus* observed along a single chronological sequence with archaeological assemblages from shores with warmer and cooler water may reflect natural differences between habitat conditions more or less optimal for these species and not necessarily variation in human foraging intensity. Consequently, when comparing this single sequence of shellfish species abundance with a regional past SST record, presence or absence of correlation between them through time could end up being meaningless if geographic locations and their long-term water temperature variation is not considered. We must include geographic-specific oceanographic and ecological information as factors of variation before ruling out or supporting environmental effects on shellfish resources and human foraging patterns.

In summary, the four main issues encountered in current approaches to evaluate environmental influence on shellfish harvesting through the Holocene around the northern Channel Islands are 1) use of regional past SST records as the only proxy for interpreting marine productivity, 2) the omission of implications of small-scale oceanographic variability in efforts to understand variability in past shellfish assemblages, 3) absence of statistical tests of significance to evaluate past correlations between environment and archaeological shellfish assemblage variation, and 4) inadequate understanding and application of published data on small-scale interactions between oceanographic patterns and shellfish species dynamics. This study addresses these issues by combining ecological, paleoclimatic and archaeological data from two locations on Santa Cruz Island, one on the south shore with warmer long-term SST and one on the west shore with cooler long-term SST. The archaeological sites date from the Late Holocene, between 2200 and 500 cal B.P., a period of high foraging pressure on rocky intertidal shellfish species.

Chapter 3. Research Question and Hypotheses

How much of the observed variation in archaeological shellfish assemblages and by inference in shellfish harvesting decisions was due to environmental factors during the Middle and Late Period (2200-500 cal B.P.)?

The present study addresses this question by assessing the degree of correlation between changes in archaeological shellfish assemblages and intertidal environmental fluctuations through the Late Holocene on Santa Cruz Island. This is done by testing the hypothesis proposed by Braje et al. (2012:117) for the northern Channel Islands that shellfish harvesting decisions during the Late Holocene were progressively less influenced by environmental conditions because increasing human pressure on intertidal habitats made shellfish harvesting the main force shaping size and availability of shellfish species. In order to test this hypothesis, two more specific hypotheses are proposed to separately evaluate human and environmental effects on past shellfish communities.

H.1. Effects of environmental variability on past shellfish communities.

If nearshore fluctuation in past sea surface temperature (SST) significantly affected *M. californianus* abundance and shell size during the Late Holocene, then a positive statistical correlation will be demonstrated between variation in SST and changes in abundance and size of *M. californianus* archaeological shells.

Under this hypothesis, it is assumed that nearshore oceanographic conditions around Santa Cruz Island remained essentially the same through time and that they were essentially the same as today's.

If expectations are met and H.1 is supported, it would imply that fluctuations through time in past nearshore oceanographic conditions did affect the size and abundance of *M. californianus* shells identified in the archaeological records of the two Late Holocene study sites at Santa Cruz Island: SCRI-496 and SCRI-195. It would also imply that shellfish harvesting decisions were influenced significantly by environmental conditions.

H.2. Effect of human predation on shellfish population.

If human predation on intertidal shellfish throughout the Late Holocene was the main force shaping size and availability of *M. californianus* (the main species collected) and other shellfish species, then a negative statistical correlation will be demonstrated between variation in SST and changes in archaeological shellfish assemblages.

Under this hypothesis, it is assumed that human foraging of intertidal shellfish species around Santa Cruz Island was non-selective. It focused on the most abundant and large-bodied shellfish species. A decline in abundance and size of collected *M. californianus* shells is expected through the chronological sequence at the study sites, together with an increase in abundance of other lower-return species (for example sea urchin and small snails) as the availability of the species with higher return (mussel) decreased.

If expectations are met and H.2 is supported, it would imply that increasing human pressure during the Late Holocene significantly affected *M. californianus*, that it does explain variations in mussel shell sizes and abundance at the two study sites, and therefore that shellfish harvesting did shape mussel availability at the exploited nearby rocky shores**.**

Chapter 4. Methods

The study area is Santa Cruz Island, the largest of the four northern Channel Islands and the one with the greatest marine and terrestrial biological diversity (Figure 2 and 36). The island is 38 km long and 16 km wide. It is located approximately 30 kilometers off the coast of California and has rugged topography with two main mountain ranges and associated ridge systems. These two mountain ranges run east-west and are separated by a central valley with steep, brushy slopes on either side of a narrow, grassy valley with oak trees and an important stream (Schoenherr, et al. 1999). The highest peak is 753 meters above sea level and is located on the northern ridge with oaks, cone pines, island ironwood and other trees on its northern slopes. Variation in topography, exposure to winds, and coastal fog creates a highly diverse local climate with average temperatures from 11ºC to 17 ºC in winter and 16ºC to 21ºC in summer. Rainfall ranges from 0.09 mm in June to 113.3 mm in January, with the lowest amounts occurring on the western end of the island (Laughrin 2005; Schoenherr, et al. 1999). There are two main drainages, one that drains to the north coast through Cañada del Puerto and the second to the west coast through Cañada Christy.

Floral diversity is composed by widespread grassland that is more abundant in the western sector of the island; coastal bluff scrub predominant on rocky south-facing slopes; chaparral, island woodland, and southern coastal oak woodland dominate north-facing slopes; and finally oak woodland and bishop pine forest prevail in and around the sheltered central valley and upper Cañada Christy (Fischer, et al. 2009; Junak, et al. 1995; Schoenherr, et al. 1999). Santa Cruz Island has the most extensive set of terrestrial fauna of the northern Channel Islands, although it is very limited in comparison to the mainland. Animals such as the spotted skunk (*Spilogale gracilis*) and the island fox (*Urocyon littoralis*), together with various species of lizards, snakes, bats, and land and sea birds (Crooks 1994; Schoenherr, et al. 1999) are present.

Productive nearshore littoral habitats influenced by the cold California Current and seasonal upwelling enhance the diversity of natural resources available around Santa Cruz Island (Hickey 1992; Hickey, et al. 2003). As discussed earlier, the location of the island between this cold current and the warm California Countercurrent shapes the mosaic of warm-water and cold-water sea life including fish, mammals, shellfish and kelp. Sea mammal haul-outs are populated by mainly California sea lions (*Zalophus californianus*) and harbor seals (*Phoca vitulina*), but northern fur seal (*Callorhinus ursinus*) and elephant seals (*Mirounga angustirostris*) also occur around the coast (LeBoeuf and Bonnell 1980). In addition, extensive kelp forest surrounds the island with the thickest forests on the south shore. The kelp forests provide shelter for a large number of sea mammals (including sea otter, *Enhydra lutris*), fish, and shellfish (Engle 1993; Fitch 1975; Schoenherr, et al. 1999). Most of the coastline is characterized by rocky shores, with most of the sandy beaches along the southwest coast. The north coast of the island is characterized by steep rocky promontories with limited access to rocky intertidal areas. Aside from *M. californianus,* other important rocky intertidal shellfish species are *H. cracherodii (*black abalone), *H. rufescens* (red abalone), and *Lithopoma undosum* (wavy top), and *Tivela stultorum* (pismo clam) inhabits sandy beaches (Schoenherr, et al. 1999; Smith and Carlton 1975).

Santa Cruz Island is an ideal research setting due to its rich archeological record and biological diversity, with decades of research on intertidal shellfish communities and prehistoric human occupation. As I discussed earlier, hundreds of archaeological sites cover the islands' coastline (primarily identified by dense shell midden deposits), with dates from the Terminal Pleistocene to Historic times (Glassow 2010) and long-term intertidal ecological study sites have more than 10 years of high resolution datasets concerning nearshore oceanographic conditions and intertidal ecological characteristics (SWAT (http://cbsurveys.ucsc.edu/index.html) and Partnership for Interdisciplinary Studies of Coastal Oceans long-term research and monitoring program (PISCO http://www.piscoweb.org/research)).

Santa Cruz Island has been part of the Channel Islands National Park since 1980, and its offshore waters are part of the Channel Island National Marine Sanctuary. Portions of its surrounding waters have been also within the network of marine protected areas since 2003. Areas of the island's coastline and nearshore waters have been released from human exploitation since 1997 after the closure of the last commercial shellfish industry (Braje and Erlandson 2007; Braje, et al. 2007b). Given the more than 10 years of very restricted human exploitation of the intertidal zone around the island, modern ecological data can be considered as a reference for intertidal habitats not altered by human harvesting. Despite the fact that it is still unclear how much time intertidal communities need to recover from human disturbance, comparisons made between protected and unprotected intertidal habitats have indicated that altered ecosystems recover after five to ten years of protection (Crowe, et al. 2000; Halpern and Warner 2002; Hockey and Bosman 1986; Moreno 2001). Additionally, except for the recent decrease (since 1980) of *H. cracherodii* abundance (Lafferty and Kuris 1993), there is no evidence of drastic ecosystem shifts around the Channel Islands. Despite documented alternate states of kelps and urchin barrens in modern times (areas where urchin populations are so large that kelp forests are depleted), giant kelp populations remain present in California regardless the presence of otters, which demonstrates the resilience of this coastal ecosystem (Dayton, et al. 1998).

Time Period of the Study: Late Holocene (3000-200 B.P.)

The Late Holocene (3000-200 B.P.) on Santa Cruz Island and the northern Channel Islands is a period of important cultural development, including population growth, technological innovation, intensification of fishing, increased territoriality, craft specialization, expansion of trade networks, and higher sociopolitical complexity (Arnold 2001b; Kennett 2005; Munns and Arnold 2002). The presence of new technology such as the circular shell fishhook around 2500 B.P., and the plank canoe around 1500 B.P. (Arnold 1995; Gamble 2002; Rick 2001) supports the expansion of a maritime-oriented economy in which intensive fishing and trade provided a base for coastal sedentism and specialization (Arnold 1995; Arnold and Bernard 2005; Colten 2001; Pletka 2001). Settlement patterns during this period also show maritime-oriented collector-based activities (sensu Binford 1980), **e**specially after 1500 B.P. (Glassow 1993; Kennett 2005; Perry and Hoppa 2012). Few and ephemeral Late Holocene sites were located in the interior of the island (possible collector-based camps), and large settlements were established on the coast (Kennett 2005; Munns and Arnold 2002). Sites SCRI-240 and SCRI-333 are examples of these primary coastal villages on the south and west coasts of the island, respectively (Arnold 1987, 2001b; Glassow 1993; Kennett 2005; Munns and Arnold 2002).

In addition, research suggests that increased human population on the islands during the Late Holocene (3000-200 B.P.) was linked to a decrease in foraging range, and to an increase in competition for nearshore resources (Arnold 2001b; Glassow 1993; Kennett

2005; Kennett, et al. 2009; Winterhalder, et al. 2010). Increased violent interactions associated with increasing territoriality during this period are indicated by projectile points found embedded in human bones of burials and wounds to bones made by projectiles (Lambert and Walker 1991). The presence of cemeteries associated with primary villages also supports territorial circumscription (Lambert and Walker 1991). As coastal settlements became increasingly permanent and densely occupied, this territorial circumscription likely contributed to further resource intensification (Glassow 1993; Kennett 2005; Munns and Arnold 2002). Also, as exploitation pressure increased on shellfish beds (the most important source of protein during previous periods) more costly alternatives were intensified, such as fishing and sea-mammal hunting. Late Holocene subsistence shows a trend toward increasing dietary breadth, increasing importance of fish, and decreasing importance of sea mammals and shellfish (Colten 2001; Colten and Arnold 1998; Glassow 1993; Kennett 2005; Munns and Arnold 2002; Pletka 2001).

Collection and Processing of the Column Samples

The archaeological records of the study sites are placed within the described context of cultural changes occurred during the Late Holocene (2200-500 cal B.P.). Site SCRI-496 is located on the south shore of Santa Cruz Island at the mouth of Willows Canyon, with warmer long-term mean SST of its nearshore waters, and site SCRI-195 is located on the west coast of the island at the mouth of Rancho Nuevo Canyon, with cooler long-term mean SST of its nearshore waters (Figure 3 and 36. Table 20). The shell midden site at Willows is located few meters from a small sandy beach and goes from the slope of a small hill to the mouth of a seasonal stream (Figure 3). Based on early excavations at Willows by

Schumacher in 1875 and Olson in 1927-1928 (California Coastal Information Center at University of California Santa Barbara (CCIC)), this shell midden site has an approximate area of 30 x 50 meters, with a depth of deposits at approximately 1.2 meters. SCRI-195, at the mouth of Rancho Nuevo Canyon, is at the edge of a marine terrace overlooking a rocky beach at the base of a low sea cliff (Figure 4). This site has an area of around 100 x 90 meters, with a depth of deposits at approximately four meters (CCIC).

Analyzed shellfish remains come from two column samples, 25x25cm in area, one at SCRI-496 and another one at SCRI-195. Both column samples were obtained from the vertical erosion banks of exposed deposits facing the beach. They were excavated following natural stratigraphic units. When strata were more than approximately 20 centimeters thick, they were divided arbitrarily into two or more levels. The column sample from SCRI-496 had a depth of 122 cm and was excavated by the author in 2008-2009 from the south side of the archaeological deposit. The column sample from SCRI-195 had 410 cm of depth and was excavated by M. Glassow and A. Ford in 1974 near the center of a house depression bisected by the seacliff. Archaeological materials from both column samples were sifted in the field. Material from site SCRI-496 was sifted through a one-sixteen inch mesh screen and material from SCRI-195 through a one-eight inch mesh. Shellfish remains from this latter column sample were obtained almost forty years after its excavation from the repository at the Department of Anthropology, University of California, Santa Barbara.

Once at the laboratory, archaeological material was dry-sifted again through one-quarter and one-eighth inch mesh to separate different size ranges. Shellfish remains greater than one-quarter inch in size were used for taxonomic identification, mollusk shell quantification, and shell size measurements. Taxonomic identification was done with the help of a reference collection and California shellfish guides (e.g. Meinkoth 1998; Smith and J. 1975). Two techniques were used for quantification of shellfish abundance: minimum number of individuals (MNI) and shell weight (Claassen 1999, 2000; Glassow 2000; Grayson 1984). MNI was estimated from the number of umbones of one side for bivalves species and the number of apices/spires/umbilici for single-shell taxa. Weight was obtained by weighing the total amount of shells per taxon. Due to the high degree of fragmentation of shell remains, not all of them could be identified to species level but were identified to the most specific taxonomic division possible. Due to the same reason, umbones and apices of the most prevalent species within the malacological assemblages (mussels and abalone species) were not well preserved, and therefore shell weight was considered a better measurement to study temporal changes in mussel foraging on rocky intertidal habitats. For each column sample, total weight of every shellfish taxon was standardized by the volume of every excavated stratum. Since the area of both column samples is 25x25 cm, shell weight (grams) was divided by the centimeters of each level's depth (See Appendix 1: Shellfish Data).

Shell size measurements made on whole shells were the maximum length for bivalves, including mussels and clams, and univalves such as abalone and limpets, and the maximum height for snails (Buchanan 1985; Claassen 1999; Jerardino, et al. 1992; Jerardino and Navarro 2008). All measurements were obtained with 0.05 cm precision calipers. Whole shell measurements were estimated from fragmented *M. californianus* shells using the linear relationship found by M. Glassow between the length of whole shells and the length of their anterior adductor scar, located near the umbones (unpublished data). These data come from the measurement of 125 modern and archaeological *M. californianus* shells from the Santa

Barbara County, California (Purisima Point in western Santa Barbara County, San Miguel Island, and Santa Cruz Island). The linear regression between length of whole mussel shells and their adductor scars (located on the interior side of the shell next to the umbones) showed an R-Square value of 0.85 which justifies the use of scar's length as a proxy for the length of complete shells (See Appendix 2: *M. californianus* Shell Length Data).

Stable Isotope Data (δO-18) on Archaeological Shells of *M. californianus*

Four *M. californianus* shells were collected from each archaeological stratum/level at site SCRI-496 and SCRI-195 for oxygen isotope analysis. To avoid contamination with the interior aragonitic nacreous layer, selected mussel shells had intact outer prismatic (calcite) layers. Selected shells were also large enough to obtain eight samples at 2-mm intervals and had visible growth lines. Not all the sampled mussel shells had intact terminal edges; therefore, season of shellfish collection was not assessed. Shell surfaces were scraped to remove any extraneous organic material from the outer shell layers, they were then rinsed in deionized water and subsequently etched with muriatic acid to remove diagenetically altered carbonate. Finally, shells were dried at 85ºC, and samples were collected every two millimeters along their growth axis.

A total of 336 shell samples from SCRI-496 and 460 shell samples from SCRI-195 were sent to the Stable Isotope Facility at University of California (UC) Davis and to the Marine Science Institute (MSI) Analytical Laboratory at UC Santa Barbara. Data provided by the MSI has an accepted error range of +/- 0.2 per mil (Glassow, et al. 2012). In order to make isotopic data obtained from the MSI laboratory comparable with data obtained from other machines (e.g., data from Kennett and Kennett 2000; Kennett, et al. 2007), a -0.2 per mil correction was applied to all MSI data. Oxygen isotope data are reported in delta (δ) notation per mil ($^{0}/_{00}$) values. The conversion of $\delta^{18}O$ values to sea surface temperature (SST) was calculated using the equation derived for calcite by Epstein et al. (1953):

$$T(°C) = 17.04 - 4.34(\delta^{18}O_{(cVPDB)}) - (\delta^{18}O_{water(SMOW)}) + 0.16(\delta^{18}O_{(cVPDB)}) - (\delta^{18}O_{water(SMOW)})^2$$

where $\delta^{18}O_{(cVPDB)}$ is the isotopic value of calcite compared with the Pee Dee Belemnite, and $\delta^{18}O_{water(SMOW)}$ is the assumed isotopic value of the water compared with the standard mean ocean water. The $\delta^{18}O_{water(SMOW)}$ value was modified following local measurements of sea water obtained by Rick et al (2006) off the west coast of Santa Rosa Island.

Mean SST for each archaeological level was first calculated based on the SST values of four *M. californianus* shells. Based on these values, a local stratigraphic sequence of past SST was then constructed for each site. Due to unexpected budget cuts, only 19 of the 27 levels identified at site SCRI-195 were sampled for isotopic analysis. The selected levels were the ones at the beginning and end of the occupation, the ones with important fluctuations in mussel abundance and size, and the levels with radiocarbon dates (See Appendix 3: Oxygen Isotope Data).

Ecological and Nearshore Oceanographic Data

Data on long-term mean SST around Santa Cruz Island was extracted from weekly satellite imagery at 5-km resolution (AVHRR) over a period of 27 years (1982-2007). From the AVHRR data, five locations around Santa Cruz Island were selected to obtain a time series with 80-97% of valid observations (Broitman, et al. 2005) (See Appendix 4: Mean SST data). The five locations around the island correspond to Prisoners Harbor on the north coast, Valley Anchorage on the southeast coast, Willows Anchorage on the south coast, and Trailer (at the mouth of Red Rock Canyon) and Fraser Point on the west coast. Archaeological site SCRI-496 is located at Willows Anchorage and site SCRI-195 is located at Trailer. Data on long-term abundance and percent cover of *M. californianus* at the five locations mentioned above come from Blanchette et al (2006) and from the University of California Santa Cruz pacific rocky intertidal monitoring website, www.eeb.ucsc.edu/pacificrockyintertidal/sites/sites-region/index.html.

Despite the unparalleled opportunity provided by the spatial and temporal shellfish ecological data around Santa Cruz Island, historical changes observed in intertidal habitats around the Channel Islands raise concerns about their direct applicability into the past. Abalone species (*H. rufescens* and *H. cracherodii*), for example, were important components of intertidal and subtidal habitats from prehistoric times until the 1980s, when a mass mortality, due to a disease, resulted in these species becoming nearly absent from modern shores around the Channel Islands (Lafferty and Kuris 1993). In spite of large changes in intertidal and subtidal communities (Miner, et al. 2006), and the difficulties involved in making strong links between past and present-day ecological conditions for these species, the near absence of abalone in modern ecological data does not preclude them from being a source for understanding past intertidal habitat dynamics around southern California Coast. Observed dynamics of species present along modern shores, such as mussels (*M. californianus*) and barnacles (*T. rubescens*), are still valid since abalone, when they were present, occupied surge channels, and mussels and barnacles inhabited intervening plateaus (Douros 1987). Extremely high abundance of abalone on intertidal reefs before 1980

(Dayton, et al. 1998) could challenge space-use patterns and the division of primary space between mussel and abalone populations. Nevertheless, the stacking behavior of abalone on reefs is described by Douros (1987) as a response to high density of individuals due to the lack of natural predators such as sea otter and humans, and not as a normal condition of these species. This implies that presence of humans harvesting abalones around the shore (like Chumash people in prehistoric and historic times) would keep their populations under control and therefore within surge channels. Also, Hewatt's (1946) description of intertidal species around Santa Cruz Island before the decline in 1980 shows that high abundance of *H. cracherodii and H. rufescens* coexisted with abundant *M. californianus* and *T. rubescens*.

In conclusion, despite some difficulties involved in using modern-day ecological data to estimate past conditions and dynamics of *M. californianus'* populations, the use of available long-term data on nearshore sea surface temperature and abundance of this mussel species around Santa Cruz Island is crucial to understand spatial and temporal variations in past human foraging around the island during the Late Holocene.

Chapter 5. Results

Previous chapters have presented the theoretical and methodological context of this study. Information about three main subjects was obtained through the analysis of the shellfish remains excavated at site SCRI-496 on the south shore of Santa Cruz Island and SCRI-195 on the west coast of the island. This information included the chronology of occupation and variation in the rate of sediment accumulation through the chronological sequence represented by the column samples, characteristics of the shellfish assemblages resulting from human gathering along prehistoric intertidal rocky shores, and finally nearshore paleoceanographic conditions around Santa Cruz Island from 2200 to 500 cal B.P. Data presented in this chapter establish the basis for evaluating implications of past small-scale ecological and oceanographic variability for human foraging on *M. californianus* beds during the Late Holocene (2200-500 cal B.P.) around Santa Cruz Island.

Chronology and Rate of Sediment Accumulation

The chronology of occupation at SCRI-195 and SCRI-496 was established through radiocarbon dates obtained from Beta Analytic, Inc., and the National Ocean Sciences Accelerator Mass Spectrometry Laboratory (NOSAMS). Four of the six dates for SCRI-195 came from Beta Analytic, Inc. and were obtained by A. Gusick in connection with her Masters research (Gusick 2007). The other two dates came from NOSAMS and were obtained by the author for the purpose of the research presented here. For SCRI-496, all dates were obtained from Beta Analytic, Inc. To standardize the results and increase the accuracy of the interpretations, all dates used in this study are from individual marine shells (*M.*

californianus) and were calibrated using Oxcal 4.22 (Bronk Ramsey 2009) with a reservoir local correction (delta R) of 225±35 B.P. (Ingram and Southon 1996; Kennett, et al. 1997). Kennett et al. (1997) have shown temporal variability in delta R values, with a slightly diminished value of 210±80 between 8440 and 4310 B.P. The sites in this study, with the oldest dates around 2400 B.P., may also require a different delta R adjustment. However, the use of the average value of 225±35 instead of Kennett et al. (1997) value of 210±80, would adjust the dates by only roughly 25 years, which is not significant for the interpretation of sites' occupation. To be cautious in light of possible problems in the use of one or another delta R values, dates for the study sites are presented as 2-sigma intervals.

Site SCRI-496

Radiocarbon dates obtained for the column sample at SCRI-496 reveal that the beginning of occupation was 2254-1937 cal B.P. and the end was 458-282 cal B.P. (Table 2). The high degree of overlap between the radiocarbon dates reported for the lowermost levels (12, 10 and 9) suggests that the lowermost 50 cm of deposits represented by these levels accumulated during a relatively short period about 2200 years ago (Figure 5).

Dates from levels 7 and 4 are statistically indistinguishable: 1940-1700 cal B.P. for level 7 and 1980-1750 cal B.P. for level 4 (Table 2 and Figure 5). The next date above pertains to level 3 (1773-1530 cal B.P.) and is statistically different from the dates for level 4 below and levels 2 and 1 above (95% confidence interval) (Figure 5). Finally, dates from the uppermost two levels are also statistically different from each other (95% confidence interval) but indicate a stratigraphic inversion within the first 20 cm of the deposit (Figure 5 and Table 2). Level 1 has an older date than level 2, probably due to mixture of sediments by bioturbation (large roots through the sediments are indicative of mixing). Level 1 dates 1049-799 cal B.P. (Table 2), but beads of time-sensitive types characteristic of the Late Period (Bennyhoff and Hughes 1986), dated to around 800 B.P., are also found in this level (a callus cup *Olivella* bead and a large cupped *Olivella* bead; see Figure 3). Level 2 dates to 458-282 cal B.P. and is not associated with any time-diagnostic artifacts (Table 2). Diagnostic artifacts and the radiocarbon date for level 1 reveal a broad chronological spectrum, which led to considering levels 1 and 2, together as representing a time interval of about 550 years of midden accumulation, from around 1049-799 to 458-282 cal B.P. Following Jerardino (1995b), accumulation rates were calculated between statistically different dated levels at SCRI-496. It is important to mention that even though accumulations rate estimations assume a constant speed of sedimentation between dated strata (Jerardino 1995a; Stein and Deo 2003), periods of abandonment may have occurred between them affecting the estimated rates of sediment deposition.

Since the area of each level is constant within the column sample, volume was not used for the accumulation rate's calculation but rather thickness of levels (Table 4). Sediment accumulation represented by SCRI-496's column sample was divided into six phases (Tables 2 and 4): The lowermost is from levels 12 to 9, representing 37 cm of deposition laid down in approximately 50 years from 2095 (midpoint) B.P. for level 12 and 2045 (midpoint) B.P. for level 9. The second phase is from levels 9 to 7, representing 18 cm of deposits accumulated within a time interval of around 225 years, between 2045 (midpoint) B.P. for level 9 and 1820 (midpoint) B.P. for level 7. The third phase is from levels 7 to 4, representing 37 cm sediment deposited within about 40 years between 1820 (midpoint) B.P. for level 7 and 1865 (midpoint) B.P. for level 4. The next phase is from level 4 to 3, with only five cm of deposits having accumulated within about 214 years between 1865 (midpoint) B.P. of level 4 and 1651 (midpoint) B.P. of level 3. The fifth phase extends from level 3 to levels 2-1, with again five cm of sediments deposited in approximately 727 years, between 1651 (midpoint) B.P. for level 3 and 924 (midpoint) B.P. for level 1. Alternatively, the 5 cm of sediments deposited in level 3 may have accumulated over a short period of time sometime between 1651 (midpoint) and 924 (midpoint) B.P. Finally, the sixth phase is represented by levels 2 and 1, with 20 cm that accumulated in about 554 years, between 924 (midpoint) B.P. for level 1 and 370 (midpoint) B.P. for level 2. Despite the statistically different dates for levels 1 and 2, they were grouped into one phase due to the stratigraphic inversion of dates pertaining to these levels.

Table 4 exhibits variations in the rate of sediment deposition of the column sample through time. This table shows an initial high rate of accumulation between levels 12 and 9 from 2095 to 2045 (midpoint) B.P. (Table 4). After this period, there is a decrease in the rate of sediment accumulation from levels 9 to 7, between 2045 and 1820 (midpoint) B.P. A dramatic increase in the rate of accumulation is observed between levels 7 to 4, from 1820 to 1865 (midpoint) B.P. (Table 4). This is the time of the highest rate of sediment accumulation represented by the column sample, with a relatively large quantity of material accumulated over a short period of time (Table 4). From levels 4 to 3 the accumulation rate dropped; this happened between 1865 and 1651 (midpoint) B.P. The lowest rate of accumulation is represented by level 3 to levels 2 and 1, between 1651 and 924 (midpoint) B.P. Finally, levels 2 and 1, from 924 to 370 (midpoint) B.P., show a slight increase in the rate of sediment accumulation. Despite the rate being six times faster than previous levels, it remained low compared to the rate of deposition represented by levels 12 to 7 (2095 to 1865 (midpoint) B.P.).

The observed changes in sediment accumulation through the column sample from SCRI-496 correspond with the fluctuations in mussel shell abundance through time, especially at the time of the highest rate of accumulation, between levels 7 and 4, which is associated with the highest abundance of mussel shell (Figure 9). This association suggests a relationship between the fluctuation in the rate of sediment accumulation and in the intensity of occupation at the site. It may be proposed, then, that between midpoint dates of 2095 and 1865 B.P. (level 12 to 4) the occupation of SCRI-496 fluctuated between times of high and low occupation intensity (Table 4). After around 1651 (midpoint) B.P., there was a significant decrease in the intensity of occupation, which stayed low with some fluctuation (Table 4). This last period of low occupation intensity at the site could be interpreted as evidence of intervals of site abandonment or more sporadic and/or shorter visits.

Site SCRI-195

The occupation represented by the column sample from this site started around 2124-1845 cal B.P. and ended around 630-501 cal B.P. (Table 3). The date 630-501 cal B.P. comes from level 2, 20 cm below the surface (Table 3). The first 20 cm of the column sample do not have absolute chronological information, but previous work by Glassow and Paige (2006) with the column sample collections, identified the presence of three *Olivella* cup beads in this level pertaining to the Late Period, after about 800 B.P. (Bennyhoff and Hughes 1986). The radiocarbon date for level 2 (Table 3) and the temporally diagnostic artifacts from level 1 circumscribe these two uppermost levels within the Late Period, between around 800 and 630-501 cal B.P.

Although no radiocarbon dates pertain to levels 3 to 8, diagnostic artifacts also identified by Glassow and Paige (2006) provide relative dates for these levels. The presence of split-punched beads in level 3 and 4 (Table 3) locates these levels within the Terminal Middle Period, around 900 B.P., and the presence of *Olivella* wall beads in levels 5 to 8 places these four levels within the Middle Period between 900 and 1200 B.P. (Bennyhoff and Hughes 1986) (Table 3). Radiocarbon dates from level 9 to the bottom of the column sample fall within the Middle Period, with five radiocarbon dates from 2124-1845 to 1407-1075 cal B.P. (Table 3).

Following the same procedure used for SCRI-496, accumulation rates were calculated for SCRI-195 (Table 5). Sediment accumulation of SCRI-195's column sample was divided into four phases (Tables 3 and 5). The lowermost is from levels 28 to 20. The high degree of overlap of the radiocarbon dates reported for levels 28, 27 and 20 (Figure 6) suggests that the first 102 cm of midden deposition represented by these levels were laid down in approximately 197 years, from 1984 (midpoint) B.P. for level 28 to 1787 (midpoint) B.P. for level 20. The second phase is from levels 19 to 14, with 57 cm of deposits accumulated within about 314 years between 1787 (midpoint) B.P. for level 20 and 1473 (midpoint) B.P. for level 14. The third phase is from levels 13 to 9, with 83 cm of sediments deposited in about 201 years between 1473 (midpoint) B.P. for level 14 and 1272 (midpoint) B.P. for level 9. The last phase is from levels 8 to 2, with 148 cm accumulated in approximately 707 years between 1272 (midpoint) B.P. for level 9 and 565 (midpoint) B.P. for level 2.

Table 5 shows variations in the rate of deposition of the column sample through time. The highest rate of accumulation of sediments is between levels 28 and 20, from 1984 to 1787 (midpoint) B.P. After this period, from levels 19 to 14, there is a decrease in the rate of accumulation between 1787 and 1473 (midpoint) B.P. A subsequent increase in the rate of sediment accumulation is observed between levels 13 and 9, from 1473 to 1272 (midpoint) B.P. A final decrease in the accumulation rate is observed between levels 8 and 2, from 1272 to 565 (midpoint) B.P. The rate of accumulation between these levels is half than between levels 13 and 9 (see Table 5 for rate of sediment accumulation).

As at SCRI-496, the observed changes through time in sediment accumulation at SCRI-195 corresponds with fluctuations in mussel shell abundance through time (Figure 10), and therefore could be reflecting variation in the occupation intensity at the site. Occupation intensity appears to have fluctuated over time. The first interval of high intensity of occupation occurred between 1984 and 1787 (midpoint) B.P. (levels 28 to 20) and the second between 1473 and 1272 (midpoint) B.P. (levels 13 to 9) (see Table 5 for accumulation rates). Each of these intervals was followed by episodes of low-intensity occupation. The first interval of low-intensity occupation was from 1787 to 1473 (midpoint) B.P. (levels 19 to 14), and the second was from 1272 (midpoint) B.P. until almost the end of the occupation around 565 (midpoint) B.P. (levels 8 to 2) (Table 5).

Comparison Between Sites SCRI-496 and SCRI-195

Dates obtained for sites SCRI-496 and SCRI-195 show that the archaeological material from the analyzed column samples was accumulated during the Late Holocene, or more specifically during the Middle Period and the beginning of the Late Period (Arnold 1992; Kennett 2005; King 1990) (Table 1, 2 and 3).

Both sites were occupied contemporaneously for about two thousand years. SCRI-496 was occupied from 2254-1937 to 458-282 cal B.P., and SCRI-195 was occupied from 2124-1845 to 630-501 cal B.P. (Figure 8). An important difference between these two sites is the amount of sediment accumulated during the two thousand years of occupation. SCRI-195 accumulated 410 cm of sediment and SCRI-496 only 122 cm (Table 2 and 3). Consequently, SCRI-195 experienced a much higher rate of sediment accumulation than SCRI-496. Figure 6 shows that the dates for SCRI-195 are uniformly distributed among the strata, which may imply a more continuous occupation than SCRI-496, although not always with the same intensity. In contrast, SCRI-496 experienced a slower rate of sediment accumulation and more irregular occupation intensity. Both sites show two intervals of high occupation intensity represented by large quantities of mollusk shell remains (levels 7 and 4 at SCRI-496 in Figure 9 and levels 25 and 12 at SCRI-195 in Figure 10) and also one interval of very low rate of sediment deposition (levels 18 and 17 at SCRI-195 in Figure 10 and level 3 at SCRI-496 in Figure 9).

Shellfish Remains and Sea Surface Temperature from Sites SCRI-496 (2200-500 cal B.P.)

From the 23 shellfish species identified through the column sample of SCRI-496, *M. californianus* is by far the most abundant (grams/cm) (Table 6 and Figure 12). The proportion of *M. californianus* shells in the sample fluctuates from 93% to 82% (Table 7), with levels of lower (levels 1, 3, 5 and 11) and higher (levels 2, 4, 6, 7 and 9) percentages

(Figure 11). Increases in abundance of other shellfish species could be one of the factors resulting in decreases in the proportion of mussels. This could be the case for level 5, where a lower proportion of *M. californianus* corresponds with higher abundance of *Balanus nubilis* (acorn barnacle*), H. cracherodii* (black abalone) *and Strongylocentrotus* sp. (sea urchin) (Table 6 and Figure 12). However, this is the only level where a relationship can be observed between lower abundance of *M. californianus* and a higher abundance of other edible species. *M. californianus* shows low abundance relative to other shellfish taxa at the beginning (from levels 12 to 10) and end (from levels 3 to 1) of the site occupation, with peaks of high abundance in levels 4 and 7 (Table 7 and Figure 12). *B. nubilis* is the second most abundant shellfish species in the sample and follows the same pattern as *M. californianus.* This pattern shows low abundance at the beginning and end of the column sample, with peaks of higher abundance in levels 7, 4 and 5 (Table 6 and Figure 12). *H. cracherodii* is third in abundance and shows a very different pattern, with decreasing abundance through time and peaks of high abundance in level 12, 8 and 5 (Table 6 and Figure 12). Finally, the abundance of *Strongylocentrotus sp.* and *Tetraclita rubescens* (volcano barnacle) shows a homogeneous distribution through time, with a decrease in abundance in level 3 for *T. rubescens* and in level 4 for *Strongylocentrotus* sp.. Among the less abundant shellfish species identified in the column sample of SCRI-496, the abundance of *Olivella biblicata* (purple dwarf olive) shows a dramatic increase in the last three levels (Table 6), and the rest of the low-abundance species exhibit a pattern similar to *M. californianus*, with high peaks around levels 7 and 4 (Table 6*).*

Number of Species

When looking at the fluctuation in the number of species through time (Figure 13), a large amount of fluctuation may be seen, with a decrease from levels 12 to 8, an increase from levels 8 to 5, a decrease from levels 5 to 3, and a final increase in the number of species from levels 3 to 1. The species present in level 12 and absent in level 8 are *Lottia gigantea* (owl limpet), *H. rufescens* (red abalone), *Mopalia* sp. (mossy chiton), *Notoacmaea incessa* (seaweed limpet), *Nucella caliculata* (dogwinkle snail), and *Polinices* sp. (moon snail). Above level 8, the species that account for the increased in level 5 are *Lottia gigantea* (owl limpet), *Mopalia* sp. (mossy chiton), and *Notoacmaea incessa* (seaweed limpet), but also *Septifer bifurcatus* (platform mussel) and *Petinella* sp. (flat-tipped paddock clam) (Table 6).

M. californianus Shell Length

The mean length of all measured shells of *M. californianus* in the SCRI-496 column sample was 5.5 cm (Table 8). A decrease in mussel shell length is observed from levels 12 to 1, from a mean length of 6.5 cm in level 12 to a mean length of 4 cm in level 1 (Table 8 and Figure 14). Despite the smaller mean mussel length at the end of the occupation, great variability is observed throughout the column, with intervals of decrease (levels 1, 3, 6, 8 and 11) and then rebound (levels 2, 7 and 9) in mean shell length (Figure 14). Standard deviations for shell length measurements within each level are shown in Table 3. Levels 2, 7 and 12 have larger standard deviations, showing greater variation of shell lengths within the samples, and levels 1, 4, 6, 10 and 11 have smaller standard deviations, indicating less variation of shell length (Table 8). Based on the similar sample size between levels with smaller and larger standard deviations, differences in the spread of shell length measurements are considered not to be a factor of sample size. Finally, the significance of the observed changes in mussel length through time was evaluated between pairs of levels (Table 9). Mann-Whitney U and t-test significance tests show that changes in mean mussel shell length are highly significant, with the exception of changes identified between levels 4 and 5, 5 and 6, and 10 and 11 (Table 9).

Dramatic and gradual changes in *M. californianus* shell length exist through the depth of deposits at SCRI-496 (Figure 14). The first major decrease in length from levels 12 to 11 is followed by a gradual increase from level 11 to 9, then mussel length dropped dramatically from level 9 to 8 and rebounded as dramatically from level 8 to 7. A gradual decrease in shell length is then observed from level 7 to 3, followed by a dramatic increase from level 3 to 2 and finally by a dramatic decrease from levels 2 to 1 (Figure 14).

Past Sea Surface Temperature (SST)

The mean Sea Surface Temperature (SST) value derived from oxygen isotope measurements for SCRI-496 is 15.7°C (Table 10). Fluctuations in water temperature are observed through the stratigraphy of the site, with the lowest mean SST of 13.3°C for level 12 and the highest mean SST of 17.3°C for level 4 (Table 10). From the mean SST of 13.3°C recorded at the beginning of the occupation in level 12, there was a significant temperature increase in levels 11 and 10. This higher temperature stays relatively stable from level 10 to 6. In levels 5, 4 and 3, SST fluctuates quite dramatically, after which water temperature remains constant at around 15°C until the end of the occupation (Table 10 and Figure 15). The significance of the observed changes in mean SST through time was evaluated between pairs of levels (Table 11). Mann-Whitney U and t-test significance tests show that changes in mean SST are significant only between levels 12-11, 11-10, 6-5, 5-4, and 4-3 (Table 11).

M. californianus Abundance and Number of Species

There is a weak positive correlation between number of species and abundance of *M. californianus* (Pearson's r = 0.299, p = 0.345) (Figure 16). This suggests that when more mussels were collected, other species were included in the collection as well. The same correlation was obtained with and without considering small shellfish species, which are not purposely introduced in the archaeological assemblage but instead came to the site attached to larger shells. When looking at the fluctuation of mussel abundance and number of species through time, levels 12, 11, 10, 7, 3 and 2 show positive correlations and levels 9, 5, 4, and 12 show negative correlations. In addition, it can be seen that levels 12 and 5 are the ones that have the highest number of species, which coincides with intervals of low abundance of mussel (Figure 17). Finally, from levels 7 to 4, corresponding to a period interpreted as of high-intensity of occupation (Table 4), there is not much correlation between number of species and mussel shell weight; at the same time that drastic increases are observed in *M. californianus* abundance from level 7 to 4, number of species stays high but relatively stable (Figure 17).

M. californianus Abundance and Mean Shell Length

There is a weak positive correlation between *M. californianus* abundance and mean mussel shell length by archaeological level (Pearson's r = 0.444, p = 0.141). Figure 18 shows that as mussel shell weight increases, so does mean mussel shell length. Exceptions to this correlation are levels 2, 9 and 12, each having a larger mean shell length than expected for its mussel abundance (Figure 18). Despite the fact that the moderate correlation may not be significant, it is still a pattern to be considered. Under a scenario of a more intensive mussel collection, levels with higher abundance of mussel shells are expected to have smaller mean shell lengths. This is not the case for SCRI-496, where levels with higher abundance of mussel (levels 4 and 7) are associated with lengths around the mean value calculated for the site (6.3 cm long) or larger (Figure 18). The weak correlation observed between mussel abundance and length may be due to the presence of instances of no correlation through the sequence. These instances are from level 9 to 8, where mussel length decreases, and from level 3 to 1, where mussel length fluctuates at the same time that abundance stays relatively stable. Another instance of no correlation is from level 5 to 4, where abundance increases while length stays constant (Figure 19).

Sea Surface Temperature (SST) and Shellfish Species Abundance

A weak positive correlation was found between mean SST and abundance of *M. californianus* shell (Pearson's r = 0.476, p = 0.114). Warmer mean SST may be related to greater mussel abundance (Figure 20). Exceptions to this correlation are levels 7 and 12, each with a higher abundance of mussel shell than expected for its SST (Figure 20). Despite the fact that the moderate correlation may not be significant, it is still a pattern worth considering. A moderate correlation was also found between mean SST and abundance of other two shellfish species. A Pearson's r of 0.572 (p = 0.058) for *T. rubescens* suggests that warmer mean SST may be related to greater abundance of this species, and a Pearson's r of -

0.577 (p = 0.056) for *H. cracherodii* indicate that cooler mean SST could be linked to higher abundance of it (Figure 21).

Sea Surface Temperature (SST) and Mean Shell Length of M. californianus

There is no correlation between mean length of *M. californianus* and mean SST (Pearson's r = of 0.026, p = 0.931). Fluctuations in mean SST (the proxy for oceanographic conditions) do not seem to have had any effect on mussel length and therefore does not explain the variation observed in mean mussel shell length through time (Figure 22). Out of the five pairs of levels where significant changes in mean SST were identified (Table 11) only two pairs also show significant changes in mean mussel length (see pairs 3-4 and 11-12 in Table 9). While mean shell length decreases in these two pairs of levels, SST increases from level 12 to 11 and decreases from level 4 to 3 (Figure 14 and 15). In addition, significant changes in mean shell length are observed in level pairs where mean SST does not show meaningful change (see levels 10 to 6 and levels 3 to 1 in Figure 14 and 15).

Shellfish Remains and Sea Surface Temperature from Sites SCRI-195 (2200-500 cal B.P.)

From the 35 shellfish species identified in the column sample of SCRI-195, *M. californianus* is again by far the most abundant (grams/cm) species through time (Table 13 and Figure 23). The proportion of *M. californianus* shells in the sample fluctuates between 94% to 53% (Table 14), with levels of extremely low percentage (levels 3 and 19), moderately low percentage (levels 8, 10 and 26) and high percentage (levels 5, 6, 9, 12 and 13) (Figure 24). The increased abundance of other shellfish species could be one of the factors making proportions of mussel decrease. This could be the case with level 3, where the second lowest proportion of mussel shell corresponds with the highest abundance of *Strongylocentrotus* sp. (sea urchin) (Table 12, 13 and Figure 25). In levels 10 and 26 the decrease in mussel shell proportion also corresponds with an increase in abundance of other species, such as *Balanus nubilis* (acorn barnacle) and *H. cracherodii* (black abalone), respectively (Tables 12 and 13 and Figure 25). The other two levels with low proportion of mussel shells (levels 8 and 19) do not correspond with the events of higher abundance of other species.

The abundance through time of *M. californianus* shows great variation, with two main peaks of high abundance in levels 25 and 13 and subsequent events of low abundance in levels 19 to 17 and levels 8 to 2 (Table 13 and Figure 23). Within the second period of low abundance, from level 8 to 2, a subtle rebound in mussel shell abundance can be observed from level 6 to 4 (Table 13 and Figure 23). *B. nubilis* is the second most abundant shellfish species in the sample and follows a similar pattern to the one shown by *M. californianus* (Table 12 and Figure 25). The pattern of barnacle shows the same two intervals of higher abundance of mussel shells, but with the second interval consisting of three events of high abundance, from levels 16 to 10. A slight rebound in abundance is also present in level 4. The lowest abundance of this species is from levels 19 to 17 (Figure 25). *T. rubescens* is the third-ranked species in abundance and exhibits fluctuations similar to *B. nubilis* (Table 12 and Figure 25). It exhibits the two described intervals of higher abundance, but in the second interval it exhibits only two peaks, one in level 15 and other in level 13. The lowest abundance of this species is in levels 18, 17 and 11 (Figure 25). *H. cracherodii* is the fourth-ranked species in abundance and shows a very different pattern, with two intervals of higher abundance, the first at the beginning of the sequence, in levels 26 and 25, and the second near the end, in level 4 (Table 12 and Figure 25). Two intervals of a small increase in abundance of *H. cracherodii* occur in the middle of the sequence (levels 16, 15 and 12), which coincides with the increase in abundance of the previously considered species. The lowest abundance of this species is from levels 20 to 17 (Figure 25). Finally, fluctuation in abundance of *Tegula funebralis* (black turban snail) and *Strongylocentrotus sp.* through time departs from the patterns previously described consisting of a single peak in level 4 for *T. funebralis* and in levels 4 and 3 for *Strongylocentrotus sp.* (Table 12 and Figure 25). The lowest abundance of these two species is in levels 18 and 17 (Figure 25).

Number of Species

When looking at the fluctuation in the number of species, a progressive increase is observed throughout the sequence, with a substantial increment from level 9 to level 2 (Figure 26). The new species present in these levels are *Cryptochiton stelleri* (gumboot chiton), *Lottia digitalis* (ribbed limpet), *Cypraea spadicea* (chestnut cowrie), *Polinices* sp. (moon snail), *Hipponix tumens* (hoof snail), and *Lithopoma undosum* (wavy top) (Table 12).

M. californianus Shell Length

The mean length of measured *M. californianus* shells in the SCRI-195 column is 6.3 cm (Table 14). A decrease in mussel shell length is observed from level 28 to level 2, from a mean length of 7.6 cm in level 28 to a mean length of 5.7 cm in level 2 (Table 14 and Figure 27). Despite this trend, great variability is observed throughout the sequence, with several intervals of decrease (levels 26-24, 21, 18, 13, 10, 7 and 3) and rebound (levels 27, 22-23, 19, 12-11, 9-8, 6 and 2) (Figure 27). Standard deviations for shell length measurements within each level are shown in Table 9. Levels 2, 3, 7, 8, 21 and 24 have larger standard deviations, that is, greater variation of shell measurements within the sample, and levels 17, 18, 19 and 20 have smaller standard deviations, indicating less variation of shell length measurements in these levels (Table 14). Based on the similar sample size between levels with smaller and larger standard deviations, differences between levels are not considered to be a factor of sample size.

Finally, the significance of the observed changes in *M. californianus* length through time was evaluated between pairs of levels (Table 15). Mann-Whitney U and t-test significance tests show that many of the changes in mean mussel shell length are significant (Table 15 and Figure 27). Dramatic and gradual changes in mussel shell length are present through the stratigraphic sequence at SCRI-195 (Figure 27). A gradual decrease in mean mussel shell length is observed at the beginning of the sequence, from level 27 to 24, followed by a dramatic decrease from level 22 to 21. After a period with the lowest mean shell length in the column (from levels 21 to 17), there was a dramatic increase from level 17 to 16, followed by a gradual increase until level 11. A dramatic decrease then is observed from level 11 to 9, followed by another dramatic increase from level 7 to 6. A gradual decrease is subsequently observed from levels 6 to 4, with a final dramatic decrease from level 4 to 3 (Figure 27).

Past Sea Surface Temperature (SST)

The mean Sea Surface Temperature (SST) value obtained from oxygen isotope analysis of *M. californianus* shells from SCRI-195 is 14.4°C (Table 16). Fluctuations in water temperature are observed through the stratigraphic sequence at the site, with the lowest mean SST of 13.9°C in level 18 and the highest mean SST of 18.7°C in level 11 (Table 16). As shown in Figure 27, the SST value of 18.7°C for level 11 departs significantly from the SST record for the site. If the mean SST value of this level is excluded, the SST fluctuation through the stratigraphic sequence ranges between 13.9°C for level 18 to 15.4°C for level 13 (Table 16). Finally, the significance of the observed changes in mean SST through time was evaluated between pairs of levels (Table 17). Mann-Whitney U and t-test significance tests show that changes in mean SST through time are not significant except for a decrease in SST from level 27 to 26, an increase from level 16 to 14, an increase from level 13-11, and a subsequent decrease from level 11 to 9 (Figure 28 and Table 17). Excluding the anomalous mean SST value for level 11, the significance of the decrease in mean SST from level 13 to 9 was evaluated, and this was also significant (Table 17). With the exception of level 11, non-significant fluctuations are observed in the SST record through time. SST stayed relatively stable around 14°C throughout the archaeological occupation (Table 16 and Figure 28).

M. californianus Abundance and Number of Species

There is a weak negative correlation between number of species and abundance of *M. californianus* (Pearson’s r = -0.210, p = 0.293). Levels with a higher number of species have a low abundance of mussel (Figure 29). The same correlation was obtained with and without considering small shellfish species, these not purposely introduced into the archaeological assemblage but coming to the site attached to larger shells. When looking at the fluctuation in mussel abundance and number of species through time, it can be seen that the interval with the greatest number of species is from level 9 to 2, which coincides with a period of low abundance of mussel (Figure 30). Intervals from level 20 to 24, and from level 15 to 14 also have a large number of species and low abundance of mussel. Levels 25 and 13, conversely, with the highest abundance of mussel, have relatively low numbers of species (Figure 30).

M. californianus Abundance and Mean Mussel Shell Length

There is a weak positive correlation between *M. californianus* abundance and mean shell length by archaeological level (Pearson's r = 0.288, p = 0.141). Figure 31 shows that as weight of mussel shells increases, so does mean mussel shell length. Exceptions to this correlation are levels 13, 21 and 25, with smaller mean shell length relative to their mussel abundance (Figure 31). Despite the fact that the weak correlation may not be significant, it is still worth considering. Under a scenario of a more intensive mussel collection, levels with higher abundances of mussel shells are expected to have smaller mean shell lengths. Only level 13, with a higher abundance, is associated with smaller mean length. Levels 12, 16 and 25, also with higher abundance, do not contain smaller shells but instead have shell lengths around the mean calculated for the site (6.3 cm) (Figure 31). Levels 28-26, 24-22, 19, 14 and 11-2, with lower abundance, have higher mean lengths. The weak correlation observed between mussel abundance and length is reflected in the fact that intervals of positive, negative, and no correlation can be observed through time. Positive correlations are observed from levels 28 to 26, 19 to 16, 8 to 5, and 4 to 2. Negative correlations are identified from level 24 to 22, 22 to 21, 21 to 19, 16 to 14, 14 to 13, 13 to 12, 12 to 11, and 5 to 4. Finally, no correlations are found in levels 25 and also from level 10 to 8 (Figure 32).

Sea Surface Temperature (SST) and Shellfish Species Abundance

No correlation was found between mean SST and abundance of *M. californianus* shells (Pearson's r = 0.160, p = 0.498). Warmer mean SST is not related to greater mussel abundance (Figure 33). The same situation exists for the rest of the shellfish species identified in the column sample, with the exception of *T. funebralis*. A moderate positive correlation was found between mean SST and abundance of this snail. A Pearson's r of 0.682 (p = 0.004) suggests that warmer mean SST is related to greater abundance of this species (Figure 34).

Sea Surface Temperature (SST) and Mean Shell Length of M. californianus

A weak positive correlation was found between mean length of *M. californianus* shells and mean SST (Pearson's r = 0.321, p = 0.173). Fluctuation in mean SST does not seem to have had a significant effect on mussel length through time (Figure 35). The only interval of a significant change in mean SST and mean mussel length is around level 11. As mean SST increases from level 13 to 11, mean mussel shell length rises from level 13 to 12. Subsequently, as mean SST decreases from level 11 to 9, mean mussel length also declines from level 11 to 10.

Comparison between Sites SCRI-496 and SCRI-195

M. californianus shells are the most profuse shellfish remains at SCRI-496 and SCRI-195, and SCRI-195 has larger quantities of mussel shells than SCRI-496. The column from SCRI-195 contains a total of 4766 grams of mussel shells, with the highest abundance in level 13, with 587 grams (Table 12). SCRI-496 has a lower abundance of mussel shells, with a total of 1291 grams, and the highest abundance is in level 7, containing 327 grams of shells (Table 7). Both archaeological sites show two peaks of mussel abundance within their stratigraphic sequences. The first peak at SCRI-195 (level 25 in Figure 10) occurred at approximately the same time as the two peaks identified at SCRI-496 (level 7 and 4 in Figure 9), around 1900-1700 cal B.P. The second peak of mussel abundance at SCRI-195 (level 12 in Figure 10) occurred between 1618-1329 cal B.P. and 1407-1075 cal B.P., which coincides with a time interval at SCRI-496 with low abundance of mussel shells (after level 3, Figure 9). An interval of very low mussel and overall shellfish abundance also occurs from levels 18 to 17 at SCRI-195 (Figure 10). The event is not dated but appears to have occurred between 1980-1595 cal B.P. and 1618-1329 cal B.P. (Table 3). This interval of lowest overall shell abundance in the record of SCRI-195 coincides with a period of time at SCRI-496, identified as of very low occupation intensity and interpreted as a possible gap in the chronological sequence (level 3, 1773-1530 cal B.P.) (Table 4).

In general, SCRI-195 exhibits larger fluctuations through time in *M. californianus* abundance and proportion than does SCRI-496 (mussel abundance in Figures 11 and 12, and mussel proportion in Figures 23 and 24). Neither of the sites exhibits a progressive decrease in mussel abundance or in the proportion of mussel shells throughout the sample.

Regarding other shellfish species identified in the column samples, the most abundant species after *M. californianus* are the same at both sites: *B. nubilis*, *H. cracherodii*, *T. rubescens* , and *Strongylocentrotus sp.* (Table 6 and 12). The exception is *T. funebralis*; while almost absent in the shellfish assemblage from SCRI-496 (Table 6), it is the fifth most abundant species in site SCRI-195 (Table 12).

The high abundance of *T. rubescens* at both sites is due to their coming to the sites attached to the abundant shells of *M. californianus* and *H. cracherodii*. This species of barnacle is common in middle and low rocky intertidal zones and grows as solitary individuals and on hard-shelled organisms such as mussels and abalones (Dawson, et al. 2010). At SCRI-496, the abundance of *T. rubescens* shows a weak positive correlation with *M. californianus* (Pearson's r = 0.391, p = 0.209) and a weak negative correlation with *H. cracherodii* (Pearson's r = -0.311, p = 0.325), suggesting that *T. rubescens* came to the site attached to mussel shells but not to shells of this abalone species. At SCRI-195, the abundance of *T. rubescens* shows a strong and highly significant correlation with *M. californianus* (Pearson's r = 0.760, p = 0.000) and a weak positive correlation with *H. cracherodii* (Pearson's r = 0.345, p = 0.085), suggesting that this barnacle came attached mainly to mussel shells but also to shells of this abalone species.

Number of Species

SCRI-195 contains a larger number of species (n = 26) than SCRI-496 (n = 16), which suggest the exploitation of a wider variety of shellfish species: the common and more abundant and also the rarer and more difficult to find (Tables 12 and 6 and Figures 13 and 26). In addition, SCRI-195 exhibits larger fluctuations between levels with the lowest and the highest number of species. At SCRI-195, the number ranges from 10 to 26 species per level and at SCRI-496 the range is 11 to 16 species per level. Finally, SCRI-195 shows a gradual increase in the number of species collected throughout the stratigraphic sequence while SCRI-496 shows oscillations without an obvious trend (Figures 13 and 26).

M. californianus Shell Length

M. californianus shells collected near SCRI-195 were longer than the ones collected near SCRI-496. This is illustrated by the mean shell length of 6.3 cm for SCRI-195 and 5.5 cm for SCRI-496 (Tables 8 and 14). At both sites, there is a reduction of around two centimeters in the mean length of mussel shells from the bottom to the top of the column samples (Table 8 and 14). Despite the overall decrease in mussel length, neither site exhibits a continuous decline through time, but instead exhibits several events of reduction and rebound (Figures 14 and 27).

Past Sea Surface Temperature (SST)

Past mean SST derived from oxygen isotope analysis of *M. californianus* shells near SCRI-496 (15.7°C) is around 1°C higher than near SCRI-195 (14.4°C). Despite of having a higher mean SST value, SCRI-496 has an anomalously low SST record of 13.3°C for level 12 (Table 10). On the other hand, SCRI-195 has an anomalously high value of 18.7°C in level 11 (Table 16). Excluding these anomalous SST values, mean water temperature fluctuated between around 15°C to 17°C throughout the occupation of SCRI-496 and between 14°C to 15°C during the occupation of SCRI-195 (Table 10 and 16).

M. californianus Abundance and Number of Species

Under the scenario of increasingly intensive foraging, predation on *M. californianus* (the most abundant species along the California coast) would have increased, with a detrimental effect on mussel abundance and length. With a decrease in accessibility and length of available mussels, collectors would have been induced to include smaller and/or less accessible species. Under these conditions, a negative correlation between mussel abundance and number of species would be expected: as mussel abundance decreases, the number of species increases. At SCRI-195, levels exhibit mainly weak negative correlations, with intervals that have decreasing abundances of mussel and increasing numbers of species, and intervals that have high abundance of mussel and relatively low numbers of species (Figure 30). In contrast, intervals through the sequence at SCRI-496 exhibit negative, positive and no correlations between number of species and abundance of mussel (Figure 17). Consequently, correlations at only SCRI-195 suggest some degree of relationship between a decline in mussel abundance and the rise in the number of species collected through time.

M. californianus Abundance and Mean Mussel Shell Length

Both sites exhibited a weak to moderate positive correlation between *M. californianus* abundance and mean shell length (SCRI-195: $r = 0.288$, $p = 0.141$, SCRI-496: $r = 0.444$, $p = 0.141$). Levels with higher abundance of mussel tend to have longer mean shell lengths (Figures 18 and 31). The degree of correlation at SCRI-195 is more variable, with several intervals of negative correlation (Figure 32); negative correlations that are absent at SCRI-496 (Figure 19).

Sea Surface Temperature (SST), M. californianus Length, and Abundance of Shellfish Species

At SCRI-195, no correlation was found between SST and *M. californianus* abundance ($r = 0.160$, $p = 0.498$). Therefore, differences in SST do not explain the variation observed in the amount of mussel shells through time (Figure 33). At SCRI-496, on the other hand, changes through time in SST may have had some influence on the abundance of shellfish species. A moderate positive correlation was found between SST and the abundance of *M. californianus* (r = 0.476, p = 0.114) and *T. rubescens* (r = 0.572, p = 0.058), and a moderate negative correlation was found between SST and the abundance of *H. cracherodii* (r = -0.577, p = 0.056).

Regarding possible correlations between variation in SST and shell length of *M. californianus*, no correlation was found at SCRI-496 (r = 0.026, p = 0.931) and a weak positive correlation was found at SCRI-195 (r = 0.321, p = 0.173). At both sites fluctuation in mean SST does not seem to have had an effect on mussel length, and therefore SST does not account for the variation observed in mean mussel shell length through time at either site (Figure 35 and 22).

Nearshore Paleoceanographic Conditions around Santa Cruz Island: 2200-500 cal B.P.

Regarding past SST, the mean SST values obtained through the stratigraphic sequences at SCRI-496 and SCRI-195 show variation in nearshore oceanographic conditions through the two thousand years of occupation (Table 18 and 19). Two intertidal ecological monitoring sites are located on rocky shores near the archaeological sites under study; the Trailer ecological site (Trailer) is located on the west coast of Santa Cruz Island next to SCRI-195 and Willows ecological site (Willows) is on the south coast of the island about 100 m from SCRI-496 (Figure 36). Modern long-term mean SST recorded near these ecological sites (from 1982 to 2007) is 15.1°C for Trailer and 15.7°C for Willows (Table 20). The mean SSTs for Willows and from the SCRI-496 shell oxygen isotopes are almost the same, which implies that nearshore water temperature on the south coast of Santa Cruz Island have been relatively stable from 2200 cal B.P. to the present (Figure 37). On the west coast of the island, mean SSTs for Trailer and from the SCRI-195 shells are different; mean SST from the SCRI-195 shells is almost 1°C lower than modern mean SST at Trailer (Figure 37). It is important to clarify that the mean SST of SCRI-195 shown in Figure 37 does include the anomalous SST value of 18.7°C. Nevertheless, the difference of almost 1°C between past and modern mean SST did not change when the anomalous SST value was excluded. This suggests that nearshore water temperature on the west coast of Santa Cruz Island during the Late Holocene was cooler than during modern times. Lower mean SST at SCRI-195 compared with SCRI-496 illustrates the deep roots of oceanographic patterns around Santa Cruz Island, with cooler waters on the northwest coast and warmer waters towards the southeast coast of the Island (Figure 36 and 37). The magnitude of the west-east thermal gradient in SST around Santa Cruz Island seems to have been greater during the Late Holocene than at present. During the occupations of the archaeological sites, the west coast of the island was 1.3°C cooler than the south coast, and during present times only 0.6°C (Figure 38).

Modern mean SST values for nearshore locations around Santa Cruz Island range from 15.0°C off the west coast to 15.8°C off the southeast coast (Table 20). Variation in mean SST values for the levels at both archaeological sites exceeds this modern range (Table 18 and 19, Figure 39). Even excluding the extreme values of 13.3°C from SCRI-496 and 18.7°C from SCRI-195, the past mean SST values show a wider variation than the modern range of mean SST around Santa Cruz Island (Figure 39). Methodological issues could be considered as a factor for higher and lower values in past mean SSTs obtained from the oxygen-isotope values (i.e., sampling of archaeological mussel shell and/or isotopic analytic procedures). Nevertheless, 335 samples from *M. californianus* shells from SCRI-496 and 461 samples from SCRI-195 exhibit a reasonable pattern of fluctuation in nearshore oceanographic conditions around Santa Cruz Island over a two thousand year period (Figure 40).

Figure 40 presents mean SST for each level through the stratigraphic sequences of SCRI-496 and SCRI-195, and the modern SST range from mean SST values around Santa Cruz Island are presented in Table 20. Three levels at SCRI-496 have mean SSTs cooler than the modern range of water temperatures around Santa Cruz Island (levels 1, 3 and 12 in Figure 40), and three levels have mean SST values within that range (levels 2, 5 and 11 in Figure 5). The other six levels of SCRI-496 have mean SST values warmer than present nearshore water temperatures around the island (levels 4, 6, 7, 8, 9, and 10 in Figure 40). These SST values suggest that despite great variation, warmer oceanographic conditions were predominant during the prehistoric occupation of SCRI-496 compared with present times around Santa Cruz Island (Figure 40). At SCRI-195, the majority of levels have mean SST values cooler than present mean sea surface temperature around Santa Cruz Island (Figure 40). However, levels 13, 14 and 27 have mean SSTs within modern mean SST range, and archaeological level 11 has a mean SST value much warmer than present mean temperatures around Santa Cruz Island (Figure 40).

Past Natural Availability of *M. californianus*

M. californianus is the most abundant shell constituent in the shellfish assemblages and the proportion of this species ranges between 82% and 93% at SCRI-496 and between

53% and 94% at SCRI-195 (Table 18 and 19). Ecological data on mussel abundance is available at five intertidal ecological sites around Santa Cruz Island (Figure 36). Table 20 shows these ecological sites with their long-term mean SST values and percent mussel cover. There are two sets of data about mussel abundance: “point contact” refers to the percentage of the rocky intertidal surface covered by mussel and “mussel plot” indicates percentage of mussel cover inside the mussel bed. Considering that mussel beds around present Santa Cruz Island cover 5 to 17% of the rocky intertidal zone, the consistently high percentage of mussel shells found within the deposits of SCRI-496 and SCRI-195 suggest that ancient people were intensively foraging these small areas within the intertidal zone near the sites. The rest of the rocky intertidal area at the five ecological sites around Santa Cruz Island is variably covered by algae and sea grass (~50%), small barnacles (~20%) and other taxa such as whelks, limpets, snails, chitons and urchins (~10%) (Blanchette, et al. 2006). Another indication of intensive collection of mussel beds during prehistory is that the percentage of mussels in modern intertidal mussel beds is 34% to 46% of the bed area, half the proportion of mussel shells in each archaeological level at SCRI-496 and SCRI-195.

Considering the locations of SCRI-496 next to the Willows ecological monitoring sites and of SCRI-195 adjacent to the Trailer site (Figure 36), natural characteristics of these rocky shores may be used as references for past conditions. Table 20 shows that the rocky intertidal zone at Trailer, which experiences lower long-term mean SST, has the smaller percentage of space covered by *M. californianus* (point contact data) but at the same time has a high percentage of mussels in mussel beds (mussel plot data). Rocky intertidal zone at Willows, with a higher mean SST, has the largest percentage of space covered by *M. californianus* but a lower percentage of mussels in mussel beds. This indicates that around

Santa Cruz Island, coastal locations with cooler mean water temperatures have smaller mussel beds but higher percentage of mussels in those beds, and locations with warmer mean water temperatures have more extensive mussel beds but with lower abundances of mussel in them (Table 20). Complementing these data, ecological studies have found that due to higher rates of mussel growth in coastal locations with warmer waters, mussel beds at sites with warmer SSTs have larger individuals but in low densities, and mussel beds at sites with cooler SSTs have smaller individuals but in high densities (Blanchette and Gaines 2007; Smith, et al. 2009). Two other factors enhanced this pattern: 1) A higher abundance of large mussels at warmer sites is facilitated by the relative absence of sea star predators, allowing mussel beds to exist even in the low intertidal zone and potentially increasing feeding time and growth. 2) Increased intra-specific competition at warmer-water sites with fast-growing mussels may be responsible for higher mortality rates of small individuals (Blanchette and Gaines 2007). Because of the faster growth rates of mussel at warmer-water sites around Santa Cruz Island, Blanchette and colleagues (2006) also found low densities of large mussels at Willows and high densities of small mussels at the cooler-water site of Trailer. Assuming that past characteristics of the rocky intertidal were similar to those at present, one could propose that during the occupation of SCRI-496, the rocky intertidal area at Willows had a more extensive mussel bed from which to collect larger mussels, and during the occupation of SCRI-195, the rocky intertidal area at Trailer had small mussel beds with a high abundance of smaller mussels. If this were the case, the archaeological deposits at Willows should have larger lengths and proportionally more mussels than at the archaeological site next to Trailer. This is not the case, however. SCRI-195, next to Trailer, has proportionally more mussel shells and larger lengths through time than SCRI-496 at Willows (Tables 7 and 8 for SCRI-496 and Tables 13 and 14 for site SCRI-195).

Chapter 6. Discussion

Shellfish data from two shell midden sites occupied contemporaneously during the Late Holocene around Santa Cruz Island have been presented. The occupation of SCRI-496 on the west coast of the island ranged from 2254-1937 to 458-282 cal B.P., and the occupation of SCRI-195 on the south coast of the island ranged from 2124-1845 to 630-501 cal B.P. (Table 2 and 3). The dynamics of occupation at these two shell midden sites was different, with a less intense and more irregular occupation at SCRI-496 and a more intense and continuous occupation at SCRI-195.

Information on chronology, rates of sediment deposition and *M. californianus* abundance reveals that these shell midden sites had two main periods of occupation. The first is characterized by a high intensity of occupation evidenced by great, although fluctuating, abundances of mussel shells. It is dated between 2254-1937 cal B.P. and 1980-1750 cal B.P. at SCRI-496 (level 12 to 4) and between 21124-1845 cal B.P. and 1980-1595 cal B.P. at SCRI-195 (level 28 to 21) (Figure 9 and 10). After this period, a decrease in mussel abundance is observed at both sites. At SCRI-496, this period of lower-intensity occupation dates around 1773-1530 cal B.P. and at SCRI-195, this episode does not have a direct date but may have occurred between 1980-1595 cal B.P. and 1618-1329 cal B.P. (Figures 9 and 10). Following this interval of significantly lower-intensity occupation, SCRI-496 and SCRI-195 were not occupied with equal intensity. SCRI-496 exhibits a low but steady abundance of *M. californianus* and SCRI-195 shows an initial very high abundance with a subsequent decrease until the end of the occupation. This second interval of occupation occurred between 1773-1530 cal B.P. and 458-282 cal B.P. at SCRI-496 and between 1618-1329 cal B.P. and 630-501cal B.P. at SCRI-195 (Figure 9 and 10).

What happened around 1700 B.P. that caused people to use coastal locations on the south and west coasts of Santa Cruz Island less intensively than earlier? Based on the Holocene climatic record of the Santa Barbara Basin, the interval of low occupation identified at SCRI-496 and SCRI-195 occurred at the end of a period of warm SST and higher precipitation, between 2300 and 1500 B.P. This interval may have been a period of transition and probably of some environmental instability that may have had repercussions on human groups inhabiting the coast. Mean SSTs derived from the oxygen isotope analysis for the archaeological levels with little evidence of occupation are very low, probably "announcing" the cooler and drier period to come (see level 3 for SCRI-496 in Figure 41 and level 18 for SCRI-195 in Figure 42). After this period, the paleoclimatic record of the Santa Barbara Basin exhibits cooler seawater and low precipitation dominating between 1500 and 500 B.P., which coincides with the second interval of occupation at these sites, with low-intensity occupation at SCRI-496 and high-intensity occupation at SCRI-195. Why was this difference in intensity between sites during the second interval of occupation? Studies around the Channel Islands have ranked suitability of coastal localities based on the size of drainages, kelp forest, rocky intertidal and sandy beaches (Kennett, et al. 2009; Winterhalder, et al. 2010). Based on these parameters, Willows, where site SCRI-496 is located, was ranked as the forth most suitable place to live in around Santa Cruz Island. Trailer, on the west coast of the island, where site SCRI-195 is located, is not ranked due to the absence of substantial drainages in the area, but the site is ~4.5 km from Canada Christi, the second highest-ranked coastal habitat (Kennett, et al. 2009; Winterhalder, et al. 2010). Under a scenario of drier conditions, a location near the mouth of a drainage with perennial water (Willows) would be expected to be used more intensively than a location farther away from one (Trailer). However, aspects other than natural suitability of coastal habitats may have been considered in the selection of a habitation location, such as trade opportunities, social interactions, and even social protection. This last aspect may have been important within a context of increasing population and warfare identified around the Channel Islands after 1500 B.P., a date that approximately coincides with the beginning of the second interval of occupation described at SCRI-496 and SCRI-195.

The record of past SST obtained from oxygen isotopes of *M. californianus* shells through the sequence of occupation at SCRI-496, coincides with the regional paleoclimatic record proposed by Kennett and colleagues (2007:355). Column sample levels dated within the warmer period, between 2200 and 1500 cal B.P., have higher mean SST values than levels after this time, with dates between 1500 and 500 B.P. (Figure 41). An exception is the low mean SST of level 12, which, based on its date around 2200 cal B.P., could be interpreted as a continuation of the previous period dominated by cool SSTs and low precipitation (Kennett, et al. 2007:355). In contrast, mean SST through the sequence of occupation at SCRI-195, does not coincide with the regional paleoclimatic record. There are no differences between levels dated within the warmer period of the regional record, between 2200 and 1500 B.P., and levels after it dating within the cooler period, between 1400 and 500 B.P. (Figure 42). There is a high degree of variation in mean SST throughout the sequence at this site; in fact, the level with highest mean SST value is within the time period defined as cooler in the regional paleoclimatic record (Kennett 2005; Kennett and Kennett 2000; Kennett, et al. 2007).

The lack of coincidence between the regional paleoclimate record derived from the Santa Barbara Basin and local SST record throughout SCRI-195 is not surprising. The west coast of Santa Cruz Island, where the shell midden site is located, is characterized by persistent influx of cold upwelled waters (Broitman, et al. 2005), and localities with strong and permanent upwelling have been suggested to be less affected by fluctuations of regional oceanographic conditions, and therefore more stable environmentally through time. Examples of higher stability of upwelled localities are shown in studies about the effect of regional oceanographic phenomena such as El Niño Southern Oscillation (ENSO), an intrusion of warm waters masses into the eastern Pacific Ocean (Blanco, et al. 2001; Broitman, et al. 2005; Elbert, et al. 1994; Navarrete, et al. 2002; Vargas, et al. 2007). These studies show that upwelling is not strongly reduced during El Niño (Blanco, et al. 2001), and also that dynamics of coastal resources do not always coincide with the presence of this warm-water oceanographic event (Elbert, et al. 1994; Navarrete, et al. 2002). As there is not always a linear relationship between coastal upwelling and variability of regional oceanographic phenomena such as ENSO (Vargas, et al. 2007), SST at locations with persistent and strong upwelling (west coast of Santa Cruz Island) may have been more influenced by prolonged cold events, associated with the impact of upwelling episodes, than by long-term variation in regional oceanographic conditions. In fact, paleoceanographic data from SCRI-496 and SCRI-195 support higher frequency, magnitude, and perhaps duration of upwelling events along the west coast of Santa Cruz Island during the Late Holocene (2200-500 B.P.). Oxygen-isotope analysis of *M. californianus* shells from these two shell midden sites shows that SSTs were cooler on the west coast and that the average SST difference between the west and south coast of the island was 1.3°C during the Late Holocene, in contrast to 0.6°C during modern times (Figure 37 and 38). Glassow et al. (2012) also show larger difference between past and historic water temperatures at the west end of the island. They compared past SST from a Middle Holocene deposits (6300-5300 cal B.P.) at the west and southwest coasts of Santa Cruz with modern SST from the same locations, and they also found that sea waters were cooler in the west and that temperature differences were greater in prehistory.

Data presented above concerning persistently cooler waters on the west coast of the island through time and the higher frequency, magnitude, and perhaps duration of upwelling events off the west coast during the Middle and Late Holocene (~6300-500 B.P.), suggest that this part of the island was a more stable local environment, highly productive in fish resources (e.g. Parrish, et al. 1981) and probably more humid due to the fog generally related to upwelling locations than south or east parts of Santa Cruz Island (Breaker and Ronald 1981; Fischer, et al. 2009; Fischer and Still 2007; Tont 1981). A locality with these characteristics must have been desirable during a period of unstable regional climatic conditions of cold SST, low precipitation, and increasing demographic and foraging pressure on coastal resources (1500-500 B.P.). Together with socio-cultural variables, the combination of regional climatic conditions and local nearshore oceanographic characteristics may help explain the higher intensity of occupation at SCRI-195 compared with SCRI-496, and also the higher intensity of occupation of the west coast of the island during the Late Holocene (1500-500 B.P.) (Glassow 1993; Kennett 2005; Munns and Arnold 2002).

What is the prehistory of occupation at the nearby archaeological sites contemporaneous to the occupation of SCRI-496 and SCRI-195 (2200-500 B.P.)? At least twelve archaeological sites near SCRI-496 are recorded, but none has been investigated

(California Coastal Information Center at University of California Santa Barbara (CCIC)). Early excavations at Willows by Schumacher in 1875 and Olson in 1927-1928 mention human remains and artifacts (CCIC). A later publication based on the work of Olson (Rogers 1929) mentions a complex settlement with a large shell midden and associated workshop and burial areas, house floors, and domestic artifacts such as asphalt with basket impressions, red ocher, wood objects, bones, mortars, pestles and chert drills. Unfortunately, no direct chronological information is provided, but the presence of scarce Spanish artifacts (an iron-bound keg) reveals that the site was used until early in the historic period. Other coastal sites near SCRI-496 are SCRI-109 and SCRI-1, both approximately five kilometers distant (Glassow 1993; Glassow, et al. 2008; Kennett 2005; Munns and Arnold 2002). SCRI-109, at Punta Arena, was occupied between 8530-8380 cal B.P. and 2115-1915 cal B.P., with a sporadic use suggested during the last period (Glassow, et al. 2012; Glassow, et al. 2008). Occupation of site SCRI-1, at Coches Prietos Anchorage, began around 2532-2180 cal B.P. and was occupied until historic times (Glassow 1993; Kennett 2005; Munns and Arnold 2002). Regarding SCRI-195, there are several shell middens within a radius of one to four kilometers (SCRI-333, 328, 330, 191, 236, and 257) occupied at different times between 2857-2753 cal B.P. (site SCRI-333) and 264-0 cal B.P. (site SCRI-328) (Glassow 1993; Kennett 2005; Munns and Arnold 2002). A disruption in settlement has been identified between 800 and 650 B.P. around Santa Cruz Island. It is known as the Middle-Late Period Transition and is believed to have resulted in people aggregating into relatively few locations (Munns and Arnold 2002). Some of the sites near SCRI-195 were occupied through this period (SCRI-191 and 236) and some were inhabited after it (SCRI-328, 330 and 257) (Arnold 2001a; Kennett 2005). Chronological data from SCRI-195 and SCRI-496 do not have dates within this period, but malacological data show evidence of continuous shellfish harvesting from before to after 800-650 B.P. (Figure 9 and 10). Finally, the evidence of minimal occupation about 1700 B.P. at SCRI-496 and SCRI-195 does not seem to have correlates at the nearby sites, although the quantity of radiocarbon dates is too small to be sure. What can be said, though, is that after this period, while site SCRI-496 was occupied at very low intensity, site SCRI-195 was intensively occupied, as were other archaeological sites on the west coast of the island (sites SCRI-333, 236, 191) (Kennett 2005; Munns and Arnold 2002).

Effect of Natural Factors on Archaeological Shellfish Assemblages

The archaeological records of SCRI-496 and SCRI-195 show that fluctuation in past SST did not significantly affect abundance or length of *M. californianus* collected by the sites' occupants during the 2200-500 B.P. period of their occupation. Correlation between variation in past SST and abundance of shellfish species and mussel shell length through time was weak or absent, revealing that fluctuations in mean SST do not explain the variation observed in the archaeological records of shellfish collecting at the sites.

In addition, oxygen isotope data from archaeological shells of *M. californianus* spanning the occupations at the sites show that past oceanographic conditions around Santa Cruz Island did not differ substantially from present times. Although there was considerable variation in past mean SST, nearshore oceanographic conditions at SCRI-496 (south coast) were consistently warmer than at SCRI-195 (west coast). These results agree with the modern oceanographic pattern around Santa Cruz Island, with cooler waters towards the west coast and warmer waters along the south coast (Figure 36) (Blanchette, et al. 2006;

Blanchette, et al. 2009; Broitman, et al. 2005). Additionally, the described variation in past SST during the period represented by the archaeological sites (2200-500 cal B.P.) was within modern temperature ranges of *M. californianus* habitats (Smith, et al. 2006, 2009). This implies that fluctuations in past nearshore oceanographic conditions were not significant enough to modify rocky intertidal resources available for human foragers, or to explain fluctuations in *M. californianus* abundance and length observed in the sites' archaeological records (Figure 43 and 44).

As mentioned in Chapter 3, season of occupation and resource use at SCRI-496 and SCRI-195 was not possible to infer from the oxygen isotope data obtained from *M. californianus* shells. Studies of seasonality based on oxygen isotope data from mollusk shells utilize changes in inferred SST variation along the shell's growth axis to interpret seasonal fluctuations in water temperature through the shell's life span. The sample from the shell margin is used as indication of season (warmer or cooler water temperature) of mollusk death and therefore mollusk foraging (Bailey, et al. 1983; Glassow, et al. 1994; Kennett and Voorhies 1996; Killingley 1981; Killingley and Berger 1979; Shackleton 1973). Unfortunately, the samples of mussel shells used in this study did not contain enough intact edges for this analysis.

Effect of Human Factors on Archaeological Shellfish Assemblages

Natural characteristics of *M. californianus* make mussel populations highly resilient to human foraging (Jones and Richman 1995; Whitaker 2008; Yamada and Peters 1988). *M. californianus* form large patches of dense beds within the rocky intertidal zone, become reproductive at 35-40 mm in length, that is, within four to eight months of attaching to the rock (Suchanek 1981), and spawn throughout the year, with mussel larvae broadcasted over great distances (Broitman, et al. 2005; Suchanek 1981). Regarding length of *M. californianus*, small mussels are often crowded out in thick beds by larger individuals that monopolize the space on rocks (Blanchette and Gaines 2007; Yamada and Peters 1988). Despite the fact that human predation on shellfish species such as *M. californianus* has been strongly correlated with reductions in number of large individuals (Castilla and Duran 1985; Hockey and Bosman 1986; Keough, et al. 1993; Sagarin, et al. 2007), regular human harvesting of larger mussels may relieve intraspecific competition within mussel beds, thus enhancing the growth rate of the remaining mussels and increasing the overall productivity of mussel populations (Hockey and Bosman 1986; Whitaker 2008; Yamada and Peters 1988). All these characteristics may contribute to the long-term record of mussel foraging through prehistory (Braje, et al. 2007a; Erlandson, et al. 2008; Jones and Richman 1995; Whitaker 2008).

As discussed above, nearshore oceanographic conditions recorded during the occupation of SCRI-496 and SCRI-195 do not explain variation observed in their shellfish archaeological records but may help to explain differential effects of human foraging on shellfish populations exploited at the rocky shore next to the two archaeological sites. Trailer, next to SCRI-195, as a cold-water coastal location, experiences a shorter influx of *M. californianus* larvae, mussel specimens have a slower growth rate and therefore mussel beds are less extensive, and with smaller individuals than at Willows, a warm-water coastal location (Blanchette, et al. 2006; Blanchette and Gaines 2007; Blanchette, et al. 2009; Broitman, et al. 2005; Smith, et al. 2006, 2009; Suchanek 1981; Yamada and Peters 1988). In consequence, lower *M. californianus* productivity at Trailer makes its intertidal rocky shore less resilient to human foraging pressure than the rocky shore at Willows. As past oceanographic conditions around the island did not differ substantially from present, human harvesting during the occupation of SCRI-195 may have had a greater impact on mussel beds at Trailer than mussel foraging at Willows during the occupation of SCRI-496. Actually, several aspects of the shellfish assemblage from SCRI-195 show signs of increased predation pressure and decreased foraging efficiency, signs absent in the malacological record at SCRI-496. These aspects are 1) a wide variety of shellfish species (Table 12); 2) a gradual increase in the number of species through time (Figure 26); 3) an increase in the abundance of *Strongylocentrotus sp.*, *T. funebralis*, and *H. cracherodii* at the end of the site's occupation, coincident with the decrease in the abundance of mussel (Figure 23 and 25); 4) an overall decrease in length of *M. californianus* through time (Figure 27); 5) several events of coincident decline in abundance of *M. californianus* and increase in number of species (Figure 30); and 6) several intervals through the chronological sequence of coincident decline in abundance of *M. californianus* and increase in their length (Figure, 32). In addition, the weak correlation between mean SST and mean mussel length (Figure, 35), and the absence of correlation between SST and abundance of mussel (Figure, 33) at SCRI-195, suggest that fluctuations in shellfish abundance was related to human foraging activities and not to nearshore oceanographic conditions; that is, SST fluctuations were not as strong as the effect of variation in *M. californianus* collecting intensity (Figure, 33). The described characteristics, seem to fit the expectations of the Diet Breath and Prey Choice models under conditions of increased human pressure on intertidal resources, which coincides with what has been described concerning marine resource utilization during the Middle and Late periods (2200-500 cal B.P.) on the northern Channel Islands and Santa Cruz (Arnold 2001b; Glassow 1993; Kennett 2005; Kennett, et al. 2009; Winterhalder, et al. 2010).

Data on the effect of warmer and cooler long-term sea surface temperatures (SST) on mussel beds' productivity, and the implications for past shellfish foraging around Santa Cruz Island, do not fit with the relationship widely assumed by archaeologists working on the northern Channel Islands between cooler sea waters, higher marine productivity and larger length and greater abundance of mussels (e.g. Braje, et al. 2007a:749; 2012:117; Erlandson, et al. 2008:2149). This assumption is based on the relationship between cooler waters of productive marine upwelling regions and productivity of kelp forest and fish habitats (e.g. Graham 2004; Kinlan, et al. 2005). Archaeologists have assumed that this productivity also includes intertidal shellfish habitats, especially *M. californianus* beds. As discussed above, cold-water coastal locations such as Trailer on the west coast of Santa Cruz Island receive shorter influxes of mussel larvae and have slower mussel growth rates, and therefore mussel beds are less extensive with smaller individuals than at warm-water coastal locations (Blanchette, et al. 2006; Blanchette and Gaines 2007; Blanchette, et al. 2009; Broitman, et al. 2005; Smith, et al. 2006, 2009; Suchanek 1981; Yamada and Peters 1988). The combination of low SST and higher marine productivity apply to fish resources (Dayton 1985; Parrish, et al. 1981) but do not apply for mussel beds' productivity.

The more continuous and intensive human occupation at SCRI-195, next to Trailer, fits with the evidence of higher foraging pressure on *M. californianus* populations described for this site. One aspect that does not fit within this scenario though, is that despite higher foraging pressure on the intertidal rocky shore at Trailer, the overall mean mussel length through the occupation of SCRI-195 is larger than at SCRI-496. This may be explained by the presence of a more extensive rocky shore available for exploitation at Trailer, and also to the fact that due to intraspecific competition for space among mussels in mussel beds, regular human harvesting of larger mussels may enhance growth rate of the remaining individuals and increase the overall productivity of mussel populations (Hockey and Bosman 1986; Whitaker 2008; Yamada and Peters 1988). Other factors known to influence size and growth of *M. californianus* are wave exposure and tidal elevation (Blanchette, et al. 2007). However, in addition to the fact that there are no archaeological tools yet to reconstruct the degree of wave exposure of exploited coasts or tidal location of mussels in the past, these two factors are highly correlated, and their differential influence and effect on intertidal communities are difficult to identify even in modern ecological studies (Blanchette, et al. 2007). Another aspect that could be playing a role in the characteristics of the shellfish assemblage at SCRI-195 is the increasing importance of fish resources during the Late Holocene around the Santa Cruz Island and the other Channel Islands, particularly during the Middle and Late Periods (2400-200 B.P.) (Colten 1994; Glassow 1993; Pletka 2001). Persistent present and past upwelling conditions around the west coast of Santa Cruz makes this area highly productive in fish resources, and therefore, fishing activities could have buffered foraging pressure on rocky shellfish intertidal during the study period (2200-500 cal B.P.). In fact, studies of faunal remains from SCRI-195 and other sites on the west coast of the island show an increasing intensity of fishing during the Middle Period, with an increase in fish abundance after 1500 B.P. and an increase in the number of fish species after 1100 B.P. (Colten 2001; Glassow 1993; Gusick 2007; Pletka 2001).

Shellfish Foraging and Human Impact

The effect of human predation on intertidal ecosystems has been recorded at several places around the world as reduction in mean length and abundance of several species such as mussels, oysters, gastropods and limpets (e.g., Castilla and Duran 1985; Fenberg and Roy 2007; Hockey, et al. 1988; Kingsford, et al. 1991; Lasiak and Dye 1989; Moreno 2001; Roy, et al. 2003). Through the archaeological sequence of SCRI-496 and SCRI-195, negative and positive correlations were found between mean length and abundance of *M. californianus* shells, and are interpreted as evidence of varying degrees of the effects of human predation on mussel beds. Positive correlations between length and abundance of mussel shells are interpreted as the result of human foraging with low effect on natural abundance and length of mussel. On the other hand, negative correlations are interpreted as the result of human foraging with significant effect on mussel beds. The predominance of positive or negative correlations and the speed of the changes observed in abundance and length (increase or decrease) are different at the two sites under study. SCRI-195 shows large and abrupt fluctuations in mussel length and abundance though time (Figure 43). Negative correlations prevail through the sequence, reflecting the effect of mussel harvesting on mussel length expected at a place with a more continuous and higher intensity of occupation and natural conditions of high upwelling intensity, low mussel recruitment, and low growth rate. Of interest is the gradual decrease in abundance together with fluctuating but larger length of mussels from level 11 to 2 (Figure 43). The positive correlation observed through these last levels of the sequence is interpreted as the result of lower pressure on mussel beds during the last period of occupation at SCRI-195 (Glassow 1993; Gusick 2007). SCRI-496 on the other hand, shows less fluctuation in mussel length and abundance though time, as well as more intervals with gradual changes through the archaeological sequence. The exceptions are level 7 and 4, where mussel abundance increase more abruptly, and level 2, where mussel length also shows an abrupt increase (Figure 44). Positive correlations dominate through the sequence of SCRI-496 indicating a minimal effect of mussel harvesting on mussel length (Figure 44), which is expected at a place like Willows with sporadic and lower intensity of occupation and natural conditions for high mussel recruitment and growth rate.

In light of the patterns just discussed, SCRI-195 exhibits evidence of higher foraging pressure on *M. californianus* beds that when released (evidenced by levels with low abundance), a response may be observed in mussel length (larger mussels). As harvesting during the occupation of this site was on mussel beds with a relatively lower recovery rate and under continuous harvesting, increased collecting pressure resulted in the procurement of smaller overall mussel lengths (Figure 43). In contrast, SCRI-496 exhibits evidence of lower foraging pressure that when released, no signs of response in mussel length are observed. As harvesting during the occupation of this site was on mussel beds with fast recovery rates and lower foraging pressure, intervals of increased collecting pressure did not result in the acquisition of smaller mussel lengths (Figure 44). Finally, two specific intervals of abrupt increase in abundance and length are observed from level 17 to 16 at SCRI-195 and from level 8 to 7 at SCRI-496 (Figure 43 and 44). These positive correlations are interpreted as evidence of re-occupation of the sites after a period of abandonment, which allowed mussel beds to recover enough for humans to obtain high abundance of larger mussels than before.

When evaluating human impact on *M. californianus* beds, it is important to mention the existence of predators other than humans, which are also size selective. Seastars are important predators of *M. californianus* around the California Channel Islands, and huge increases in their abundance could wipe out mussel populations in the absence of human predation (Blanchette, et al. 2005). Despite the fact that the presence of this predator species would be harder to detect in the faunal archaeological record, this issue highlights the importance of considering the potential effect of this and other non-human factors on the patterns observed in archaeological shellfish assemblages.

Chapter 7. Conclusion

How much of the observed variation in archaeological shellfish assemblages and by inference in shellfish harvesting decisions was due to environmental factors during the Middle and Late Period (2200-500 cal B.P)?

Shellfish and stable isotope data from SCRI-496 and SCRI-195 do not support Hypothesis 1, which states that fluctuation in past sea surface temperature throughout the Late Holocene significantly affected abundance and/or size of *M. californianus* collected by the archaeological site's occupants. Weak or no correlation was found between mean SST fluctuations and changes in abundance and length of *M. californianus* through time. Consequently, fluctuation in nearshore paleoceanographic conditions throughout the Late Holocene does not explain abundance or length of mussels collected by the archaeological site's occupants. Additionally, shellfish data from the study sites do support Hypothesis 2, which states that increasing human predation pressure on intertidal shellfish throughout the Late Holocene resulted in shellfish harvesting becoming the main force shaping size and availability of *M. californianus* and also the number and amount of other shellfish species exploited. Data from SCRI-195 show evidence of increasing human pressure on *M. californianus,* with an overall decrease in mussel length together with an increase in the number of species and the abundance of lower-return species such as *T. funebralis* and *Strongylocentrotus sp* .

The process of hypotheses testing presented in this study entailed a careful evaluation of the main issues encountered in current approaches used to evaluate environmental influence on shellfish harvesting through the Holocene around the northern Channel Islands.

This study considered the regional record of past SST available for the Santa Barbara Channel region (Kennett 2005; Kennett and Kennett 2000; Kennett, et al. 2007), as a complement to local SST records obtained from oxygen isotope analyses of *M. californianus* shells from SCRI-195 and SCRI-496 rather than treating the regional record as the single proxy for past marine productivity affecting *M. californianus* beds. In addition, spatial small-scale past oceanographic variability was considered in efforts to understand variability in the archaeological shellfish assemblages. Statistical tests of significance were used to evaluate past correlations between environment and archaeological shellfish assemblage variation, and finally, published information on small-scale interactions between oceanographic patterns and shellfish species dynamics were used to estimate past *M. californianus* beds productivity at the shores near SCRI-496 and SCRI-195.

The hypothesis proposed by Braje et al. (2012:117) that shellfish harvesting decisions during the Late Holocene were progressively less influenced by environmental conditions because increasing human pressure on intertidal habitats made shellfish harvesting the main force shaping length and availability of shellfish species has been evaluated and supported. However, greater complexity was found within this general pattern. Although fluctuations in SST through time within the waters near the archaeological sites did not have a significant effect on changes in *M. californianus* length and abundance, differences in long-term mean SST between shoreline locations did explain variation between archaeological sites. In addition, even though occupation at both archaeological sites spans the same time interval, with increasing sedentism, territoriality, and resource intensification, only SCRI-195 showed evidence of increasing human predation pressure on *M. californianus* beds. The explanation for this complex relationship between natural and human factors considers two main aspects:

sites' occupation dynamics and small-spatial variation in ecological and oceanographic characteristics near the sites.

The present SST gradient around Santa Cruz Island is an oceanographic pattern with more than 2000 years of antiquity. Late Holocene SST records from the study sites (2200-500 cal B.P) reflect the modern SST gradient, with cooler waters in the west and warmer waters in the south coast. Within this gradient, however, the difference between west and south coast SST was greater during prehistoric times due to stronger-than-present upwelling conditions along the west coast of the island.

SCRI-496 is located on a warmer water shoreline, and its occupation was irregular and of low intensity. Shellfish foraging during the occupation was along a rocky intertidal shoreline with propitious natural characteristics of more extensive mussel beds and larger individuals (a fast growth rate and constant recruitment of larvae from far-away populations). SCRI-195, in contrast, was located on a cold-water shoreline and experienced a more intense and continuous occupation. Shellfish foraging during the occupation of this site was along a rocky shore with less favorable conditions (shorter influxes of mussel larvae and a slow growth rate) that resulted in less extensive mussel beds and smaller individuals. The lower mussel productivity at the rocky shore near SCRI-195 made mussel populations less resilient to human foraging pressure. Consequently, the combined factors of occupation intensity and mussel bed performance may explain differences in archaeological shellfish assemblages, with signs of predation pressure and a decreased foraging efficiency at SCRI-195, signs absent in the malacological record at SCRI-496. Unfortunately, data obtained from this study do not allow answering the remaining question regarding the importance of occupation intensity versus mussel bed performance in the observed patterns.

The intriguing overall larger shells of *M. californianus* harvested through the occupation of SCRI-195 led to the proposition that higher predation pressure may have been buffered by the increasing importance of fish resources at this highly productive west coast location and also by a human-induced increase of mussel bed productivity. Frequent collection of larger mussels, together with a more extensive rocky shore available may have reduced competitive space pressure within the mussel beds, allowing smaller mussels to grow more rapidly (Hockey and Bosman 1986; Whitaker 2008; Yamada and Peters 1988). In other words, continuous prehistoric human harvesting may have modified/enhanced mussel productivity expected under the nearshore oceanographic conditions recorded for the west coast of Santa Cruz Island, thus allowing sustained mussel foraging through time.

Several authors have highlighted the difficulties in disentangling human from natural effects in understanding shellfish foraging strategies reflected in archeological records (Erlandson 2001; Jerardino 2012b; Mannino and Thomas 2002). Data presented and discussed in this study show once again how intertwined human and natural factors are in influencing shellfish resource availability and human foraging behavior. The results presented here show that fluctuations in regional SST records through time do not explain changes in archaeological remains of *M. californianus,* nor do fluctuations in local SST records derived from oxygen isotope analyses at each shell midden site. What did help to explain changes in archaeological remains of *M. californianus* were differences in SST between the sites' locations. A comparison between past SST along the west and south coast of Santa Cruz Island helped in understanding differential effects of human foraging on shellfish populations inhabiting the rocky shores next to the two archaeological sites. In addition, a significant misunderstanding has been clarified regarding the relationship between

SST, marine productivity and mussel abundance and length. Based on the particular interaction between *M. californianus* characteristics (recruitment, growth and intra-species competition) and nearshore oceanographic conditions, this study has demonstrated that the relationship between low SST and higher marine productivity does not apply to mussel beds. In fact, it is the opposite correlation that should be used (higher SST, greater abundance, and larger lengths) to evaluate the effects of marine environment on mussel length and abundance observed in archaeological shellfish assemblages.

A comparative approach between regional and local SST records also helps to understand small-scale nearshore ecology and oceanographic dynamics and their effect on human subsistence. The contrast between persistently cold SST throughout the occupation of SCRI-195 on the west coast of Santa Cruz Island and the shift from warmer to cooler nearshore oceanographic conditions seen in the regional SST record reflects the persistence of upwelling activity on this part of the island. The presence of these persistent cold and nutrient-rich waters at certain locations during prehistoric times may generate cooler local SST than indicated by contemporaneous regional SST record. The use of only regional past SST records to interpret variability in shellfish or other faunal assemblages from archaeological sites on shorelines exposed to upwelled waters may lead to spurious interpretations about the effects of environmental fluctuation on subsistence strategies.

On the other hand, due to the lower intensity and persistence of upwelling conditions along warmer-water shorelines, local past SST records from archaeological sites along these shorelines may show fluctuations closer to patterns recorded in regional past SST records. Examples are the local SST record for SCRI-496 presented in this study and the record for site SRI-147 in Robbins et al. (2013). These sites are located on the south coasts of Santa

Cruz and Santa Rosa islands, respectively. Consequently, if local SST records are not available for a particular archaeological site, present nearshore oceanographic characteristics from the coast where the site is located have to be investigated before attempting to use regional SST records as a proxy for past nearshore oceanographic conditions. It seems that researchers studying archaeological sites along warmer shorelines of the northern Channel Islands may be able to use the regional SST record, but caution would be necessary so as to not overlook possible small-scale ecological and oceanographic variables affecting past shellfish species productivity and human foraging.

Upwelling conditions during the occupation of site SCRI-195 between 2200 and 500 cal B.P suggest that the west coast was climatically more stable than other areas around the island, more productive in fish resources, and perhaps more humid due to upwelling-related fog. Such locations experiencing cold and upwelled waters may have been less resilient to human foraging on *M. californianus* beds due to the irregular influx of mussel larvae and slow mussel growth. These characteristics lead to the proposal that, all things being equal, Late Holocene archaeological sites on shores with persistent upwelling should show more signs of foraging pressure on mussel beds and greater differences between the importance of shellfish (with higher human impact and low productivity) and fish (with lower human impact high productivity) in the diet than archaeological sites on shores with warmer waters (higher productivity of mussel beds, lower productivity of fish).

Before concluding, it is important to mention that due to the nature of data coming from column samples, additional research will be required to evaluate the patterns observed in the archaeological record at SCRI-195 and SCRI-496, and to evaluate the proposed interpretations of this patterning. Additional comparisons are also necessary between Late

Holocene sites with different intensities of occupation and at locations with contrasting ecological and oceanographic characteristics to evaluate the effects of Late Holocene climate and foraging behaviors on *M. californianus* beds, one of the most important resources exploited prehistorically along the north Pacific coast.

Patterns described by previous research within shellfish assemblages from archaeological sites on the northern Channel Islands, and offered interpretations about the role of human and natural factors on these patterns, have been a significant contribution to understanding prehistoric human adaptations on the islands and past maritime subsistence strategies in California and around the world (e.g. Braje, et al. 2007a; 2012; Erlandson, et al. 2008; Glassow, et al. 2008; Kennett 2005; Kennett and Kennett 2000; Kennett, et al. 2007; Rick 2007). Despite the importance of these regional-scale patterns, they cannot be directly applied to particular archaeological records. Both, regional and local past SST records are needed to understand complex nearshore oceanographic conditions and their effect on natural resources and human subsistence throughout prehistory. The research presented here has demonstrated the importance of considering present and past small-scale variability in natural habitats. Small-scale variability in intertidal ecology and nearshore oceanography is not unique to the Channel Islands or to southern California. It is an intrinsic characteristic of coastal environments around the Atlantic, the Pacific and other oceans (2009; Blanchette, et al. 2008; Blanco, et al. 2001; Broitman, et al. 2008; Bustamante, et al. 1995; Helmuth, et al. 2006; Lagos, et al. 2005). Small-scale variation influenced coastal foraging behavior through the course of prehistory, and therefore it has to be studied and included in any research that aims to understand human-coastal environmental interactions and marine resource use in the past anywhere around the world.

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Figures

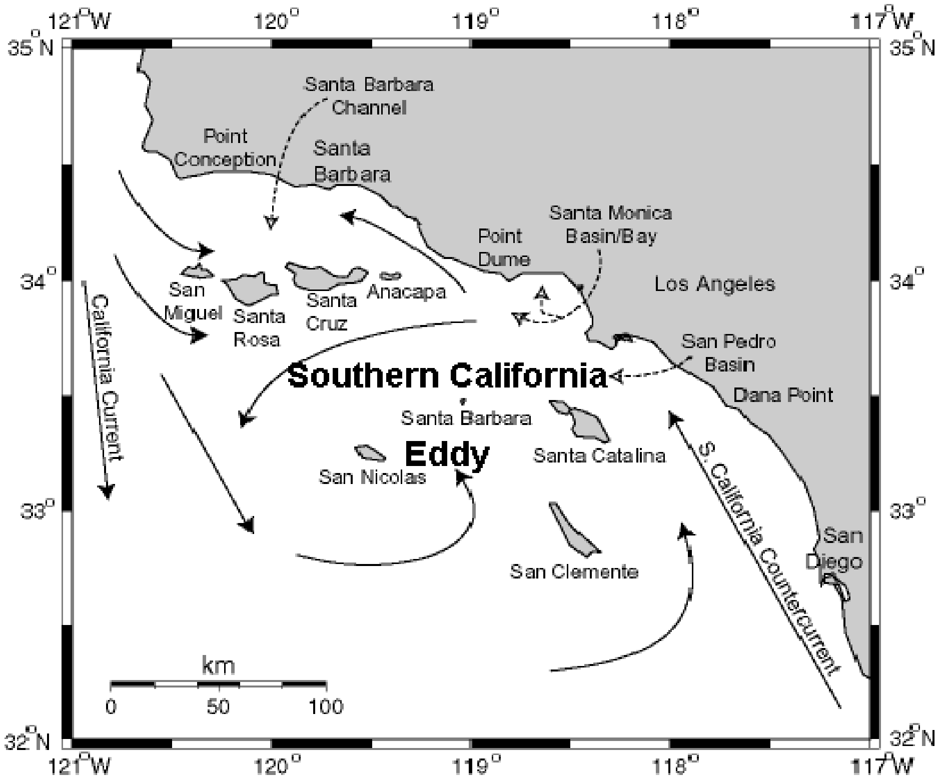

Figure 1. Circulation Patterns in Southern California (from Hickey 1992:39).

Figure 2. Santa Cruz Island topography: a) central valley, b) cliffs south coast, c) west end, d) rocky shore in eastern sector


Figure 3. SCRI-496 at Willows. Shell midden resting on the eroding rocky wall.


Figure 4. SCRI-195 at Trailer, with shell midden eroding onto the shoreline.

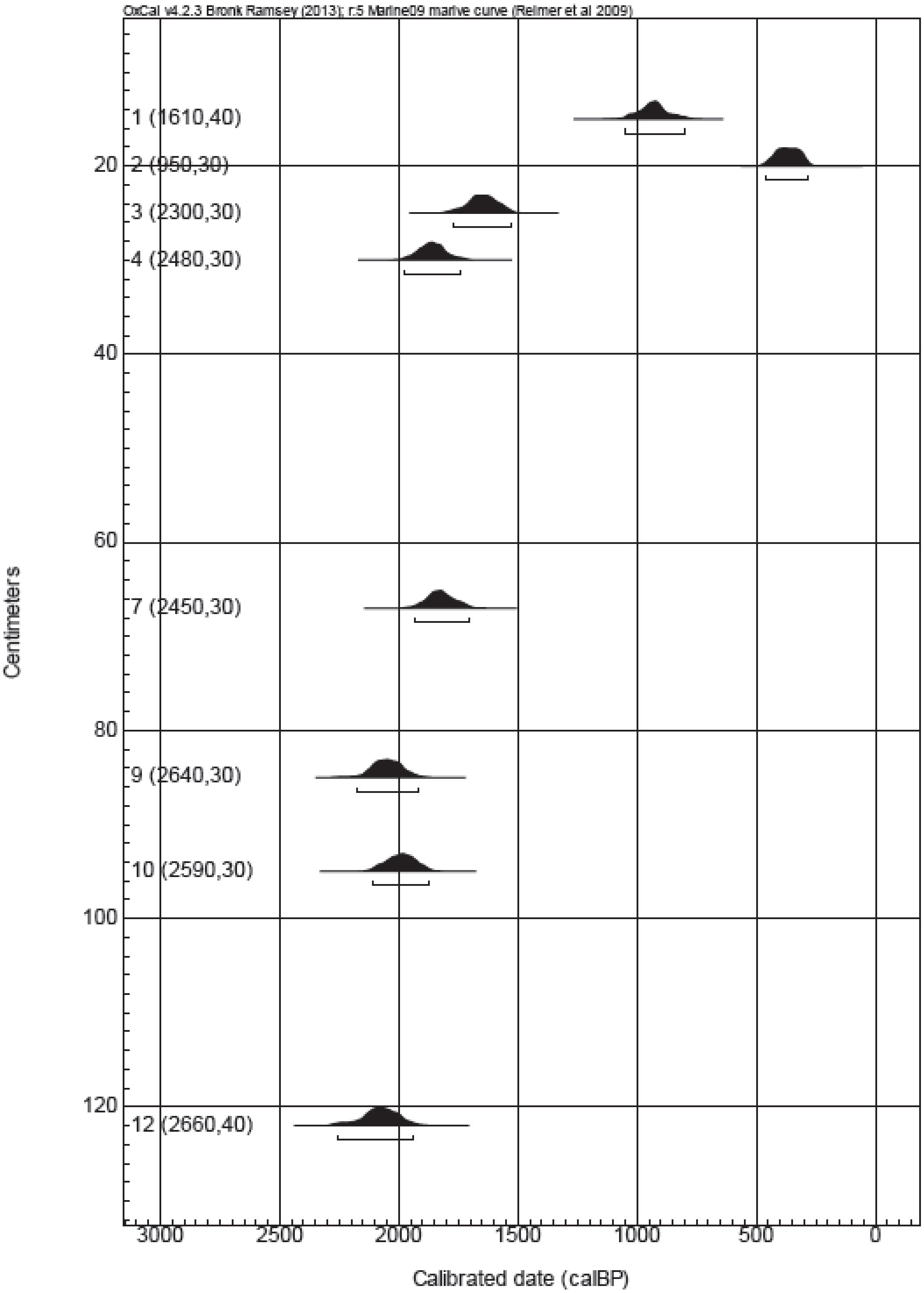

Figure 5. Radiocarbon dates in relation to stratigraphic levels at SCRI-496. Numbers to the left of each date pertain to stratigraphic levels and conventional age B.P.

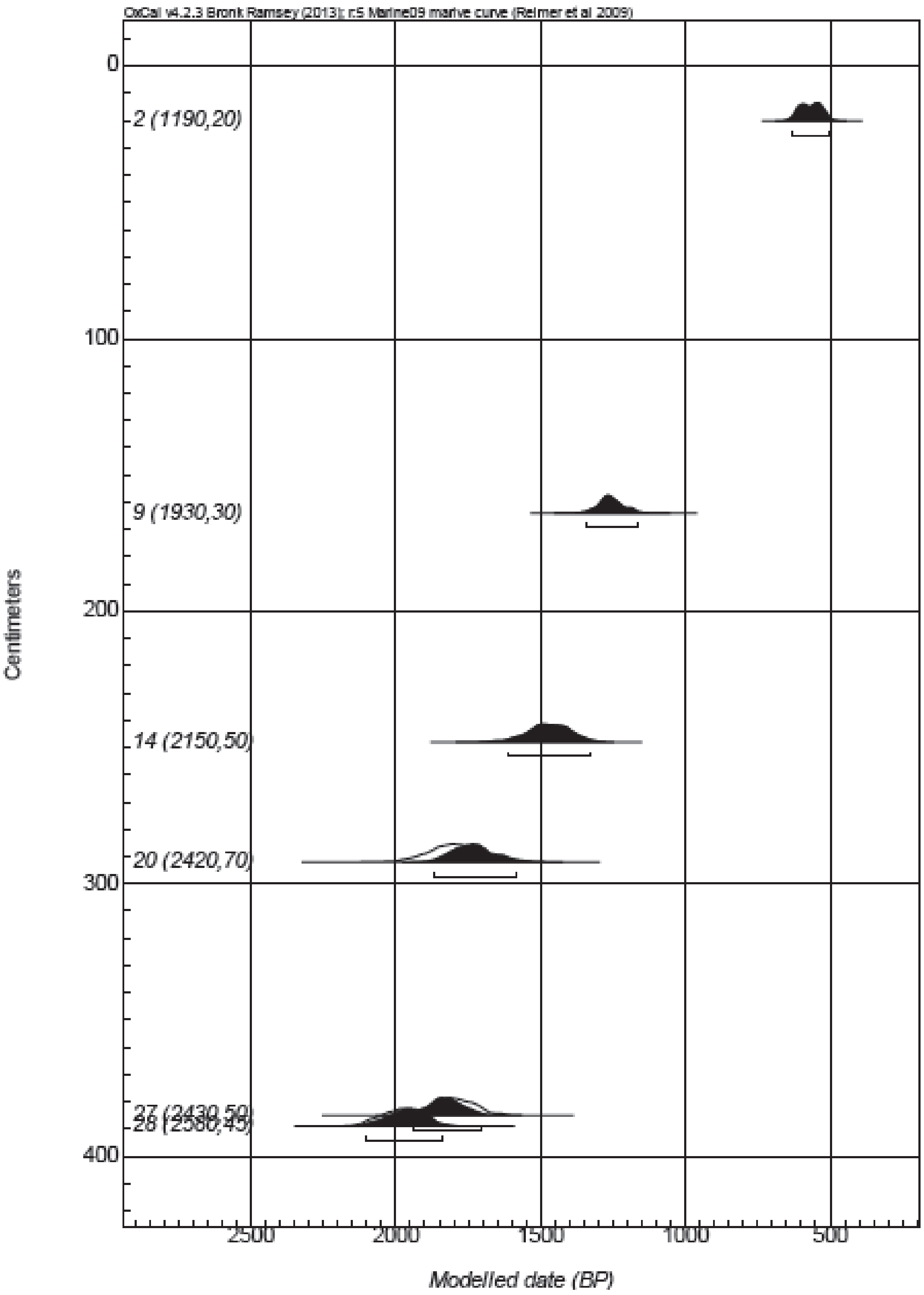

Figure 6. Radiocarbon dates in relation to stratigraphic levels at SCRI-195. Numbers to the left of each date pertain to stratigraphic levels and conventional age B.P.

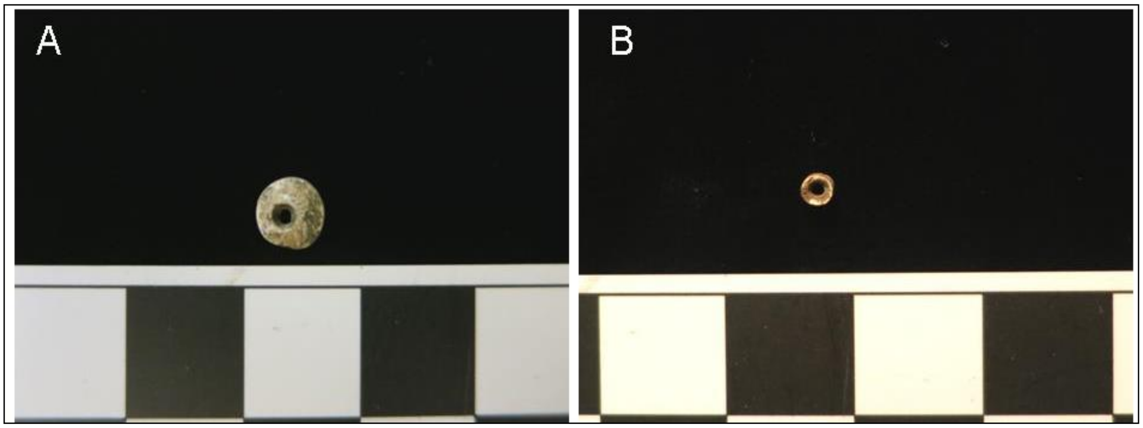

Figure 7. Beads from level 1, SCRI-496. A is large cupped *Olivella* bead and B is a callus or cup *Olivella* bead.

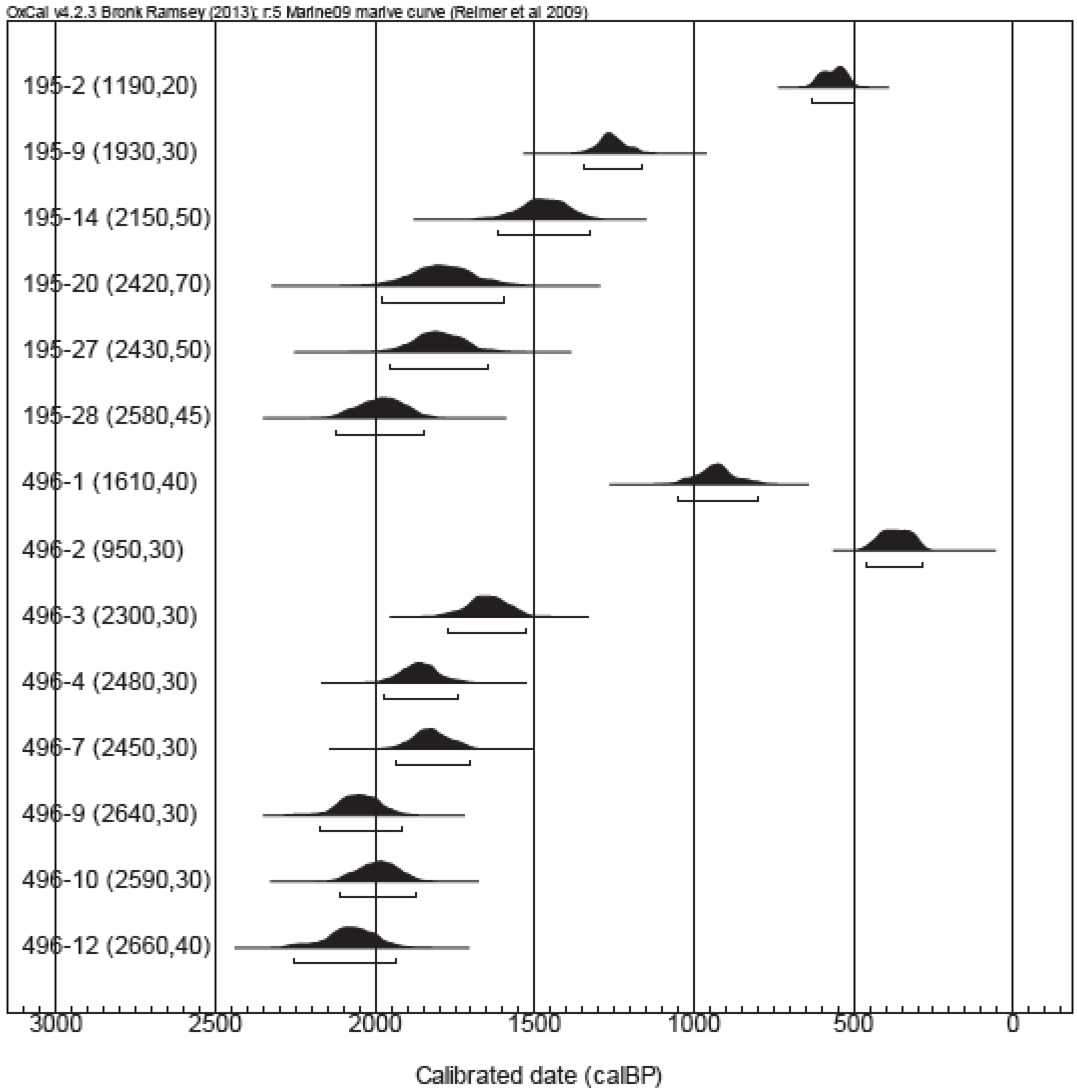

Figure 8. Radiocarbon dates in relation to stratigraphic levels at both SCRI-195 and SCRI-496. Numbers on the left are the site number and stratigraphic level and conventional age B.P.

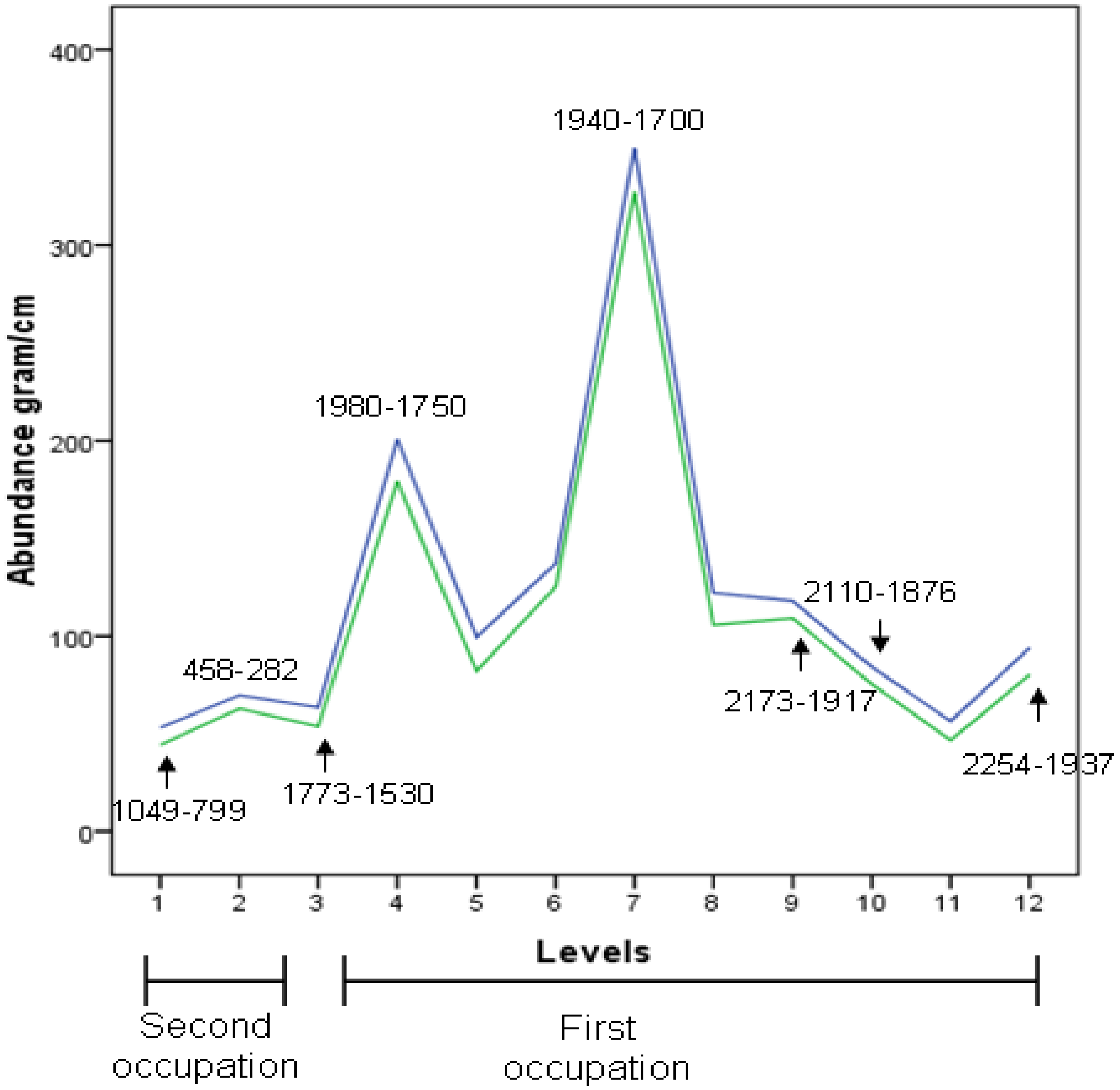

Figure 9. *M. californianus* abundance (green line) and overall shell abundance (blue line) at SCRI-496 standardized by thickness in cm of each stratigraphic level. Also shown are radiocarbon dates (calibrated years BP) for the stratigraphic levels.

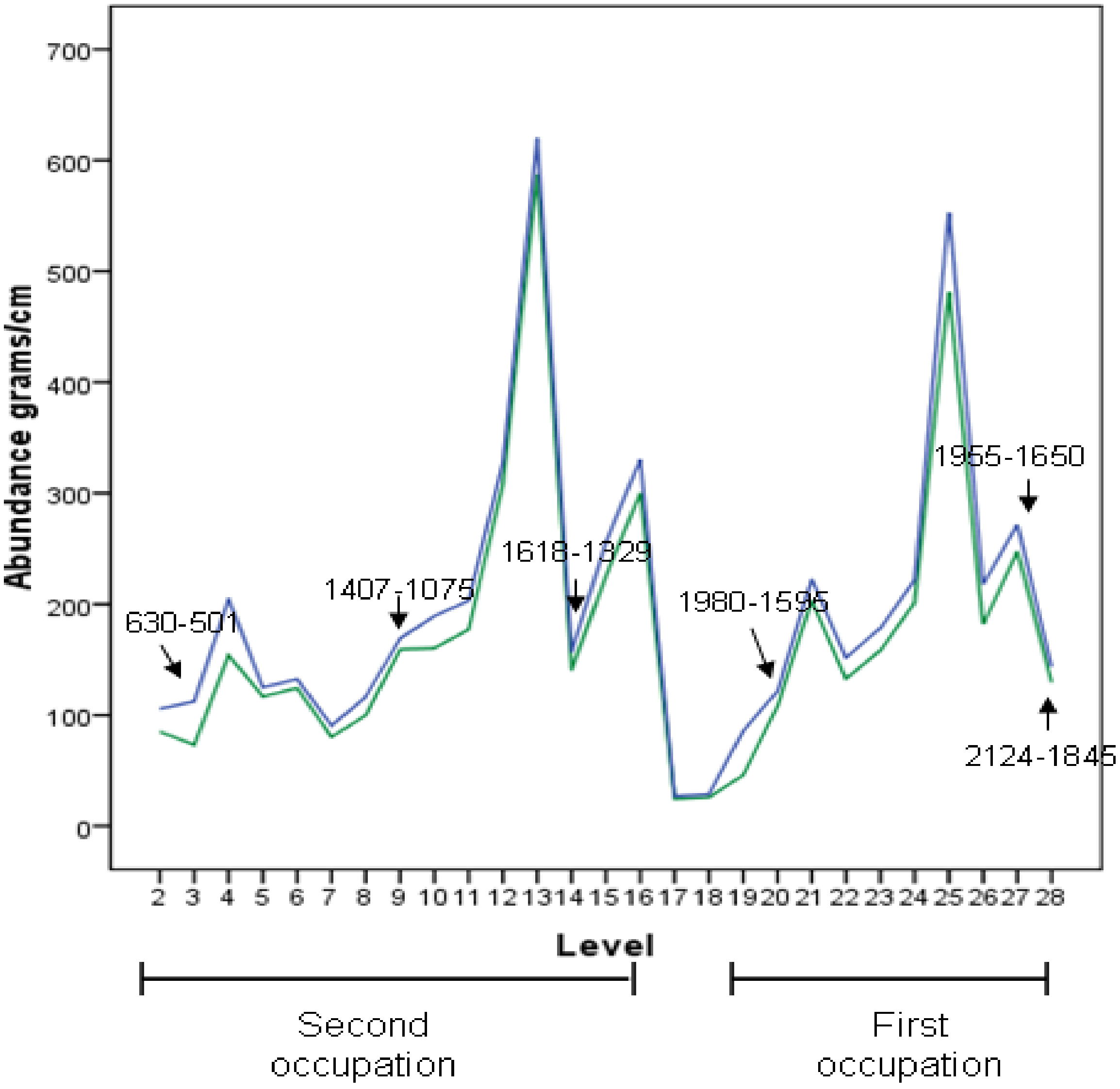

Figure 10. *M. californianus* abundance (green line) and overall shell abundance (blue line) at SCRI-195 standardized by thickness in cm of each stratigraphic level. Also shown are radiocarbon dates (calibrated years BP) for the stratigraphic levels.

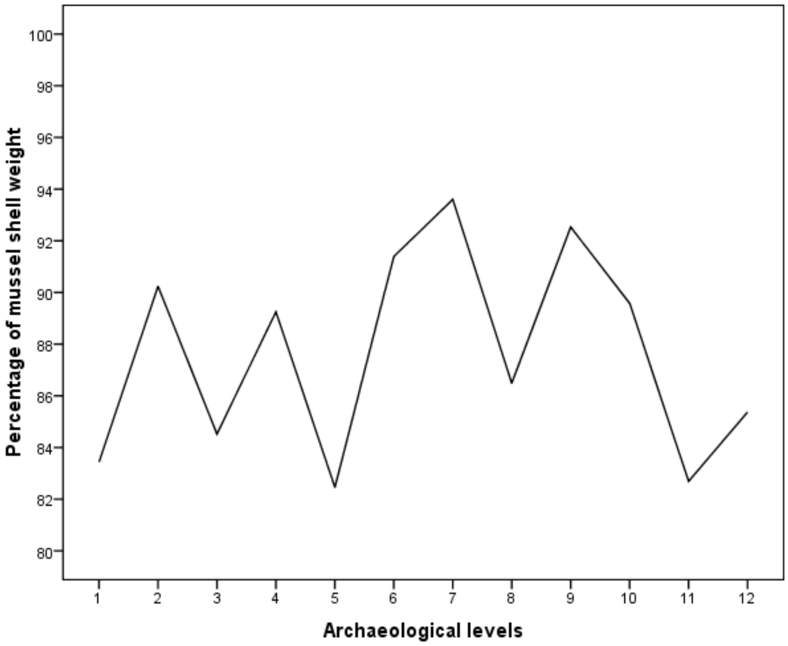

Figure 11. Proportion (%) of *M. californianus* (mussel) shell through time at SCRI-496. Shell weight used to calculate percentage was standardized by level thickness in cm.

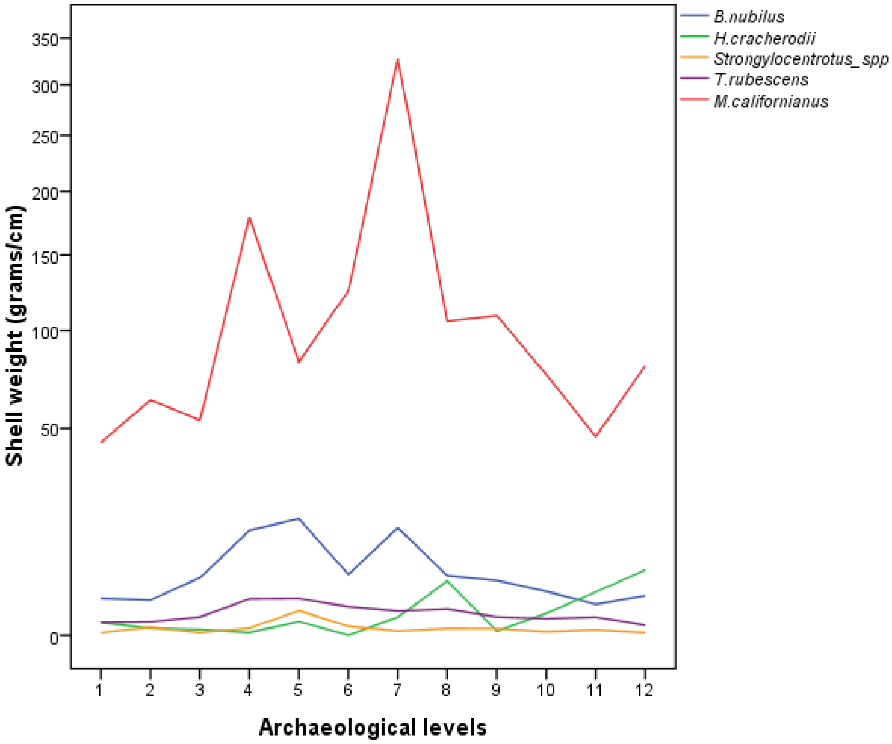

Figure 12. Abundance through time of *M. californianus* and the following most abundant shellfish species: *B. nubilus, H. cracherodii, Strongylocentrotus* sp*, and T. rubencens* at SCRI-496. Shell abundance, represented by weight, was standardized by level thickness in cm.

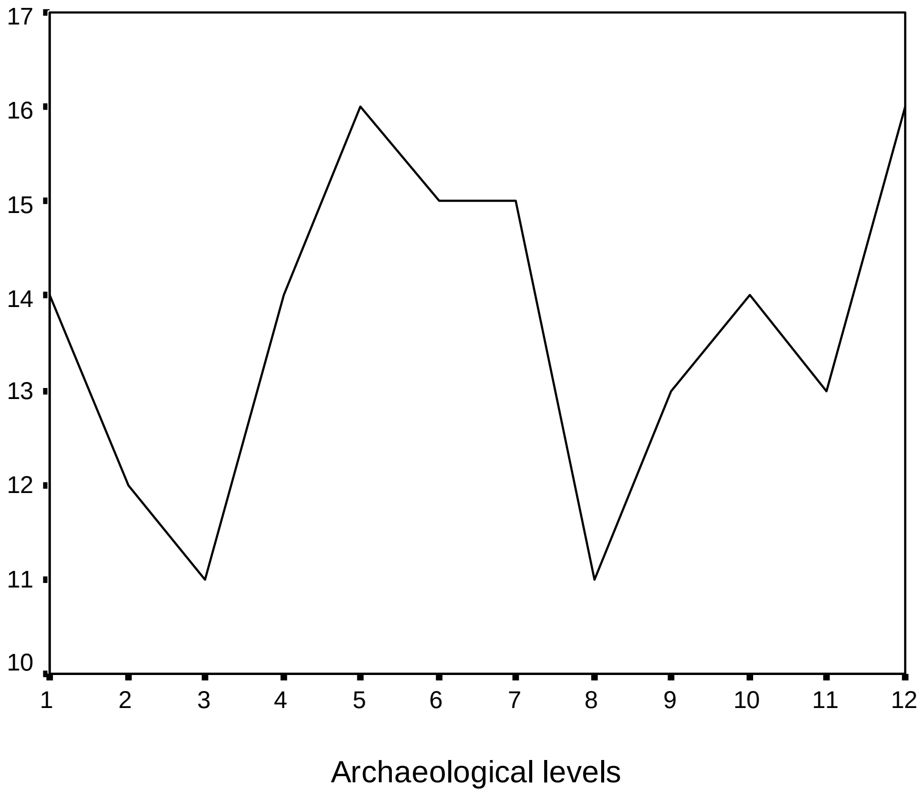

Figure 13. Number of species throughout the stratigraphic levels at site SCRI-496

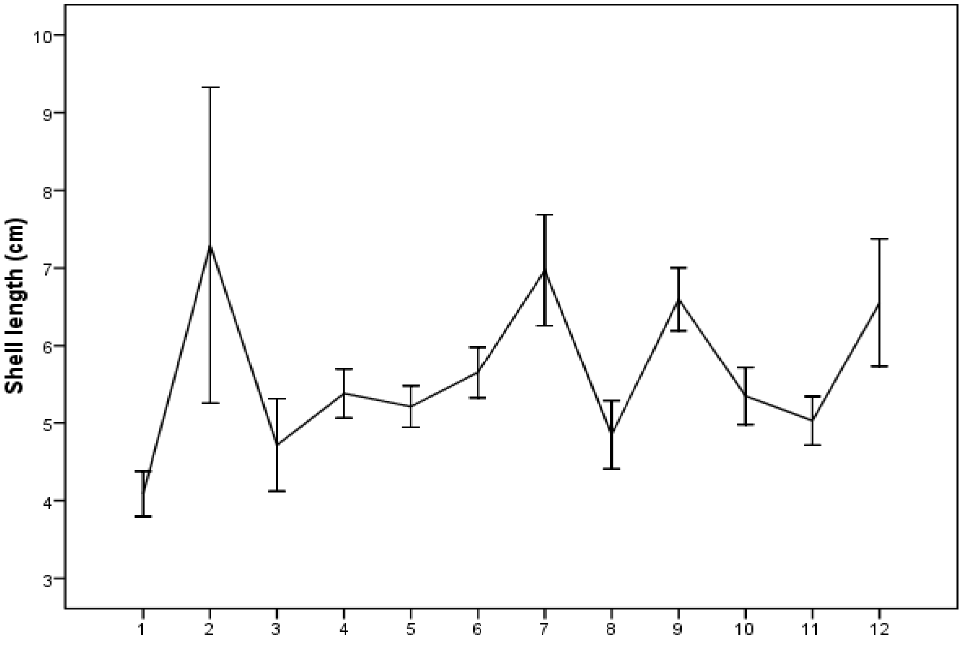

Figure 14. Mean *M. californianus* shell length (cm) per level at SCRI-496. Confidence intervals of 95%.

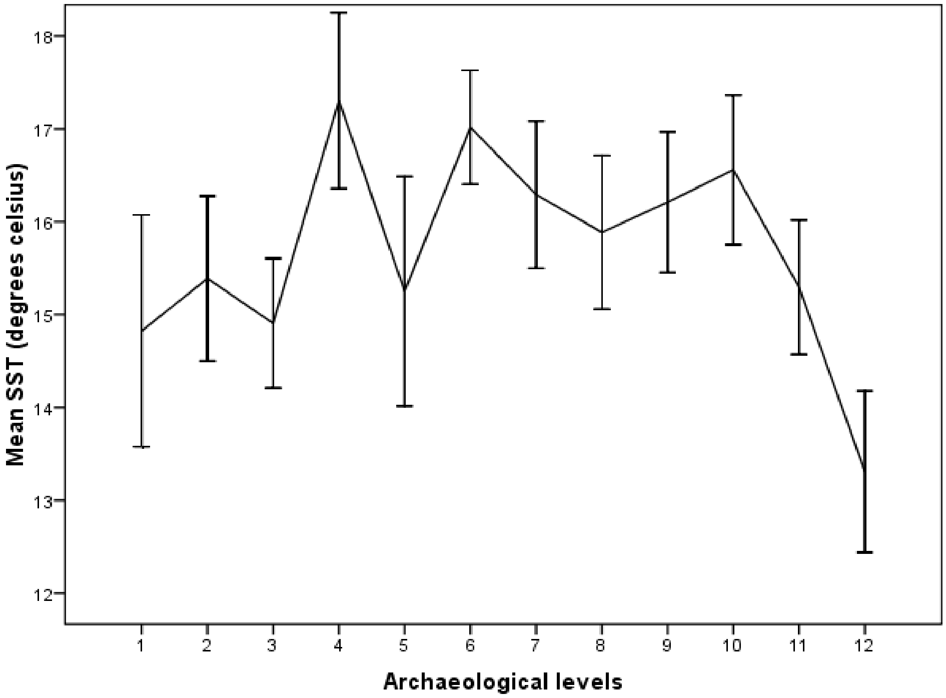

Figure 15. Mean SST (degrees Celsius) derived from oxygen-isotope analysis per stratigraphic level at SCRI-496. Confidence intervals of 95%.

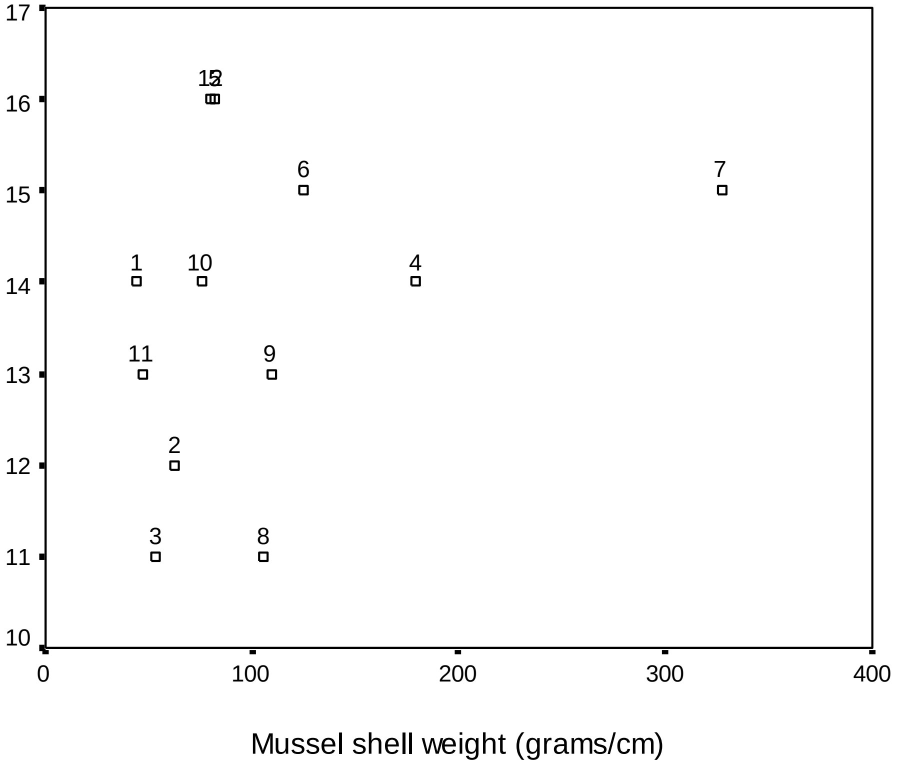

Figure 16. *M. californianus* (mussel) shell weight (grams/cm) and number of species. Each square corresponds to a stratigraphic level at SCRI-496.

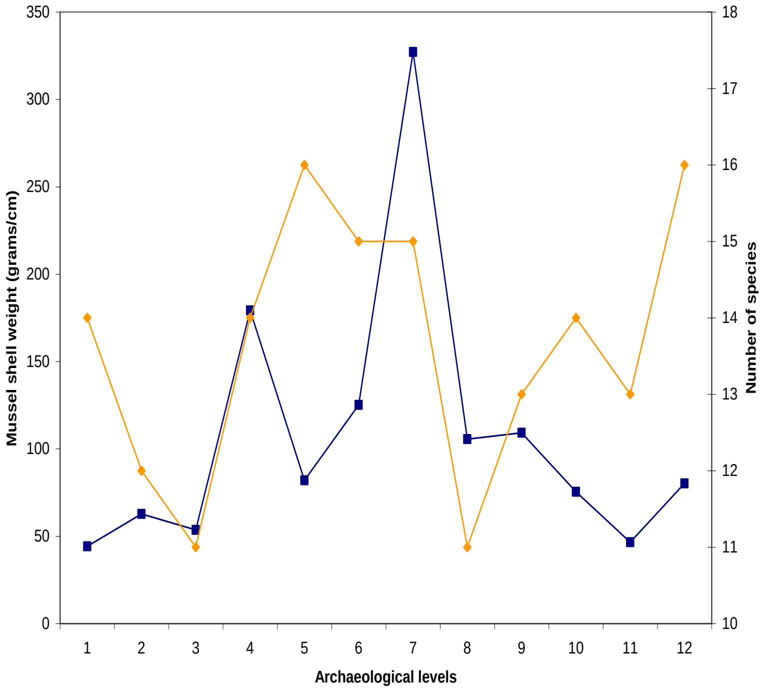

Figure 17. *M. californianus* (mussel) abundance (grams/cm) and number of species by stratigraphic level at SCRI-496. The blue line is abundance and the orange line is number of species. Abundance, represented by shell weight, was standardized by level thickness in cm.

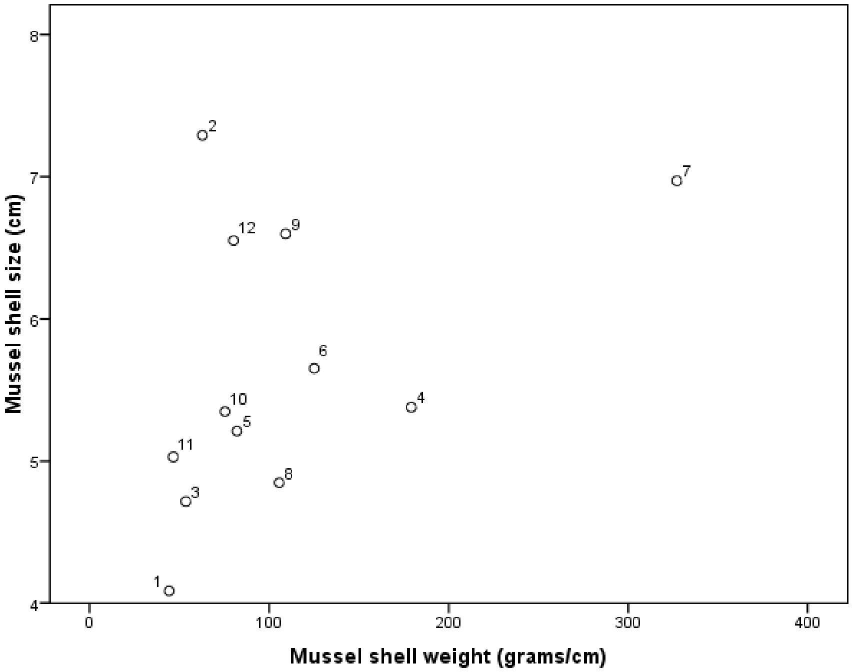

Figure 18. *M. californianus* (mussel) abundance (grams/cm) and shell length (cm). Each circle corresponds to a stratigraphic level at SCRI-496. Abundance, represented by shell weight, was standardized by level thickness in cm.

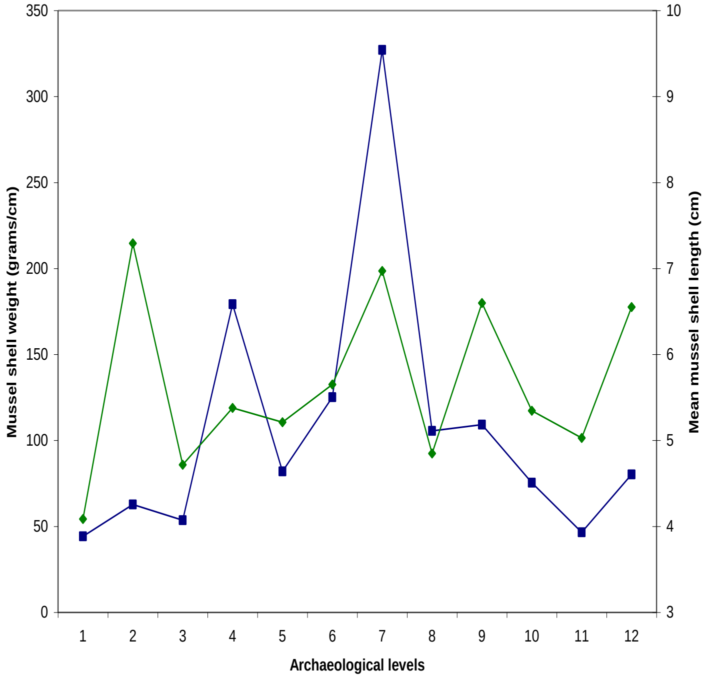

Figure 19. *M. californianus* (mussel) abundance (grams/cm) and mean shell length (cm) by stratigraphic level at SCRI-496. The blue line is abundance and the green line is length. Abundance, represented by shell weight, was standardized by level thickness in cm.

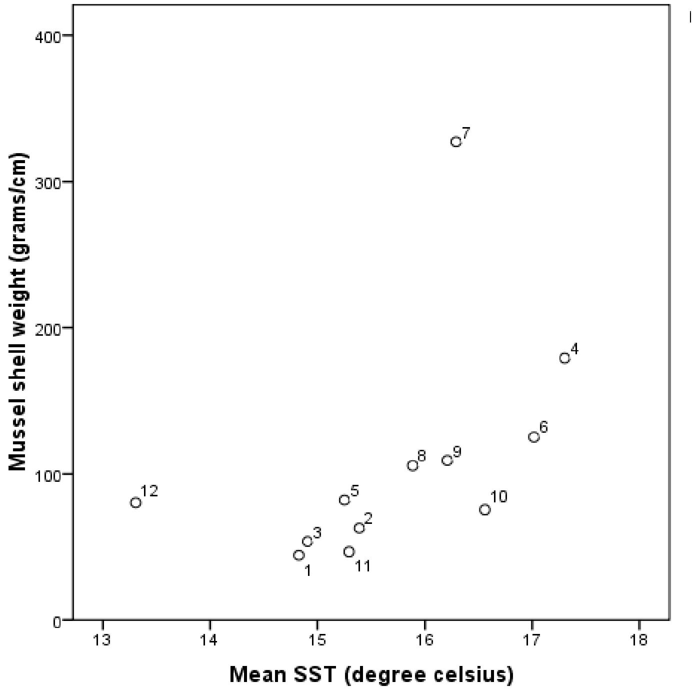

Figure 20. *M. californianus* (mussel) abundance (grams/cm) and SST (°C) at SCRI-496. Each circle corresponds to a stratigraphic level. Abundance, represented by shell weight, was standardized by level thickness in cm.

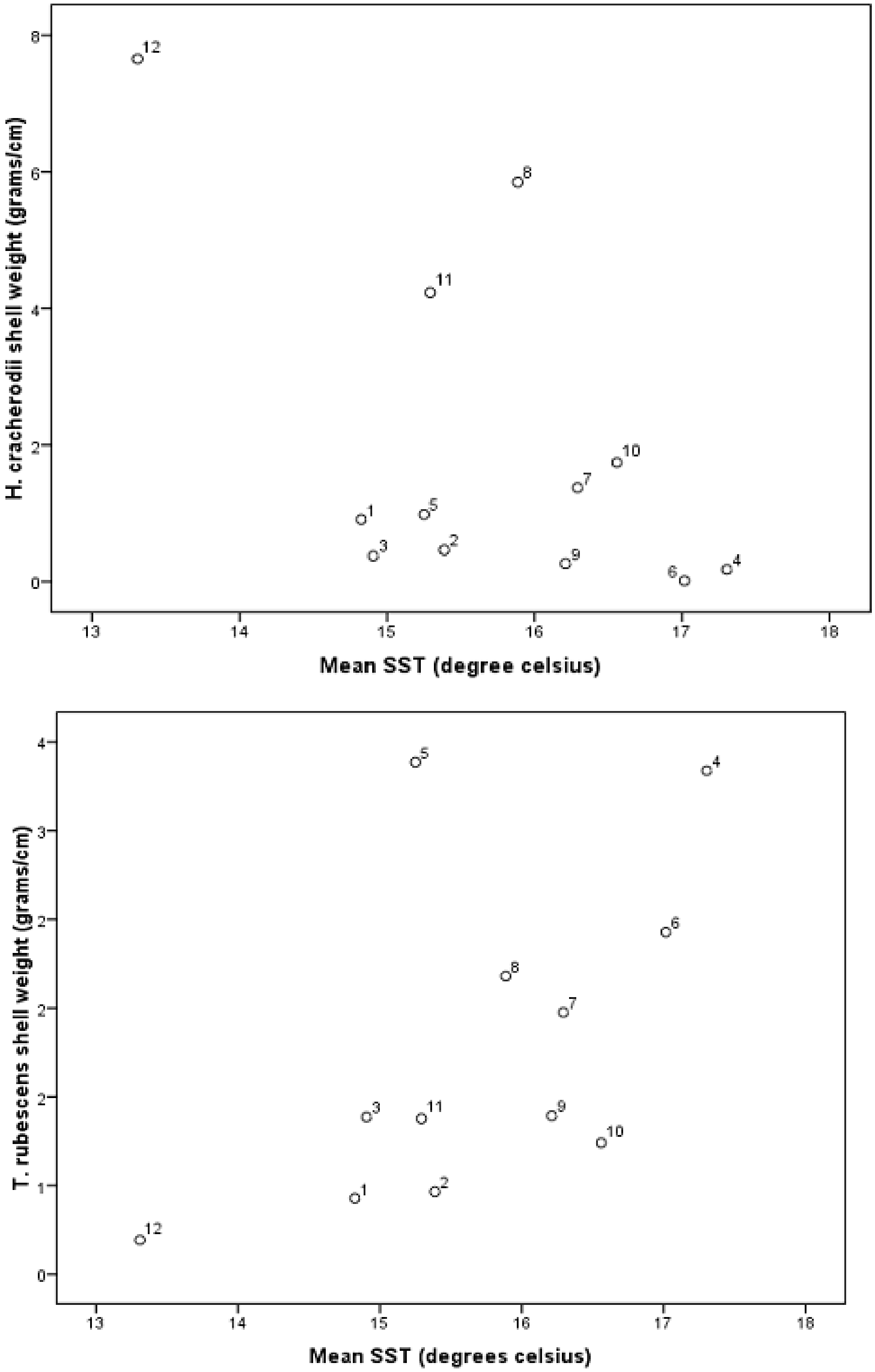

Figure 21. *T. rubescens* and *H. cracherodii* abundance (grams/cm) and SST (°C) at SCRI-496. Each circle corresponds to a stratigraphic level. Species abundance, represented by shell weight, was standardized by level thickness in cm.

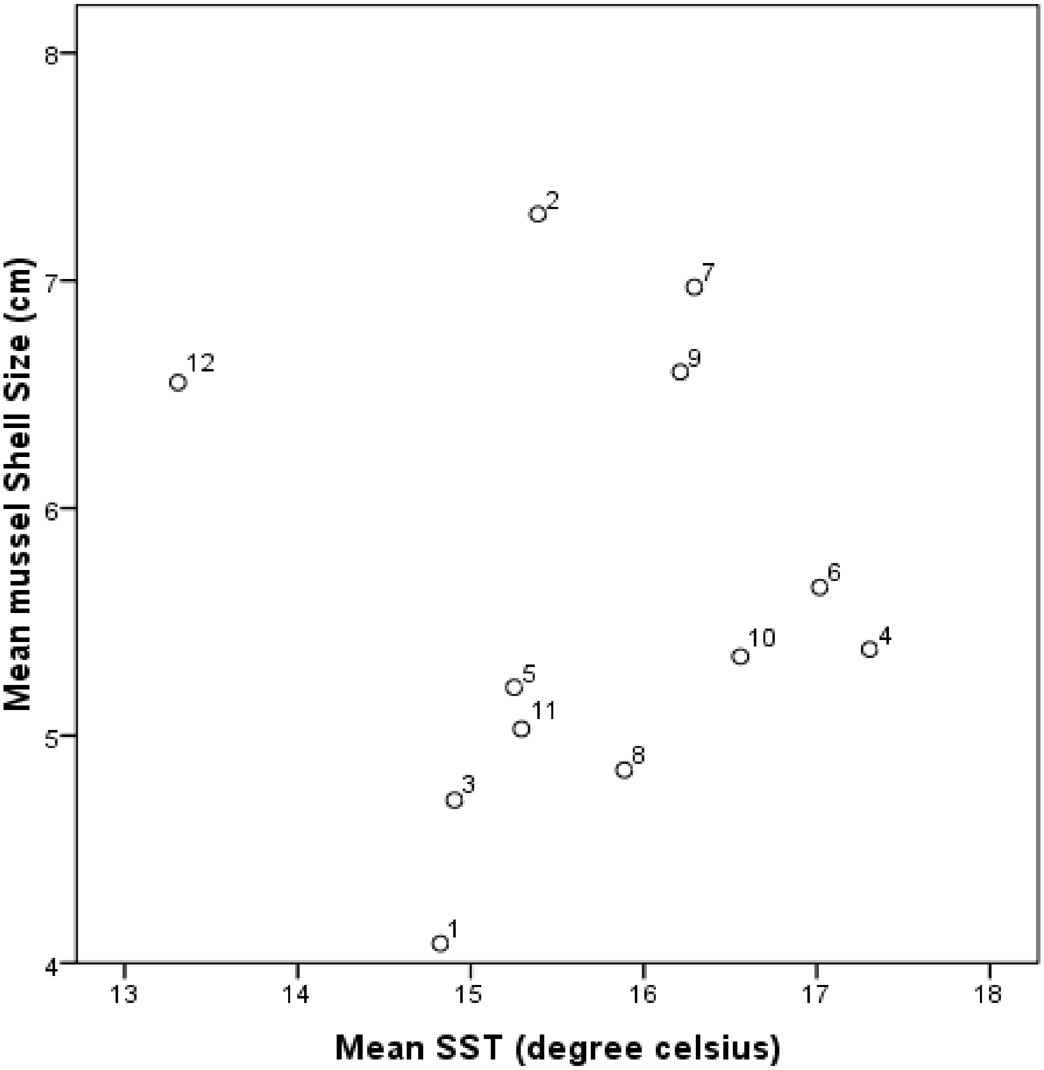

Figure 22. Mean *M. californianus* (mussel) shell length and SST (°C) at SCRI-496. Each circle corresponds to a stratigraphic level.

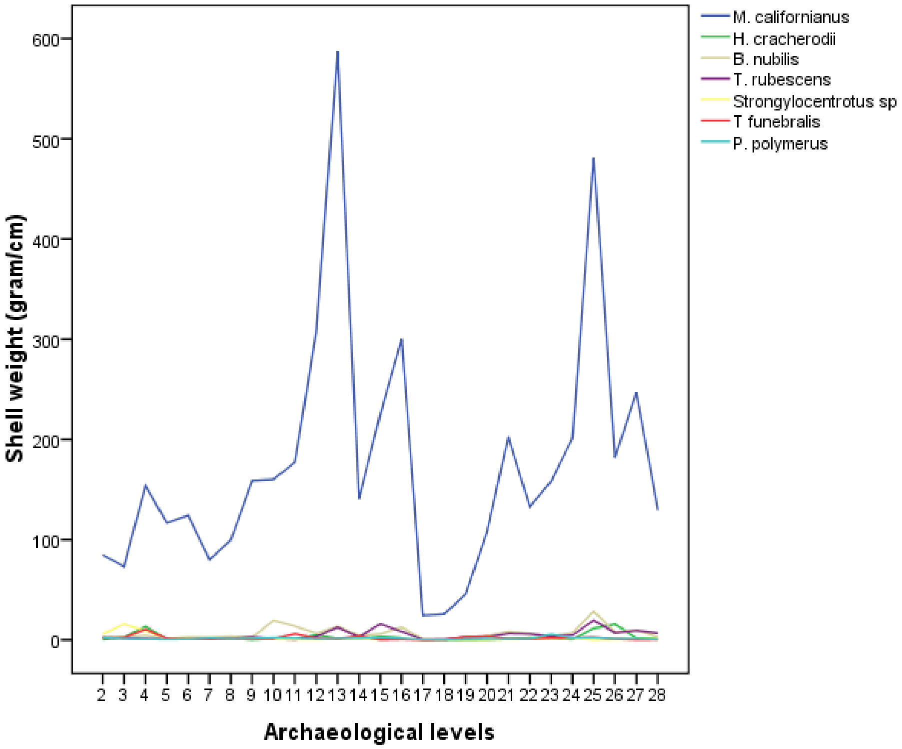

Figure 23. Abundance through time of *M. californianus* and the following most abundant shellfish species: *H. cracherodii, B. nubilus, T. rubencens, Strongylocentrotus* sp., *T. funebralis* and *P. polymerus* at SCRI-195. Shell abundance, represented by weight, was standardized by level thickness in cm.

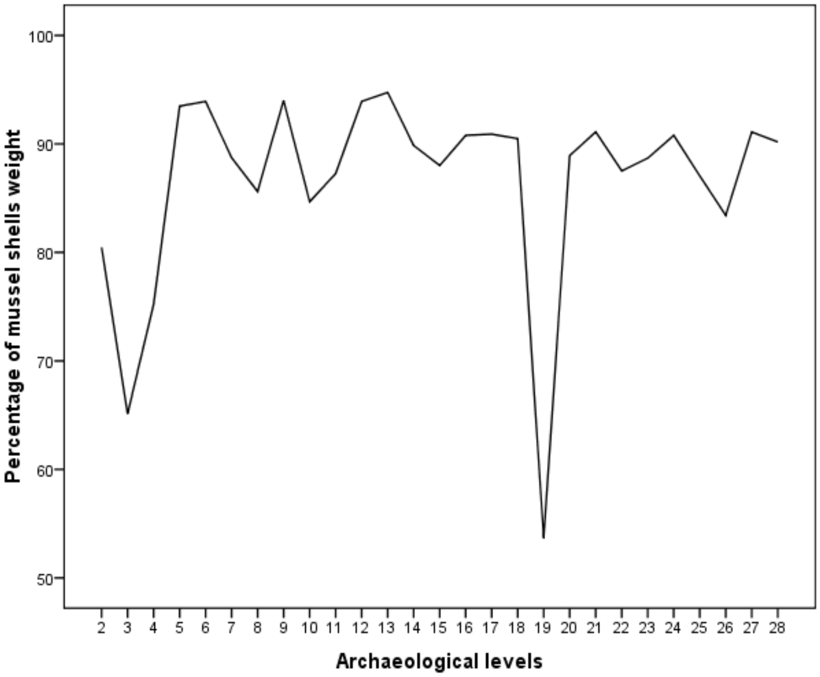

Figure 24. Proportion (%) of *M. californianus* (mussel) shell through time at SCRI-496. Shell weight, used to calculate percentage, was standardized by level thickness in cm.

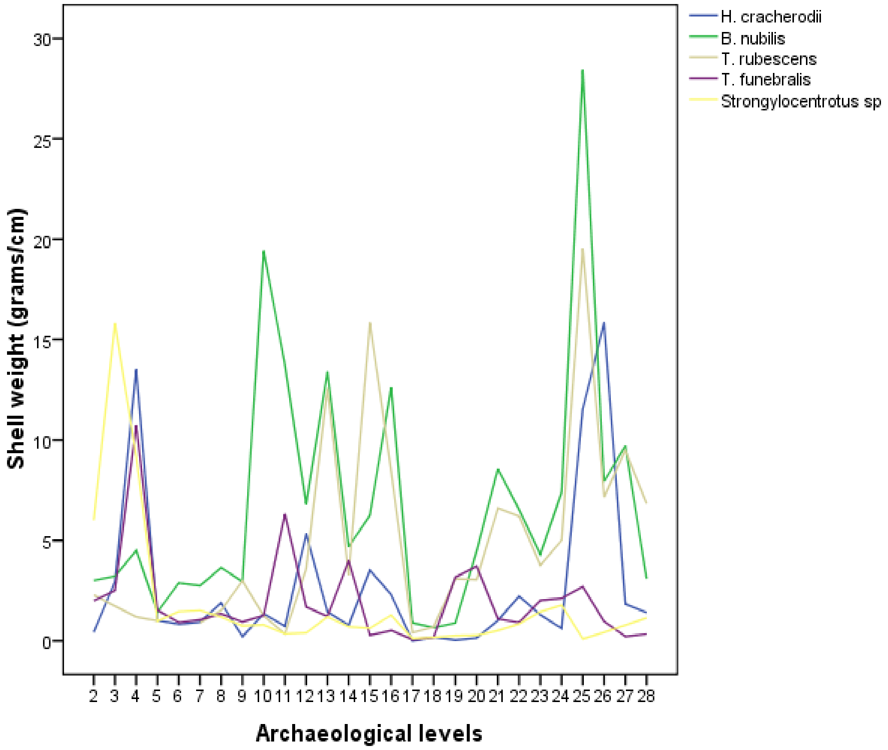

Figure 25. Abundance through time of the following most abundant shellfish species: *H. cracherodii*, *B. nubilus*, *T. rubencens*, *Strongylocentrotus* sp., and *T. funebralis* at SCRI-195. Shell abundance, represented by weight, was standardized by level thickness in cm.

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Figure 26. Number of species per stratigraphic level at SCRI-195

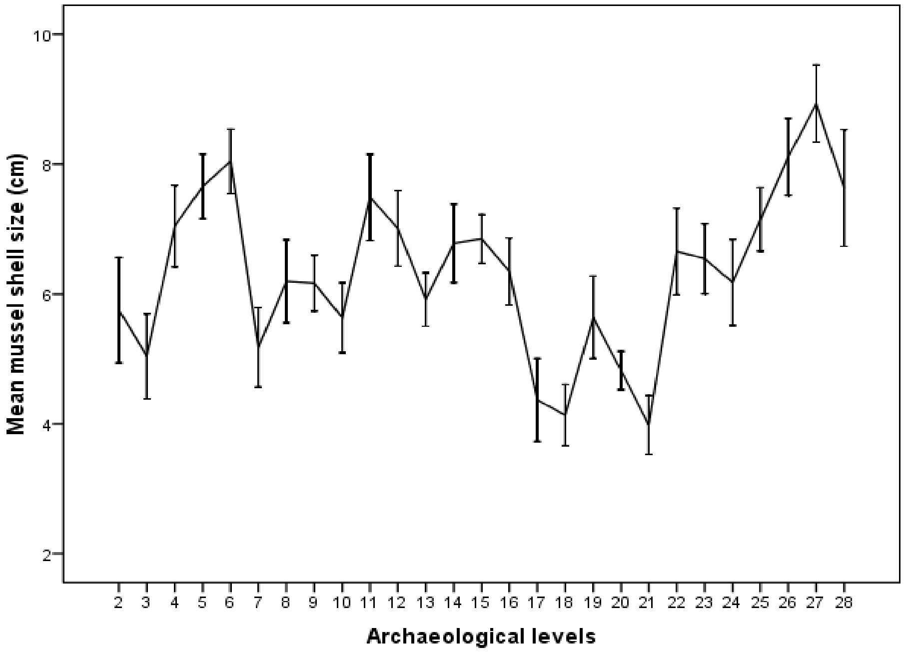

Figure 27. *M. californianus* (mussel) shell length (cm) per stratigraphic level at SCRI-195. 95% confidence intervals.

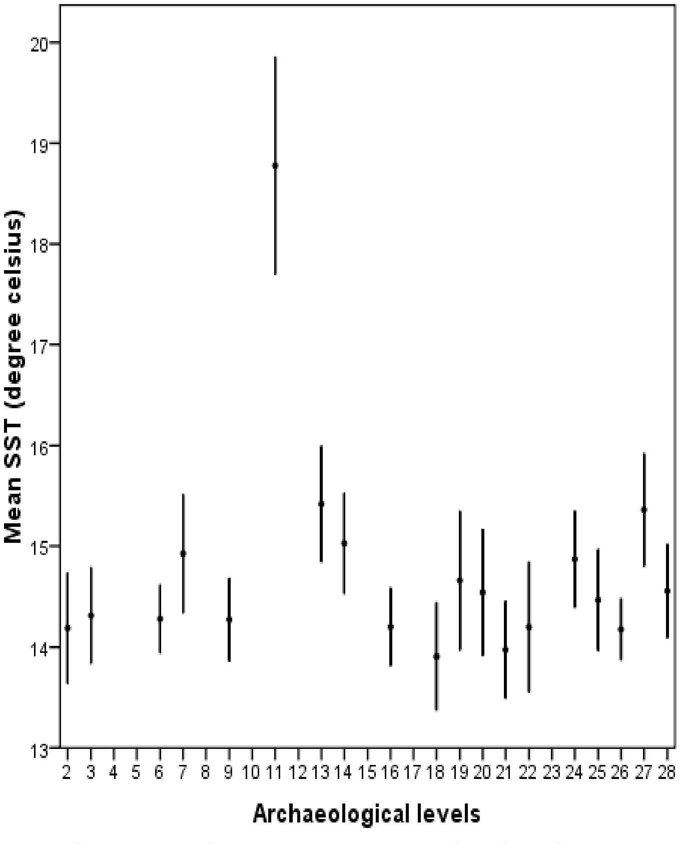

Figure 28. Mean SST (in degrees Celsius) per stratigraphic level at SCRI-195. Confidence intervals of 95%. No data are available for levels 4, 5, 8, 10, 12, 15, 17 and 23.

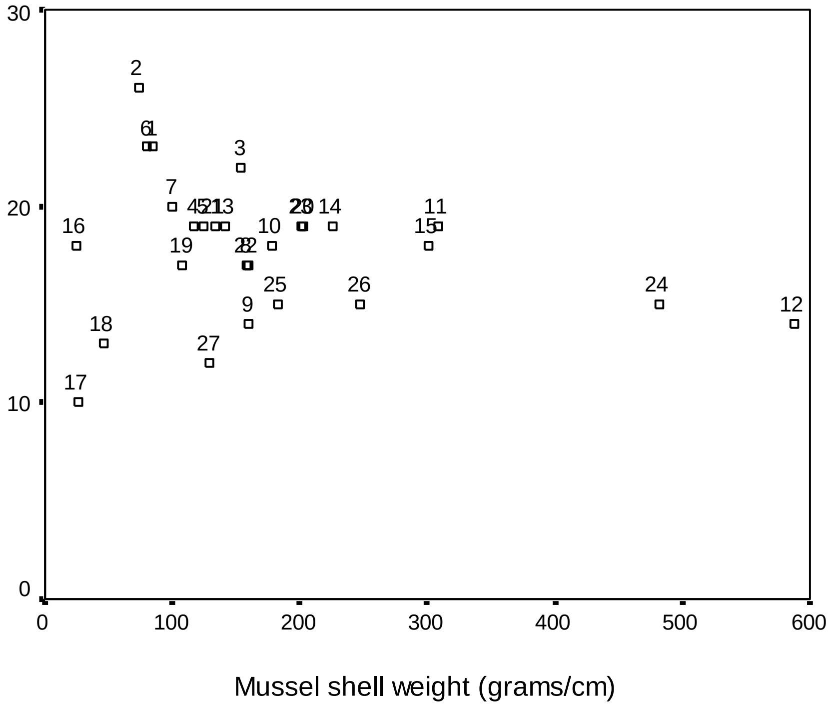

Figure 29. *M. californianus* (mussel) shell weight (grams/cm) and number of species at SCRI-496. Each square corresponds to a stratigraphic level.

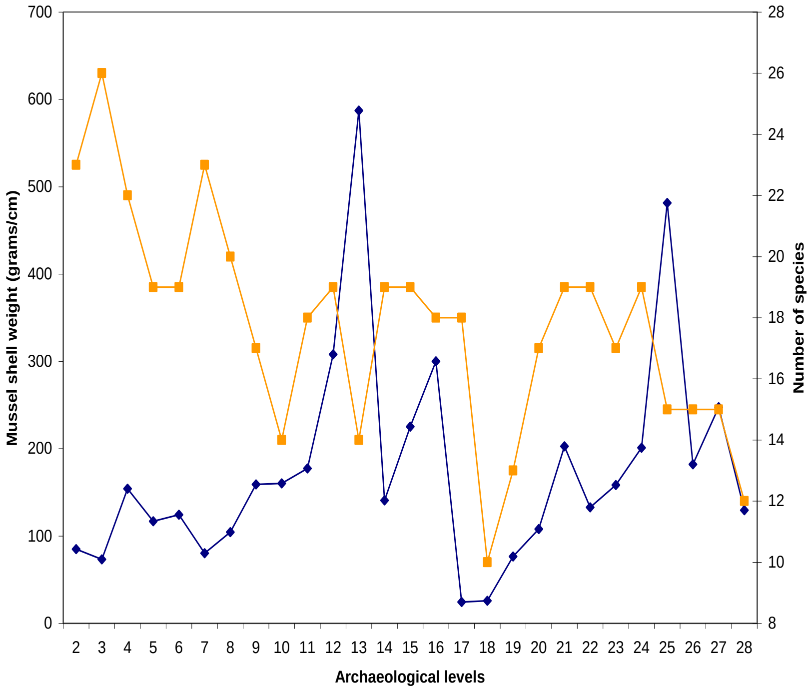

Figure 30. *M. californianus* (mussel) abundance (grams/cm) and number of species per stratigraphic level at SCRI-195. The blue line is abundance and the orange line is number of species. Abundance, represented by shell weight, was standardized by level thickness in cm.

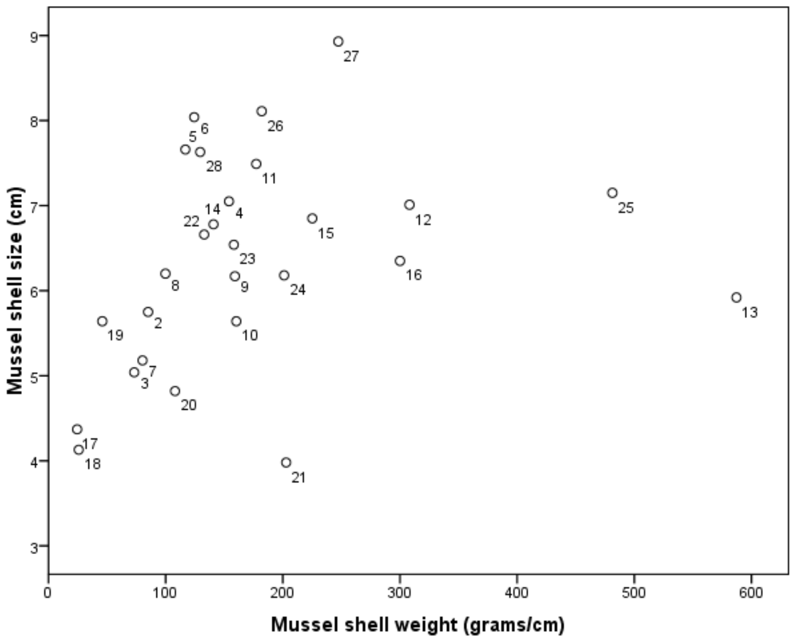

Figure 31. *M. californianus* (mussel) abundance (grams/cm) and shell length (cm) at SCRI-195. Each circle corresponds to a stratigraphic level. Abundance, represented by shell weight, was standardized by level thickness in cm.

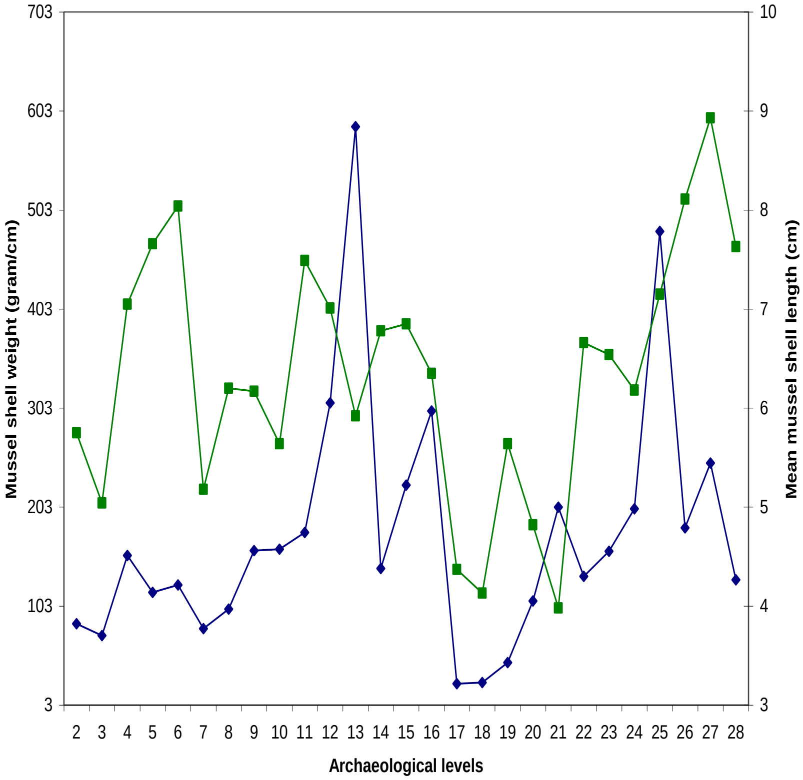

Figure 32. *M. californianus* (mussel) abundance (grams/cm) and mean shell length (cm) per stratigraphic level at SCRI-195. The blue line is abundance and the green line is shell length. Abundance, represented by shell weight, was standardized by level thickness in cm.

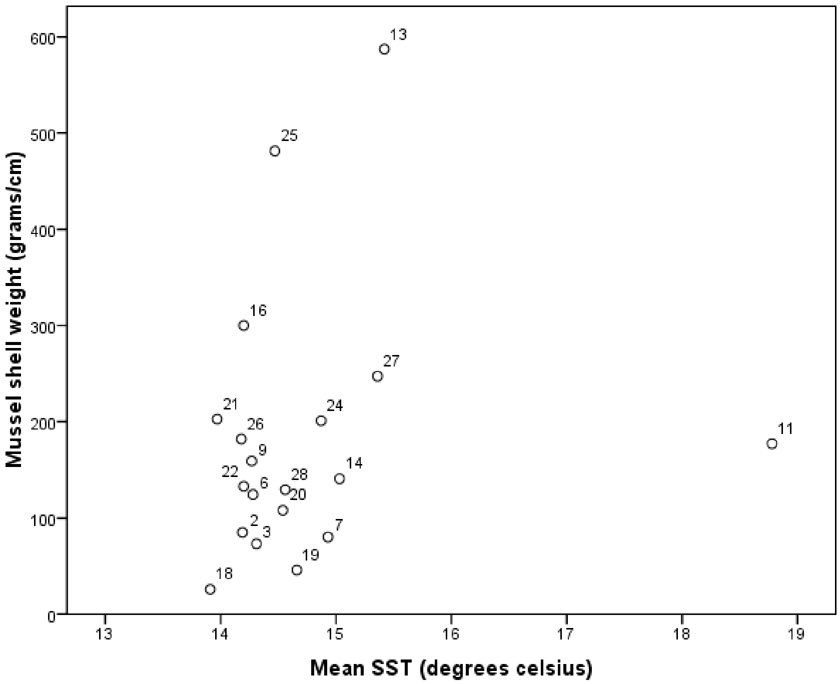

Figure 33. *M. californianus* (mussel) abundance (grams/cm) and SST (°C) based on oxygen-isotope analysis at SCRI-195. Each circle corresponds to a stratigraphic level. Abundance, represented by shell weight, was standardized by level thickness in cm.

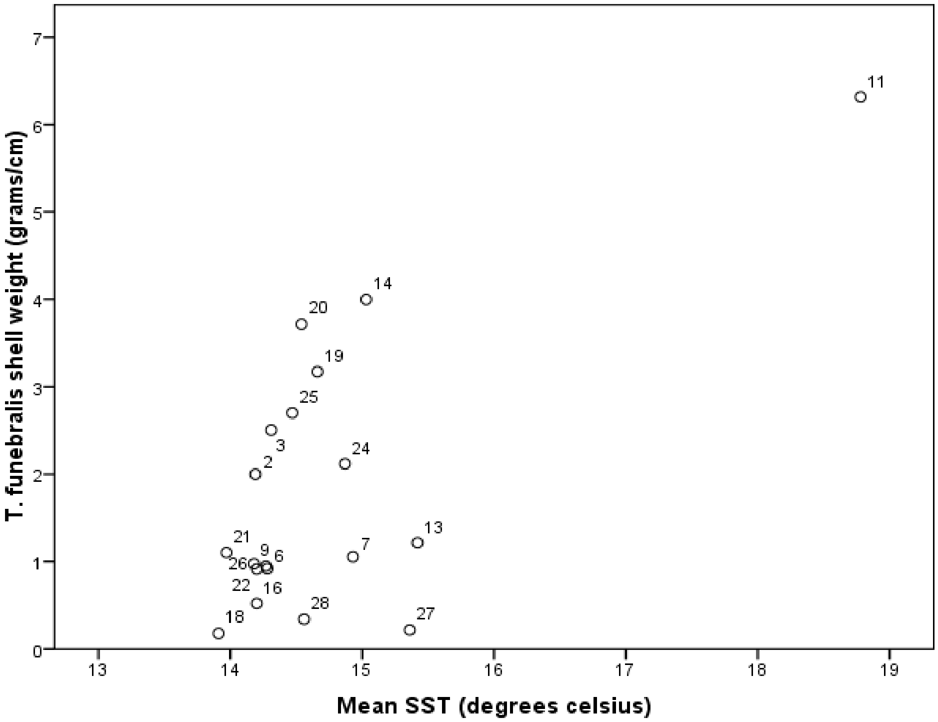

Figure 34. *T. funebralis* abundance (grams/cm) and SST (°C) at SCRI-195. Each dot corresponds to a stratigraphic level. Species abundance, represented by shell weight, was standardized by level thickness in cm.

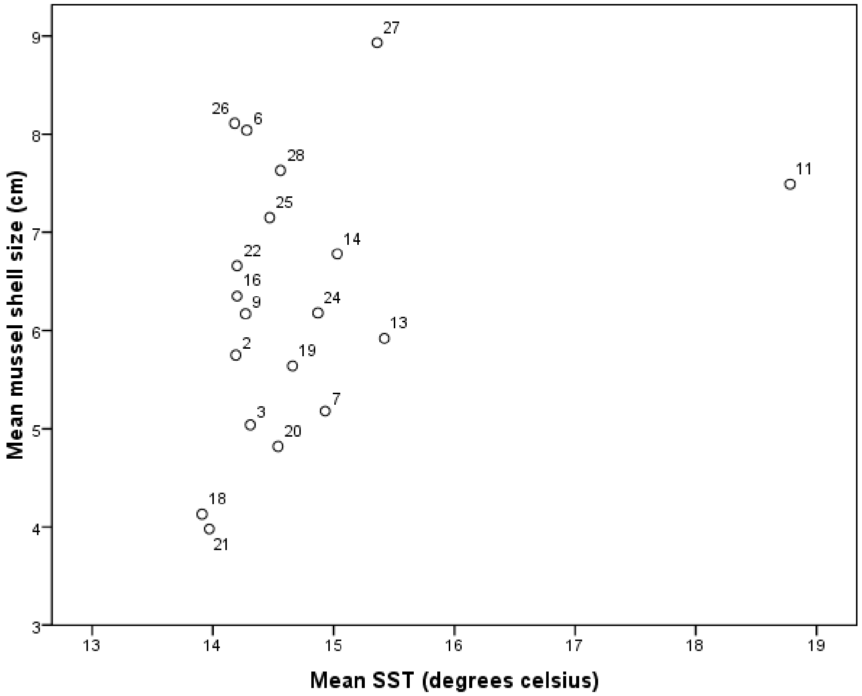

Figure 35. *M. californianus* (mussel) mussel shell length and SST (°C) obtained from oxygen-isotope analysis at SCRI-195. Each circle corresponds to a stratigraphic level.

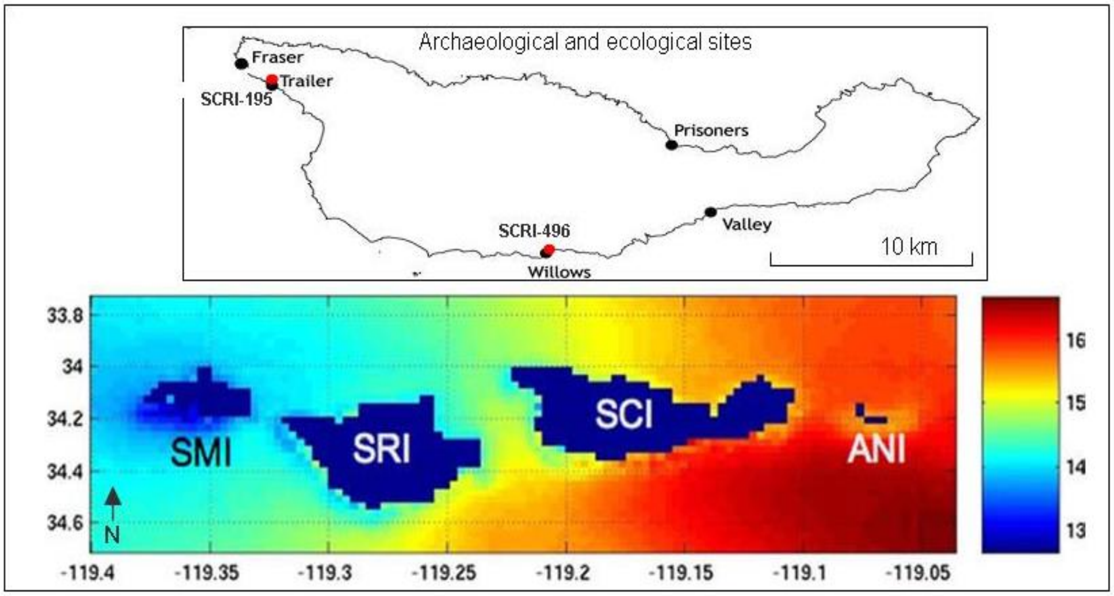

Figure 36. Long-term mean SST around Santa Cruz Island (Advanced Very High Resolution Radiometer (AVHRR) from 1997 to 2002). Modified from Blanchette et al. 2006:691. The color bar on the right depicts temperature in ºC. The white box shows ecological monitoring sites around Santa Cruz Island and the study sites.

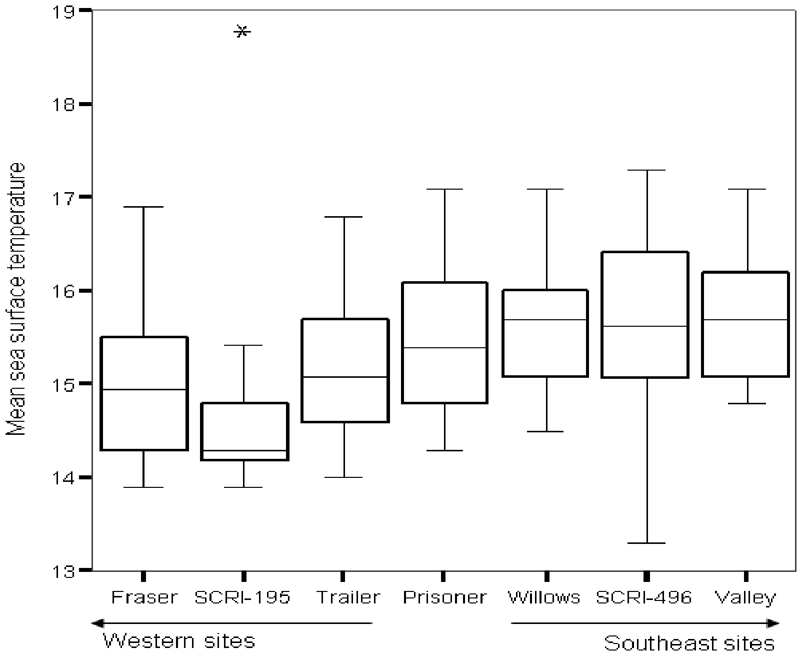

Figure 37. Box plots of modern annual mean SST values at nearshore locations around Santa Cruz Island and overall mean SST at SCRI-195 and SCRI-496. Data for modern nearshore locations comes from 25 years (1982-2007) of satellite imagery at 5-km resolution (AVHRR), and data from archaeological sites come from stable isotope (δO18) analyses of archaeological shells (*M. californianus*).

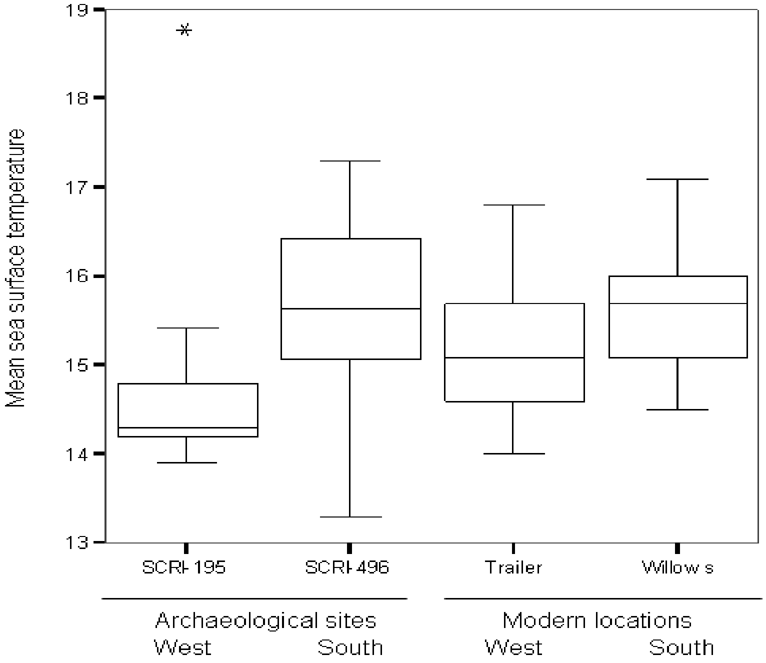

Figure 38. Box plots of modern annual mean SST values at Trailer and Willows nearshore locations and overall mean SST from shells obtained from SCRI-195 and SCRI-496. Data for modern nearshore locations comes from 25 years (1982-2007) of satellite imagery at 5-km resolution (AVHRR), and data for the archaeological sites come from stable isotope (δO^{18}) analyses of archaeological shells (*M.californianus*).

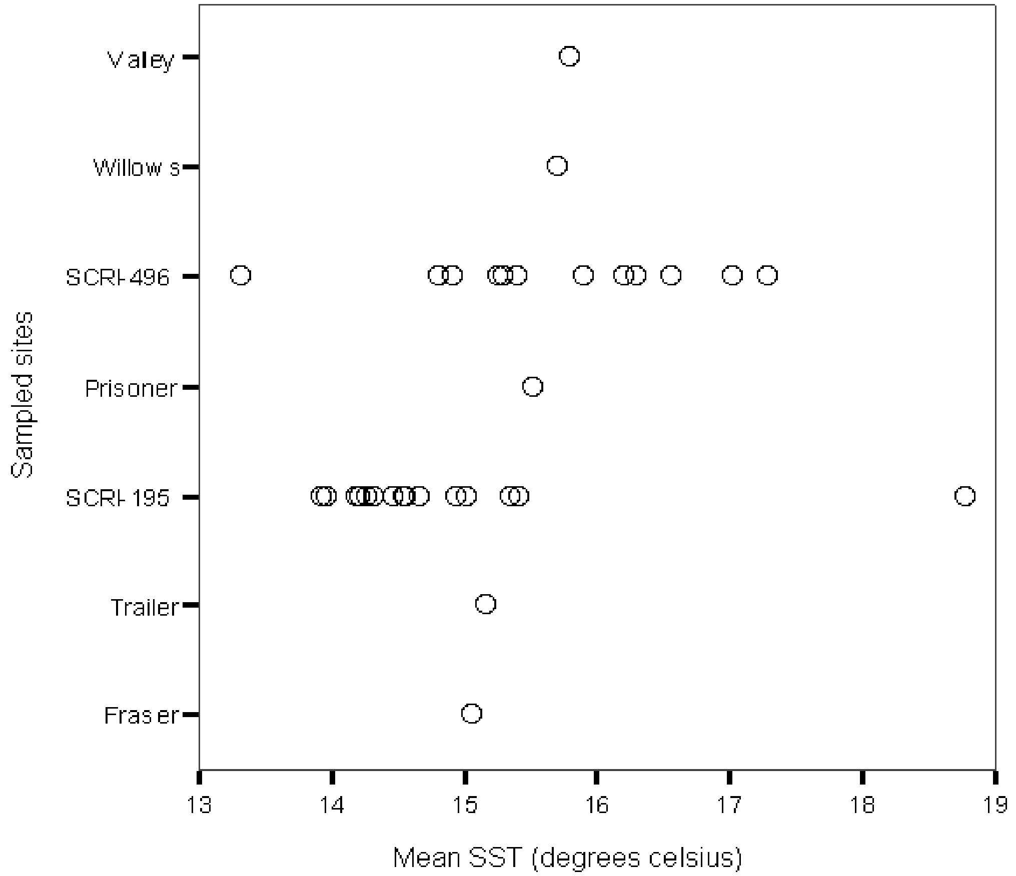

Figure 39. Modern annual mean SST values at nearshore locations around Santa Cruz Island, and mean SST from shells obtained from stratigraphic levels at SCRI-195 and SCRI-496. Data for modern nearshore locations comes from 25 years (1982-2007) of satellite imagery at 5-km resolution (AVHRR), and data for the archaeological sites come from stable isotope (δO^{18}) analyses of archaeological shells (*M.californianus*). Locations are distributed west to east: from the Fraser monitoring site on the west coast to the Valley monitoring site on the southeast coast.

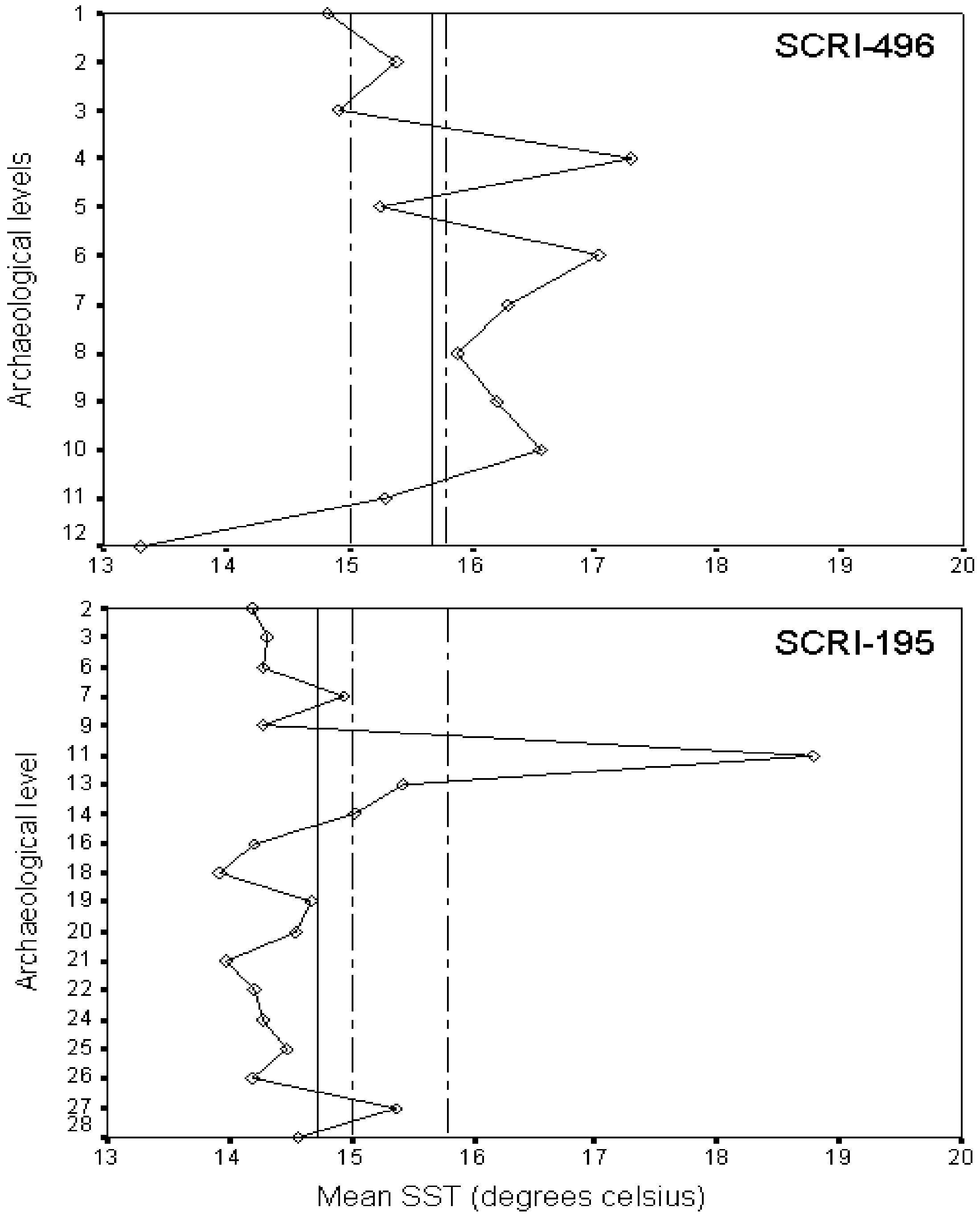

Figure 40. Mean SST for each stratigraphic level at SCRI-496 and SCRI-195. The solid vertical line is the mean value for the archaeological sites. The dashed lines define highest and lowest mean SST for the five intertidal monitoring sites around Santa Cruz Island.

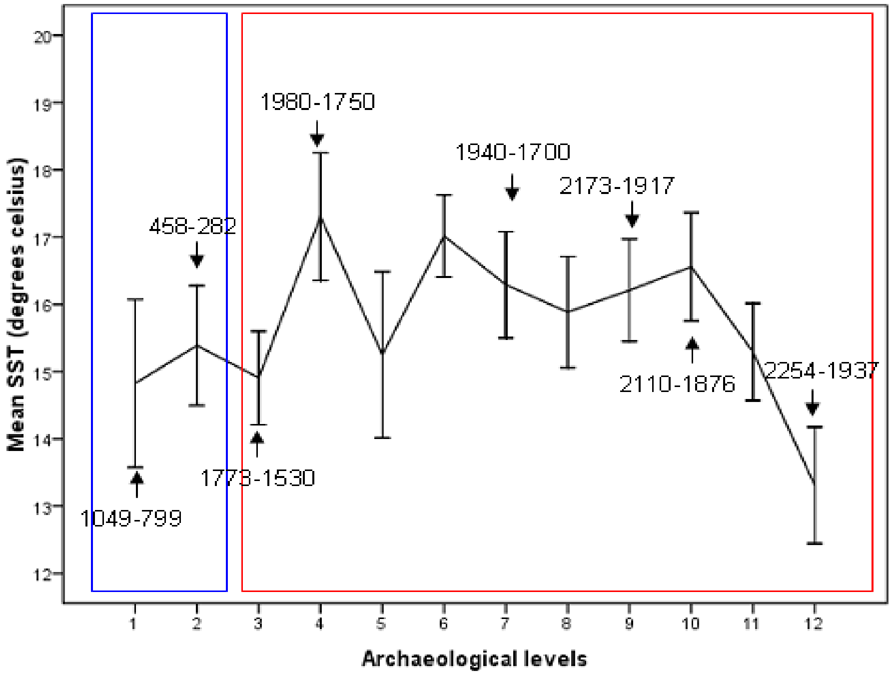

Figure 41. Mean SST per stratigraphic level at SCRI-496, including radiocarbon dates (calibrated years BP). The red square shows the period of warm SSTs and higher precipitation between 2300 and 1500 BP, and the blue square shows the period of cold SSTs and low precipitations between 1500 and 500 BP, both identified in the regional climatic record (Kennett, et al. 2007:355).

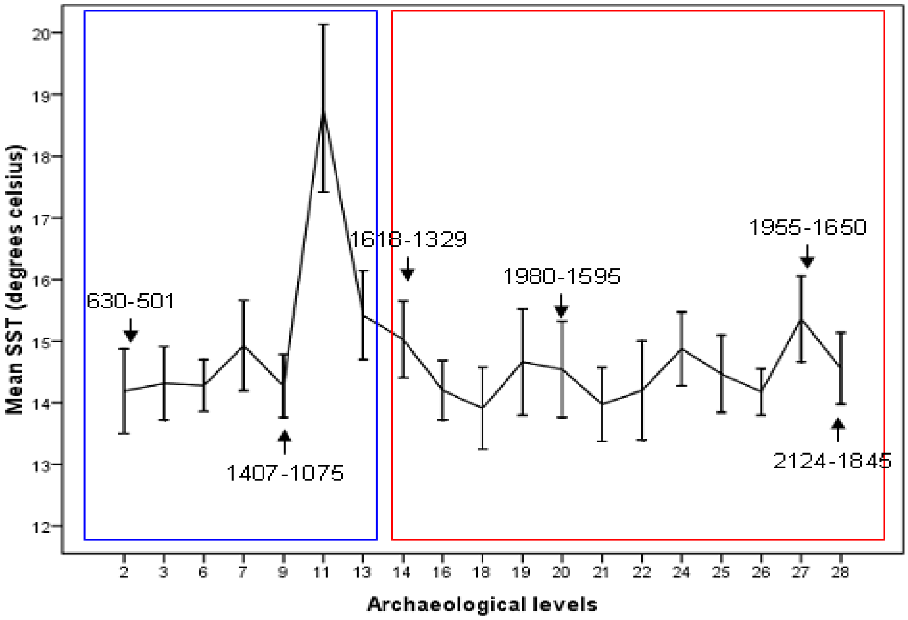

Figure 42. Mean SST per stratigraphic level at SCRI-195, including radiocarbon dates (calibrated years BP). The red square shows the period of warm SSTs and higher precipitation between 2300 and 1500 BP and the blue square shows the period of cold SSTs and low precipitations between 1500 and 500 BP, both identified in the regional climatic record (Kennett, et al. 2007:355).

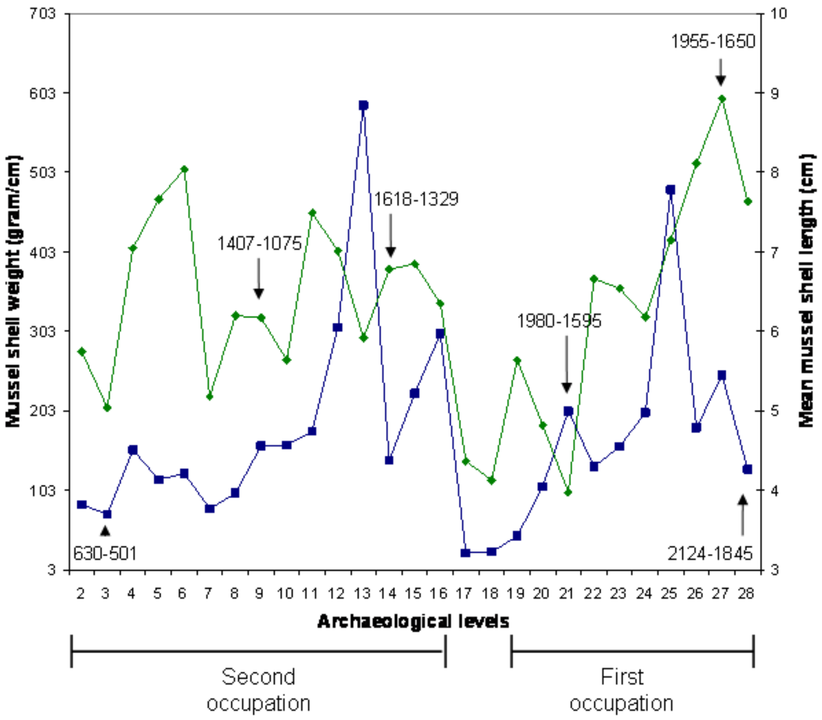

Figure 43. *M. californianus* (mussel) abundance (weight) and mean length per stratigraphic level at SCRI-195, including radiocarbon dates (calibrated years BP). The blue line is abundance and the green line is length. Abundance, represented by shell weight, was standardized by level thickness in cm.

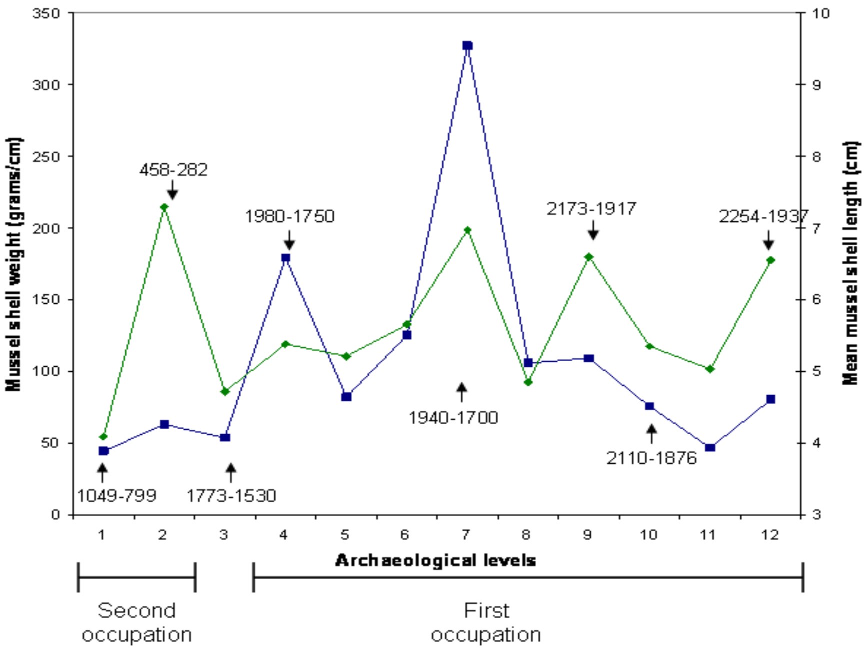

Figure 44. *M. californianus* (mussel) abundance (weight) and mean length per stratigraphic level at SCRI-496, including radiocarbon dates (calibrated years BP). The blue line is abundance and the green line is length. Abundance, represented by shell weight, was standardized by level thickness in cm.

Tables

Time Period	Calibrated yrs. B.P.	Calibrated yrs. B.C/A.D.
Historic	After 168	After A.D. 1782
Late Period	800-200	A.D. 1150-1782
Middle Period	2440-800	BC 490-AD1150
Early Period	8060-2440	BC 6120-490

Table 1. Time periods for the Santa Barbara Channel region (Arnold 1992; Kennett 2005:83)

Level	Thickness (cm)	Depth (cm)	Period	Diagnostic artifacts	Conventional Age BP	Material	Lab code	Calib. Age BP 2 Σ interval
1	15	0-15	Middle & Late	Olivella wall (saucers) and Cup bead	1610±40	*M. californianus*	Beta-282537	1049-799
2	5	15-20	Late		950±30	*M. californianus*	Beta-291144	458-282
3	5	20-25	Middle		2300±30	*M. californianus*	Beta-291145	1773-1530
4	5	25-30			2480±30	*M. californianus*	Beta-362455	1980-1750
5	12	30-42						
6	15	42-57						
7	10	57-67			2450±30	*M. californianus*	Beta-362456	1940-1700
8	5	67-72						
9	13	72-85			2640±30	*M. californianus*	Beta-291146	2173-1917
10	10	85-95			2590±30	*M. californianus*	Beta-291147	2110-1876
11	17	95-112						
12	10	112-122			2660±40	*M. californianus*	Beta-282538	2254-1937

Table 2. SCRI-496 chronological information.

Level	Thickness (cm)	Depth (cm)	Period	Diagnostic artifacts	Convent. age BP	Material	Lab code	Calib. Age BP 2 Σ interval
2	20	20-40	Late	cup olivella bead	1190±20	*M. californianus*	NOSAMS-96578	630-501
3	13	40-53	Terminal Middle	split-punched beads				
4	27	53-80						
5	20	80-100	Middle	wall olivella beads				
6	20	100-120						
7	25	120-145						
8	23	145-168						
9	17	168-185			1930±70	*M. californianus*	Beta-240436	1407-1075
10	14	185-199						
11	28	199-227						
12	20	227-247						
13	4	247-251						
14	18	251-269			2150±50	*M. californianus*	Beta-240437	1618-1329
15	11	269-280						
16	10	280-290						
17	9	290-299						
18	6	299-305						
19	3	305-308						
20	5	308-313			2420±70	*M. californianus*	Beta-240438	1980-1595
21	10	313-323						
22	12	323-335						
23	14	335-349						
24	23	349-372						
25	4	372-376						
26	11	376-387						
27	19	387-406			2430±50	*M. californianus*	Beta-240439	1955-1650
28	4	406-410			2580±45	*M. californianus*	NOSAMS-96579	2124-1845

Table 3. SCRI-195 chronological information.

Period	Calibrated ages BP midpoints	Dated levels	Thickness (cm)	Number of years	Thickness/ time	Rate (cm/year)
Middle and Late	924-370	2-1	20	554	20/554	0.036
Middle	1651-924	3-1&2	5	727	5/727	0.006
	1865-1651	4-3	5	214	5/214	0.023
	1820-1865	7-4	37	40	37/40	0.822
	2045-1820	9-7	18	225	18/225	0.08
	2095-2045	12-9	37	50	37/50	0.74

Table 4. Accumulation rate estimations calculated for each dated level (with statistically different dates) of the column sample from SCRI-496.

Period	Date calibrated BP midpoints	Dated levels	Thickness (cm)	Year	Thickness/time	Rate (cm/year)
Middle and Late	1272-565	8-2	148	707	148/707	0.20
Middle	1473-1272	13-9	83	201	83/201	0.41
	1787-1473	19-14	57	314	57/314	0.18
	1984-1787	28-20	102	197	100/197	0.51

Table 5. Accumulation rate estimations calculated for each dated level (with statistically different dates) of the column sample from SCRI-195.

N	Species	Common name	Levels												Total weight
			1	2	3	4	5	6	7	8	9	10	11	12	
1	*Balanus nubilis*	Acorn barnacle	3.4	3.2	6.34	15.92	18.97	6.9	16.58	6.67	5.91	4.31	2.7	3.74	94.64
2	*Crepidula* sp	Slipper snail	0.05									0.03			0.08
3	*Fisurella volcano*	Volcano limpet				0	0.01	0.01	0.11	0.01	0.01			0.01	0.16
4	*Haliotis cracherodii*	Black abalone	0.91	0.46	0.38	0.18	0.99	0.01	1.37	5.85	0.26	1.74	4.23	7.65	24.03
5	*Haliotis rufescens*	Red abalone											0.47	0.01	0.48
6	*Lottia gigantea*	Owl limpet	0.01	0.05		0.07	0	0.02	0.02		0.01	0.01	0	0.02	0.21
7	*Lottia pelta*	Shield limpet	0	0.03	0.03	0.07	0.07	0.08	0.13	0.1	0.04	0.02	0.02	0.02	0.61
8	*Lottia scabra*	Rough limpet	0		0.01	0	0.01	0.01	0.02	0.01	0.01	0.01			0.08
9	*Megathura crenulata*	Giant keyhole limpet											0.03		0.03
10	*Mopalia* sp	Mossy chiton		0.02		0.01	0	0.03					0.02	0.02	0.1
11	*Mytilus californianus*	California mussel	44.25	62.8	53.63	179.17	82	125.11	327.15	105.61	109.15	75.37	46.62	80.21	1291.07
12	*Notoacmaea incessa*	Seaweed limpet					0.09	0.13						0	0.22
13	*Nucella canaliculata*	Dogwinkle snail	0	0.01		0		0.19	0.03			0.01	0	0.02	0.26
14	*Olivella biplicata*	Purple dwarf olive	2.99	1.28	1.14	0.29	0.18	0.63	0.42	0.32	0.45	0.71	0.23	0.53	9.17
15	*Penitella* sp	Flat-tiped Piddock					0.01				0.01				0.02
16	*Polinices* sp	Moon snail	0.15											0.61	0.76
17	*Pollicipes*	Leaf	0.06	0.15	0.22	0.86	0.71	0.66	0.88	0.61	0.13	0.3	0.16	0.09	4.83

	polymerus	barnacle													
18	*Prothotaca* sp	Littleneck clam			0.1				0.01			0.03			0.14
19	*Septifer bifurcatus*	Platform mussel					0.01								0.01
20	*Serpulorbis squamigerus*	Scaled worm snail	0.11	0.03	0.01	0.24	0.13	0.04	0.43	0.29	0.11	0.04	0.16	0.14	1.73
21	*Strongylo-centrotus* sp	Sea urchin	0.17	0.54	0.17	0.47	2.01	0.61	0.27	0.44	0.43	0.23	0.35	0.18	5.87
22	*Tegula funebralis*	Black turban snail							0.03						0.03
23	*Tetraclita rubescens*	Volcano barnacle	0.93	0.97	1.39	3.34	3.39	2.43	1.98	2.18	1.39	1.24	1.38	0.69	21.31
		Unidentified remains	0.00	0.04	0.04	0.08	0.05	0.02	0.08	0.03	0.04	0.08	0.02	0.02	0.51
	Total weight per level		53.03	69.58	63.46	200.70	108.63	136.88	349.51	122.12	117.95	84.13	56.39	93.96	1456.35

Table 6. Shellfish species abundance (weight) for each archaeological level (levels 1 to 12) through the column sample of SCRI-496. Shell abundance, represented by weight, was standardized by level thickness and is expressed in grams per centimeter.

Level	Cm. below surface	Level thickness (cm)	Dates Cal BP	Period	*M. californianus* weight grams/cm	Total shell weight grams/cm	*M. californianus* %
1	0-15	15	1049-799	Middle	44.25	53.03	83.44
2	15-20	5	458-282	Late	62.80	69.59	90.24
3	20-25	5	1773-1530	Middle	53.63	63.45	84.52
4	25-30	5	1980-1750		179.17	200.75	89.25
5	30-42	12			82.00	99.44	82.46
6	42-57	15			125.11	136.89	91.39
7	57-67	10	1940-1700		327.15	349.52	93.60
8	67-72	5			105.61	122.11	86.49
9	72-85	13	2173-1917		109.15	117.96	92.53
10	85-95	10	2110-1876		75.37	84.15	89.58
11	95-112	17			46.62	56.39	82.69
12	112-122	10	2254-1937		80.21	93.96	85.37

Table 7. Abundance and percentage of *M. californianus* shells, and total shell abundance per level at SCRI-496. Shell abundance was standardized by level thickness and is expressed in grams per centimeter.

Levels	Cm	Dates Cal BP	Period	n	Mean	Std. Deviation	Median	Min	Max
1	0-15	1049-799	Middle	50	4.086	1.02378	3.9551	2.4	7.79
2	15-20	458-282	Late	9	7.292	2.64894	6.2513	4.8	11.5
3	20-25	1773-1530	Middle	31	4.716	1.62319	4.5518	2.2	9.6
4	25-30	1980-1750		50	5.379	1.10528	5.51	3.1	8.1
5	30-42			99	5.211	1.33828	4.9134	2.5	8.49
6	42-57			50	5.651	1.1577	5.5371	3.5	10.8
7	57-67	1940-1700		50	6.971	2.51267	6.4411	3.5	13.9
8	67-72			43	4.848	1.42475	4.7868	2.7	8.8
9	72-85	2173-1917		50	6.598	1.42523	6.2965	3.4	11.8
10	85-95	2110-1876		49	5.347	1.28203	5.51	2.6	8.57
11	95-112			46	5.029	1.05196	4.8953	3.1	8.6
12	112-122	2254-1937		49	6.551	2.86499	5.5823	3.7	20
Total				576	5.529	1.8246	5.2659	2.2	20

Table 8. *M. californianus* shell length (cm) for each archaeological level at SCRI-496. Number of shells measured per level is specified under column “n”.

	p value	
Levels	t-test	Mann-Whitney U
1-2	.000	.000
2-3	.001	.005
3-4	.032	.028
4-5	.445	.222
5-6	.049	.026
6-7	.001	.009
7-8	.000	.000
8-9	.000	.000
9-10	.000	.000
10-11	.192	.163
11-12	.001	.002

Table 9. Significance tests for changes in *M. californianus* mean shell length through time at SCRI-496.

Level	Cm	Dates Cal BP	Period	n	Mean	Std. Deviation	Median	Min	Max
1	0-15	1049-799	Middle Late	7	14.8244	1.3491	14.9995	13.06	16.59
2	15-20	458-282		32	15.3878	2.46542	15.5769	10.47	20.68
3	20-25	1773-1530	Middle	32	14.9057	1.9355	14.5402	11.22	18.53
4	25-30	1980-1750		32	17.3044	2.62586	17.9714	12.96	22.76
5	30-42			32	15.2505	3.42601	15.0573	10.89	27.67
6	42-57			32	17.0164	1.7001	17.2162	14.07	20.12
7	57-67	1940-1700		32	16.2917	2.19766	15.8003	12.62	20.39
8	67-72			16	15.8865	1.55098	15.788	12.92	18.74
9	72-85	2173-1917		32	16.2105	2.10238	15.8781	12.8	19.61
10	85-95	2110-1876		32	16.5582	2.23361	15.9937	12.88	22.25
11	95-112			32	15.2928	2.00698	14.9165	11.45	19.33
12	112-122	2254-1937		24	13.3077	2.0548	13.5965	9.252	16.34
	Total			335	15.7979	2.47032	15.6181	9.252	27.67

Table 10. Sea surface temperature (degrees Celsius) per level at SCRI-496. Number of shell samples of *M. californianus* per level is specified under column “n”.

	p value	
Levels	T-test	Mann-Whitney U
1-2	.564	.510
2-3	.388	.546
3-4	.000	.000
4-5	.009	.002
5-6	.011	.001
6-7	.145	.136
7-8	.513	.694
8-9	.588	.694
9-10	.524	.727
10-11	.020	.025
11-12	.001	.003

Table 11. Significance tests for changes in mean sea surface temperature (SST in °C) through time for SCRI-496.

Table 12. Shellfish species abundance (weight) for each archaeological level (levels 2 to 28) within the column sample from SCRI-195. Shell abundance, represented by weight, was standardized by level thickness and is expressed in grams per centimeter. See Appendix 5.

Level	Level (cm)	Level thickness	Dates Cal BP	Period	*M. californianus* weight (gr/cm)	All shells weight (gr/cm)	*M. californianus* %
2	20-40	20	630-501	Middle Late Transition	85.02	105.66	80.46
3	40-53	13	split-punched beads	Terminal Middle	73.17	112.33	65.14
4	53-80	27			154.04	204.79	75.22
5	80-100	20	wall bead	Middle	116.86	125.00	93.48
6	100-120	20			124.34	132.40	93.91
7	120-145	25			80.25	90.46	88.72
8	145-168	22			99.82	116.60	85.61
9	168-185	17	1407-1075		159.09	169.23	94.01
10	185-199	14			160.31	189.33	84.67
11	199-227	28			177.30	203.16	87.27
12	227-247	20			308.12	328.05	93.92
13	247-251	4			587.19	619.78	94.74
14	251-269	18	1618-1329		140.84	156.76	89.85
15	269-280	11			225.18	255.86	88.01
16	280-290	10			300.04	330.46	90.79
17	290-299	9			24.48	26.93	90.90
18	299-305	6			25.82	28.53	90.49
19	305-308	3			45.93	85.58	53.67
20	308-313	5	1980-1595		108.03	121.49	88.92
21	313-323	10			202.80	222.59	91.11
22	323-335	12			132.88	151.84	87.51
23	335-349	14			158.23	178.42	88.69
24	349-372	23			201.12	221.52	90.79
25	372-376	4			481.33	552.90	87.05
26	376-387	11			182.01	218.23	83.41
27	387-406	19	1955-1650		247.37	271.52	91.10
28	406-410	4	2124-1845		129.48	143.60	90.17

Table 13. Abundance and percentage of *M. californianus* shells, and total shell abundance per level at SCRI-195. Shell abundance, represented by weight, was standardized by level thickness and is expressed in grams per centimeter.

Level	Level (cm)	Dates Cal BP	Period	Mean	n	Std. Deviation	Median	Min	Max
2	20-40	630-501	Middle Late Transition	5.75	47	2.76	4.89	1.85	13.47
3	40-53	split-punched beads	Terminal Middle	5.04	56	2.45	4.81	0.51	10.03
4	53-80			7.05	50	2.21	6.59	3.32	14.19
5	80-100	wall bead	Middle	7.66	55	1.84	7.50	4.24	13.28
6	100-120			8.04	58	1.89	7.86	3.43	13.50
7	120-145			5.18	76	2.68	5.26	0.56	13.48
8	145-168			6.20	58	2.42	6.32	0.91	12.38
9	168-185	1407-1075		6.17	52	1.54	6.22	3.43	10.01
10	185-199			5.64	50	1.89	5.15	3.16	13.10
11	199-227			7.49	49	2.32	6.99	3.99	13.99
12	227-247			7.01	50	2.04	7.01	3.11	12.81
13	247-251			5.92	65	1.66	5.87	2.64	9.32
14	251-269	1618-1329		6.78	50	2.13	6.40	3.03	14.04
15	269-280			6.85	50	1.32	6.69	4.43	10.16
16	280-290			6.35	50	1.81	6.50	0.81	9.85
17	290-299			4.37	16	1.20	4.21	2.64	5.94
18	299-305			4.13	9	0.62	4.28	3.07	5.11
19	305-308			5.64	14	1.10	5.35	4.26	7.26
20	308-313	1980-1595		4.82	44	0.97	4.77	3.20	8.15
21	313-323			3.98	135	2.67	3.56	0.48	12.15
22	323-335			6.66	49	2.32	6.31	2.56	12.34
23	335-349			6.54	53	1.95	5.96	3.45	11.57
24	349-372			6.18	54	2.42	5.69	0.60	14.37
25	372-376			7.15	50	1.72	7.14	3.70	11.66
26	376-387			8.11	50	2.08	7.92	4.95	14.66
27	387-406	1955-1650		8.93	51	2.11	8.84	5.22	12.96
28	406-410	2124-1845		7.63	30	2.41	6.77	3.68	14.10
Total				6.30	1371	2.47	6.12	0.48	14.66

Table 14. *M. californianus* shell length (cm) for each archaeological level at SCRI-195. Number of measured shells per level is specified under column "n".

	p value	
Levels	T-test	Mann-Whitney U
2-3	.069	.143
3-4	.000	.000
4-5	.048	.076
5-6	.181	.219
6-7	.000	.000
7-8	.029	.005
8-9	.937	.531
9-10	.124	.027
10-11	.000	.000
11-12	.279	.515
12-13	.002	.003
13-14	.016	.033
14-15	.852	.504
15-16	.421	.526
16-17	.000	.000
17-18	.592	.630
18-19	.001	.002
19-20	.010	.014
20-21	.007	.075
21-22	.000	.000
22-23	.728	.581
23-24	.097	.065
24-25	.016	.004
25-26	.013	.025
26-27	.052	.040
27-28	.013	.010

Table 15. Significance tests for changes in mean *M. californianus* shell length (cm) through time at SCRI-195.

Level	Level thickness (cm)	Dates Cal BP	Period	Mean	n	Std. Deviation	Median	Min	Max
2	20-40	630-501	Middle Late Transition	14.19	24	1.62	14.21	11.01	16.75
3	40-53	split-punched beads	Terminal Middle	14.31	24	1.40	14.16	12.03	16.82
4	53-80								
5	80-100	wall bead	Middle						
6	100-120			14.28	24	0.99	14.16	12.52	16.55
7	120-145			14.93	24	1.74	15.05	11.05	17.34
8	145-168								
9	168-185	1407-1075		14.27	24	1.21	14.10	12.10	16.09
10	185-199								
11	199-227			18.78	21	2.99	19.16	14.47	23.94
12	227-247								
13	247-251			15.42	24	1.70	15.35	12.42	19.75
14	251-269	1618-1329		15.03	24	1.47	14.90	12.70	17.97
15	269-280								
16	280-290			14.20	24	1.14	13.86	12.32	16.42
17	290-299								
18	299-305			13.91	24	1.58	13.52	11.08	16.83
19	305-308			14.66	24	2.04	14.08	11.60	18.27
20	308-313	1980-1595		14.54	24	1.85	13.88	11.81	17.75
21	313-323			13.97	24	1.42	13.94	11.43	16.16
22	323-335			14.20	24	1.91	13.91	11.82	18.20
23	335-349								
24	349-372			14.87	24	1.41	15.06	12.53	17.06
25	372-376			14.47	24	1.48	14.45	11.94	16.61
26	376-387			14.18	24	0.89	14.24	11.90	15.50
27	387-406	1955-1650		15.36	24	1.65	15.65	12.88	18.36
28	406-410	2124-1845		14.56	24	1.37	14.21	12.07	16.77
Total				14.46	461	2.67	14.44		

Table 16. Sea surface temperature (degrees Celsius) per level at SCRI-195. Number of shell samples of *M. californianus* per level is specified under column “n”.

	p value	
Levels	T-test	Mann-Whitney U
2-3	.776	.805
3-6	.923	.951
6-7	.120	.045
7-9	.137	.043
9-11	.000	.000
9-13*	.010	.023
11-13	.000	.000
13-14	.399	.578
14-16	.034	.063
16-18	.465	.353
18-19	.160	.266
19-20	.833	.789
20-21	.239	.398
21-22	.646	.853
22-24	.171	.155
24-25	.337	.353
25-26	.415	.458
26-27	.003	.016
27-28	.072	.095

Table 17. Significance tests for changes in mean sea surface temperature (SST in °C) through time for SCRI-195.
*Pair 9-13 was calculated due to the anomalous mean SST value for level 11.

Arch Site	Level	Cm	Mean SST	N	*M. californianus* percentage
SCRI-496	1	0-15	14.8	7	83.44
SCRI-496	2	15-20	15.3	32	90.24
SCRI-496	3	20-25	14.9	32	84.52
SCRI-496	4	25-30	17.3	32	89.25
SCRI-496	5	30-42	15.2	32	82.46
SCRI-496	6	42-57	17.0	32	91.39
SCRI-496	7	57-67	16.2	32	93.60
SCRI-496	8	67-72	15.8	16	86.49
SCRI-496	9	72-85	16.2	32	92.53
SCRI-496	10	85-95	16.5	32	89.58
SCRI-496	11	95-112	15.2	32	82.69
SCRI-496	12	112-122	13.3	24	85.37
Mean site			15.7	335	

Table 18. Mean SST(°C) and *M. californianus* percentage for each archaeological level at SCRI-496.

Arch Site	Level	Cm	Mean SST	N	*M. californianus* percentage
SCRI-195	1	0-20			
SCRI-195	2	20-40	14.1	24	80.46
SCRI-195	3	40-53	14.3	24	65.14
SCRI-195	4	53-80			75.22
SCRI-195	5	80-100			93.48
SCRI-195	6	100-120	14.2	24	93.91
SCRI-195	7	120-145	14.9	24	88.72
SCRI-195	8	145-168			85.61
SCRI-195	9	168-185	14.2	24	94.01
SCRI-195	10	185-199			84.67
SCRI-195	11	199-227	18.7	21	87.27
SCRI-195	12	227-247			93.92
SCRI-195	13	247-251	15.4	24	94.74
SCRI-195	14	251-269	15.0	24	89.85
SCRI-195	15	269-280			88.01
SCRI-195	16	280-290	14.2	24	90.79
SCRI-195	17	290-299			90.90
SCRI-195	18	299-305	13.9	24	90.49
SCRI-195	19	305-308	14.6	24	53.67
SCRI-195	20	308-313	14.5	24	88.92
SCRI-195	21	313-323	13.9	24	91.11
SCRI-195	22	323-335	14.2	24	87.51
SCRI-195	23	335-349			88.69
SCRI-195	24	349-372	14.2	24	90.79
SCRI-195	25	372-376	14.4	24	87.05
SCRI-195	26	376-387	14.1	24	83.41
SCRI-195	27	387-406	15.3	24	91.10
SCRI-195	28	406-410	14.5	24	90.17
Mean site			14.4	461	

Table 19. Mean SST (°C) and *M. californianus* percentage for each archaeological level at SCRI-195.

Island	Modern locations	SST (°C)		*M. californianus* percent cover	
		Mean	Nº of measurements	Point contact	*M. californianus* plot
Santa Cruz	Fraser	15.0	947	7.5	45.93
Santa Cruz	Trailer	15.1	963	5	38.18
Santa Cruz	Prisoner's	15.5	1013	13	37.37
Santa Cruz	Willows	15.7	1006	17.5	34.42
Santa Cruz	Valley	15.8	1028	13	34.40

Table 20. Long-term mean sea surface temperature (SST) derived from weekly satellite imagery between 1982 and 2007 at 5-km resolution (AVHRR) and abundance of *M. californianus* (% cover) at modern intertidal ecological sites around Santa Cruz Island (point contact data from Blanchette et al 2006 and *M. californianus* plot data from Pacific rocky intertidal monitoring, University of California Santa Cruz, ~1994 to 2010).