# SHELLFISH ANALYSIS FROM A SANTA CRUZ ISLAND RED ABALONE MIDDEN: RE-EVALUATING THE MARINE COOLING HYPOTHESIS

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## ABSTRACT

"Red abalone middens" are a type of archaeological site on the Northern Channel Islands that are characterized by large quantities of red abalone shells (*Haliotis rufescens*). These sites consistently date between approximately 7,500 and 4,500 BP, with no evidence of similar deposits later in time. The presence and subsequent disappearance of these sites has been explained in terms of two competing hypotheses: (1) that the sites represent a Middle Holocene marine cooling trend when red abalone was available for intertidal harvesting, and (2) that the disappearance of these sites at the end of the Middle Holocene was a result of human overexploitation of abalone, rather than environmental change. The analysis of invertebrate remains from CA-SCRI-109, a red abalone midden on Santa Cruz Island, was used to investigate the first of these two explanations. This analysis, in combination with a review of recent ecological data and marine paleotemperature data, does not indicate that significant marine cooling took place during the period of site occupation. In the apparent absence of environmental change, possible cultural explanations for the changes in the deposits are briefly discussed, along with suggestions regarding future research on this subject.

**Keywords:** Santa Cruz Island, Northern Channel Islands, Santa Barbara Channel, archaeology; prehistory; red abalone middens, abalone, *Haliotis*, shellfish, shellfish analysis, Middle Holocene, climatic change.

## INTRODUCTION

"Red abalone middens" are a site type that has been of growing interest to Channel Islands archaeologists in recent years. These sites are unique in containing high numbers of large red abalone shells (*Haliotis rufescens*) which are typically packed closely together in relatively thin (<25 cm.) layers (Glassow 1993a). Often these deposits are laterally extensive, resembling "pavements" in cross section (Kennett 1998). At present, more than 30 of these sites have been identified and dated on Santa Cruz, Santa Rosa, and San Miguel islands. Interestingly, all of these deposits have produced radiocarbon dates between approximately 7,500 and 4,500 BP (Glassow 1993a:570; Kennett 1998:270).

Glassow (1987, 1993a) was the first to identify the temporal pattern exhibited by these sites and to realize their research potential. Building on the ideas of Hubbs (1967) and Orr (1968:97), Glassow used ecological data to argue that the red abalone middens were a result of significantly cooler ocean temperatures during the Early and Middle Holocene. In this model, red abalone (which presently occur subtidally in the study area) were available intertidally, as they are today in the northern (and cooler) part of their range in Sonoma and Mendocino counties. Black abalone (*H. cracherodii*) was noted to be rare in these deposits. The modern ranges of black abalone and red abalone overlap, but red abalone reaches farther north to Humboldt county, while black abalone seldom reaches San Francisco Bay. Throughout its range, black abalone is limited to the intertidal zone, meaning that it is easy to collect and should appear in archaeological deposits. The near-absence of the intertidal black abalone from these deposits was then interpreted as further evidence that cooler ocean temperatures had pushed species distributions south, in this case presumably pushing the northern edge of the black abalone's range somewhere to the south of the Northern Channel Islands. It is important to highlight two basic assumptions of Glassow's model: 1) that the red abalone present in the deposits were collected intertidally and not subtidally, and 2) that black abalone does not co-occur in significant numbers with red abalone in the deposits.

Salls (1988, 1991, 1992) questioned the climate change model advocated by Glassow, and argued for cultural reasons as a cause of the changes in the deposits. Salls saw a similar pattern of larger abalone in the Early and Middle Holocene deposits on San Clemente Island, but in this case the larger species were pink abalone (*H. corrugata*) and green abalone (*H. fulgens*) rather than red. He also noted that some of these deposits contained another large gastropod, wavy top (*Lithopoma undosum,* formerly *Astraea undosa*). Salls pointed out that the present subtidal distribution of the large abalone species in both the Northern and Southern Channel islands therefore mirrored the species found in early deposits. Based on this correlation between past and present distributions, as well as on his observation that species such as pink and green abalone are generally not available intertidally, Salls argued that prehistoric inhabitants were diving rather than collecting intertidally. In his study of Eel Point (CA-SCLI-43), Salls noted that black abalone occurred in small numbers throughout the entire sequence but did not gain prominence until the larger species disappeared from the deposits (Salls 1991:70). Salls interpreted this in economic terms: the prehistoric divers has passed up the intertidal black abalone because it was physically smaller and offered a tougher meat which required significantly higher processing times (Salls 1991:73; 1992:160). On San Clemente Island, Salls' argued that the shift from large subtidal species to the smaller intertidal black abalone was a result of over-exploitation, and claimed that the green and pink abalone at Eel Point decreased through time (1991:73). He was puzzled by the lack of co-occurrence of red and black abalone in the Northern Channel Island deposits, and the apparently sudden and complete shift from red to black. Salls agreed that it was suggestive of climatic change, but suggested that other possibilities included some kind of viral epidemic or changes in the physical structure of the coastline (1992:160, 164).

A subsequent study by Glassow et al. (1994) used isotopic analysis of mussel shells from a red abalone midden on Santa Cruz Island (CA-SCRI-333) to address the ocean temperature question. Their results suggested that ocean temperatures during site occupation (5,700 to 5,000 BP) were approximately 2.5°C cooler than present, roughly equivalent to the modern temperature of Monterey Bay. Glassow et al. also used Pisias' (1978) marine paleotemperature curve to support their argument, as the curve shows large-scale temperature shifts in the Santa Barbara Basin throughout the Holocene. Although the dates from their sample fell within one of Pisias' warm periods, this discrepancy was interpreted as resulting from differences in dating methods. They concluded that the midden probably accumulated during a brief cool period which Pisias saw between 5,400 and 5,200 calendar years before present (CYBP). Glassow et al. also rejected the over-exploitation model advocated by Salls, pointing out that economic explanations would not account for the complete abandonment of the subtidal red abalone later in time (1994:230).

Throughout this debate, a lack of detailed faunal data has made these competing hypotheses difficult to evaluate. Characterizations of the invertebrate assemblages in the red abalone middens on the Northern Channel Islands have been based mostly on visual impressions of the deposits. Although some of these sites have been column sampled (Glassow 1993b; Kennett 1998), quantification of faunal remains has generally been aimed at reconstructing basic subsistence patterns and have differentiated only gross faunal categories (i.e., fish vs. shellfish vs. sea mammal). Prior to this study only one red abalone midden (CA-SMI-492) has undergone a detailed analysis quantifying the relative abundance of different invertebrate species (Walker and Snethkamp 1984:102). Characterizations of the Middle Holocene abalone middens in the Southern Channel Islands generally suffer from the same lack of detail. Although Salls (1992:159) cites statistics regarding the relative abundance of species at Xantusia Cave (CA-SCLI-1178), the source of his numbers is unclear.

The goal of this study is to re-evaluate the first of these explanations, the marine cooling hypothesis, using a detailed ecological analysis of invertebrate remains from CA-SCRI-109, a large red abalone midden recently excavated on Santa Cruz Island. In addition to the data provided by these faunal remains, this study draws from two additional bodies of data unavailable to previous researchers: (1) a newer, higher resolution Holocene marine temperature curve (Kennett and Kennett 1997), and (2) more detailed studies of abalone distribution and abundance (Parker et al. 1992; Tegner et al. 1992; Haaker 1994).

## METHODS

CA-SCRI-109 is a large red abalone midden located at Punta Arena, a rocky point on the southern shore of Santa Cruz Island (Figure 1). The site has been characterized as unusual in terms of its size and thickness, and in the relatively high number of sea mammal bones it contains (Glassow 1993b). After initial column sampling of the site in 1974, more recent excavations were conducted in 1997 by a University of California at Santa Barbara (UCSB) team led by Glassow. The two-meter-thick deposit was excavated in two locations, resulting in the stratigraphic excavation of 18 to 20 strata and a total of approximately 1.89 cubic meters of site matrix. Recovered materials consist mainly of faunal remains (especially shell), but also contain occasional diagnostic artifacts. A series of 15 radiocarbon dates indicate that the site was utilized over a 6,000 year period stretching from approximately 8,800 to 2,000 BP, with the bulk of the materials representing a period from approximately 6,300 to 5,300 BP (see Glassow, this volume, for a detailed explanation of CA-SCRI-109 radiocarbon dates).

The strategies used to sample and analyze the shellfish remains for this study were geared to the research problems at hand: 1) to quantify the relative abundance of abalone and other large, possibly subtidal species, and 2) to generate a broad species list which can be used to address

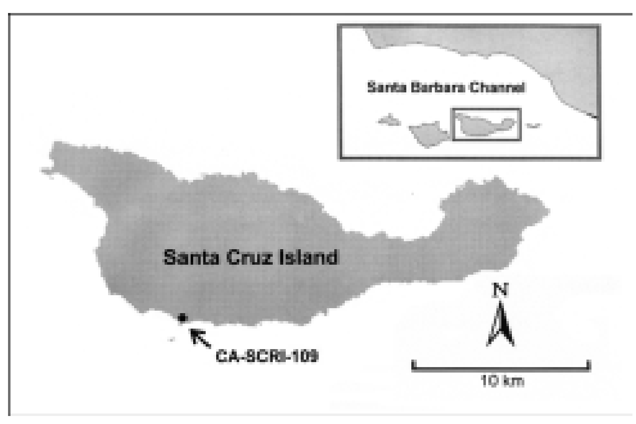


**Figure 1. Site location.**

questions of climate change. This study is based on the analysis of materials recovered from two column samples and two excavation units excavated during the 1997 season.

The two 1/8 inch-mesh column samples from the site played a relatively minor role in this analysis, and were intended primarily to catch small species that might fall through 1/4 inch-mesh used to sample the shellfish from the larger excavation units. The two 1/4 inch-mesh shellfish samples obtained from the larger excavation units were much more important, and played two key roles in this analysis. First, these relatively large samples were intended to produce a broad species list useful in addressing questions of climate change. Second, the larger samples from the excavation units were used to more accurately quantify the relative abundance of some of the larger and heavier species in the deposit, including abalone, wavy top, and Pismo clam (*Tivela stultorum*). These species appeared in low numbers in the column sample, but because of their great size and weight relative to smaller and more friable species, it was thought that they might skew the column-sample results. A review of the column-sample results indicated that only a small percentage of these species had passed through 1/4 inch screen and into the 1/8 inch screen sample. For example, an average of 2% of the abalone per level was found in the 1/8 inch screen sample, and an average of only 4% of the wavy top per level was found in the 1/8 inch screen sample. With this in mind, it was decided that sorting much larger samples of 1/4 inch (and larger) materials would be an efficient way to obtain a more accurate picture of the role of these species. For the North Unit, all (100%) shellfish remains 1/4 inch and larger from all strata were sorted for the following species: abalone (all species), wavy top, Pismo clam, and assorted rare species found in trace amounts. All other shellfish remains from these proveniences were left unsorted. This same procedure was applied to South Unit Strata 1, 2, 17, 18, 19a, 19b, and 20 (Table 1). Shellfish from the remaining strata in South Unit were not sorted.

The methods described above (especially reliance on 1/4 inch screen samples) are unusual in Channel Islands archaeology, and are tailored for the research questions at hand. The use of massive samples of 1/4 inch materials was a response to methodological criticisms of column sampling expressed by Waselkov (1987), Claassen (1991), and more recently by Mason et al. (1998). This method may not be sufficient to address many common goals of archaeological shellfish analysis, such as dietary reconstruction.

Species identifications were performed by the author using the author's personal type collection, which has been checked against specimens at the California Academy of Sciences in San Francisco and the Santa Barbara Museum of Natural History. Species not found in the author's personal collection were identified by Paul Scott and Henry Chaney of the Santa Barbara Museum of Natural History.

## RESULTS

Approximately 63 species of marine invertebrates were identified in the materials from CA-SCRI-109. With the exception of significant amounts of Pismo clam and trace amounts of a few other soft-bottom species, almost all of these species are associated with rocky substrates of unprotected coastlines (see Sharp [1999] for a complete list).

In terms of subsistence, California mussel (*Mytilus californianus*) clearly dominates every stratum in the site, accounting for approximately 60% to 80% of the shell per stratum by weight. Other significant contributors to the assemblage include wavy top, Pismo clam, urchin, and assorted species of abalone (Figure 2). Temporally, the contribution of larger species (i.e., Pismo clam, abalone, and wavy top) varies widely, from a high of approximately 30% of the assemblage in North Unit Stratum 18 (approximately 8,800 BP), to <2% of the assemblage in South Unit Stratum 2 (approximately 5,305 BP). The highest percentages of these species occur in North Unit Strata 5 to 15 (between approximately 5,610 BP and 6,300 BP), although North Unit Stratum 18 is an exception to this, exhibiting a high percentage of wavy top.

Interestingly, wavy top and Pismo clam account for a large part of the non-mussel shell weight and outweigh abalone in most strata. Pismo clam was probably obtained from nearby middle Holocene beaches similar to those adjacent to Punta Arena today. Wavy top is a rocky open coast species with ecological requirements similar to subtidal species of abalone. Pismo clam has a widespread geographical

**Table 1. Summary of shellfish sampling methods.**

| Unit | Strata sorted | 1/4" shell | 1/8" shell | Total shell weight (g) | Methods |
|---|---|---|---|---|---|
| North Unit | all | 100% | 0% | 119,521 | 1) Sorted for misc. "trace" species<br>2) Sorted for abalone spp., wavy top, Pismo clam |
| South Unit | 1, 2, 17, 18, 19a, 19b, 20 | 100% | 0% | 49,929 | 1) Sorted for misc. "trace" species<br>2) Sorted for abalone spp., wavy top, Pismo clam |
| North Column Sample | all | 100% | 100% | 17,632 | 1) Sorted for misc. "trace" species. |
| South Column Sample | all | 100% | 100% | 23,226 | 1) Sorted for misc. "trace" species. |

range, while wavy top has a distinctly southerly range, occurring from Point Conception to Isla Asunción, Baja California (Morris et al. 1980).

A closer look at the abalone, on which so much attention has been focused, reveals three interesting trends (Figure 3). First, black abalone is present throughout the assemblage, accounting for approximately 10% to 90% of all abalone per stratum by weight. Black abalone remains a significant contributor even in the levels with the most pink and red abalone, and in fact outweighs these species in a few strata. Second, red abalone is clearly a relatively minor constituent of the assemblage, appearing in only three of the North Unit strata. Even in these strata it never accounts for more than 4% of the total shell assemblage by weight. Third, pink abalone is present through most of the deposit, appearing in more strata (12) than red abalone (4). Pink abalone, which has a shell very similar to red abalone, has not been previously identified in the red abalone middens of the Northern Channel Islands. Pink abalone has a distinctly more southerly range than red abalone, appearing from Point Conception to Punta Abreojos, Baja California (Parker et al. 1992).

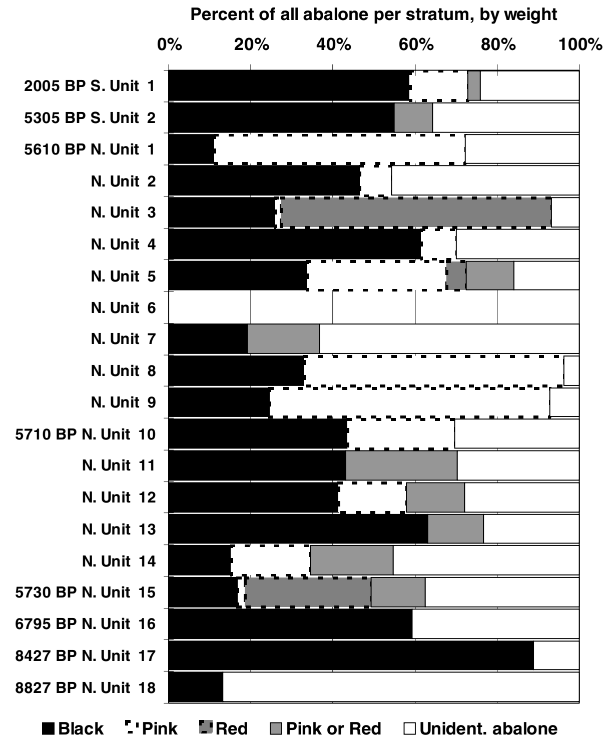


**Figure 3. Relative abundance of different abalone species at CA-SCRI-109. Species values were determined by weight, and are expressed as percentages of the total weight of abalone per stratum. Strata are chronologically ordered from youngest to oldest (top to bottom); dates represent calibrated shell dates.**

## DISCUSSION

Salls (1988, 1991, 1992) appears to have been correct in questioning the evidence for significant marine cooling during the Middle Holocene. The invertebrate assemblage from CA-SCRI-109 provides scant evidence of temperature change between the earliest occupation of the site and the present day. A comparison of the 63 invertebrate species at the site and those species found on the island by modern biological studies identifies only 11 species in all of the excavated materials which have not been collected on the island by biologists. Of these 11 species, 9 have widespread geographic distributions and are not useful in investigating temperature change. The remaining two species are both chitons: *Cryptochiton stelleri* (giant gumboot chiton) and *Mopalia lignosa* (lined chiton). Each of these species is represented in the deposit by only a single individual (MNI=1). Both of these species have cold-water affiliations: *M. lignosa* ranges from Alaska to Point Conception, California (Morris et al. 1980), and *C. stelleri* ranges from Alaska to the cold-water islands of San Miguel and San Nicolas (but see Salls [1988:54-55] regarding this species). Temporally, however, both of these cool-water specimens were found in South Unit Stratum 1 (2,005 BP), suggesting that if there was any cooling trend represented in the deposit, it occurred well after the Middle Holocene period associated with red abalone middens.

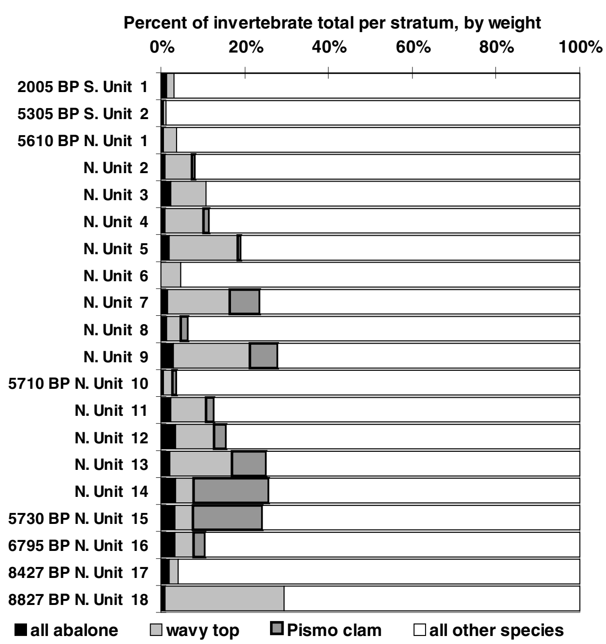


**Figure 2. Relative abundance of major invertebrate species at CA-SCRI-109. Species values were determined by weight, and are expressed as percentages of the total weight of shellfish per stratum. Strata are ordered chronologically from youngest to oldest (top to bottom); dates represent calibrated shell dates.**

A presence/absence chart of all of the temperature-sensitive species in the deposit yields similar results (Table 2). With the exception of the two extra-limital specimens discussed above, there are no clear patterns to suggest that Santa Cruz Island was significantly cooler or warmer during the 7,000-year span of site occupation than during the present day. The presence of significant amounts of wavy top and pink abalone throughout the deposit clearly indicates that marine temperatures during the Middle Holocene period of site occupation were not as cool as those suggested

**Table 2. Vertical distribution of temperature-sensitive species at CA-SCRI-109. "Northern" and "southern" designations follow Hewatt (1946) and Seapy and Littler (1980, 1993). Strata are chronologically ordered from youngest to oldest (top to bottom); dates represent calibrated shell dates.**

| | Southern Species | | | | | | | Northern Species | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Strata and dates** | *Lithopoma undosum (A. undosa)* | *Haliotis corrugata* | *Norrisia norrisi* | *Tegula aureotincta* | *Crepidula coei/norrisarium* | *Opalia funiculata* | *Stenoplax conspicua* | *Haliotis rufescens* | *Cryptochiton stelleri* | *Mopalia lignosa* | *Acmaea mitra* | *Ocenebra lurida* | *Tegula brunnea* |
| S. Unit Strat 1 2005 BP | X | X | | | | X | X | | X | X | | | |
| S. Unit Strat 2 5305 BP | X | | | | | | | | | | | | |
| N. Unit Strat 1 5610 BP | X | X | X | | | | | | | | | | |
| N. Unit Strat 2 | X | X | X | X | | | | | | | | X | |
| N. Unit Strat 3 | X | X | | | X | | | X | | | | | |
| N. Unit Strat 4 | X | X | X | | | | | | | | | | |
| N. Unit Strat 5 | X | X | X | | | | | X | | | | | |
| N. Unit Strat 6 | X | | | | | | | | | | | | |
| N. Unit Strat 7 | X | | | | X | | | | | | | | |
| N. Unit Strat 8 | X | X | X | X | X | | | | | | X | | |
| N. Unit Strat 9 | X | X | | | | | | | | | | | |
| N. Unit Strat 10 5710 BP | X | X | X | | | | | | | | | | X |
| N. Unit Strat 11 | X | | X | | | | | X | | | | | |
| N. Unit Strat 12 | X | X | X | | X | | | | | | | | |
| N. Unit Strat 13 | X | | X | | X | | | | | | | | |
| N. Unit Strat 14 | X | X | X | | | | | | | | | | |
| N. Unit Strat 15 5730 BP | X | X | X | | X | | | X | | | | | |
| N. Unit Strat 16 | X | | X | | | | | | | | | | |
| N. Unit Strat 17 8427 BP | X | | X | | | | | | | | | | |
| N. Unit Strat 18 8827 BP | X | | X | | | | | | | | | | |

by Glassow (1987, 1993a) and Glassow et al. (1994). Both of these species are presently limited to the warmer waters south of Point Conception, and could not have survived in the site vicinity if Middle Holocene water temperatures were as cool as the modern-day coastlines of Sonoma and Mendocino counties or Monterey Bay. The discrepancy between these results and Glassow et al.'s (1994) oxygen isotope analysis is puzzling, and suggests that further research is needed in this area.

It is possible to get a more precise idea of the marine temperature ranges represented by the deposit by comparing the abalone species in the CA-SCRI-109 deposits with the modern distribution of abalone species. Abalone are especially useful in this regard because they appear in significant quantities in most of the deposit, and because their modern distribution and abundance in the Channel Islands are well documented due to their history as a commercial fishery. A series of papers on abalone ecology has recently made this information available to broader audiences (Parker et al. 1992; Tegner et al. 1992; Haaker 1994). Comparison of past and present abalone distribution suggests that marine temperatures during periods of site occupation generally did not drop below those of modern day Santa Rosa Island or exceed those of modern-day Santa Barbara Island (Figure 4). Using modern eleven-year temperature averages generated for these islands (Engle 1994), this suggests winter temperatures generally between 13.5 and 14.5 °C and summer temperatures between 17.5 and 20 °C. The absence of green abalone in the CA-SCRI-109 deposits would seem to contradict this hypothetical temperature range (Figure 4), but this is probably a sampling problem resulting from ecological factors. In the northern portions of their range, green abalone have historically made up a very small portion of the commercial and recreational abalone catch (Haaker 1994). There are two reasons for this: 1) in that area their vertical range in the subtidal zone is relatively thin, and 2) they occupy the upper subtidal zone, preferring areas of high turbulence and strong surge which make collecting relatively dangerous (Ault 1985:16; Parker et al. 1992:389).

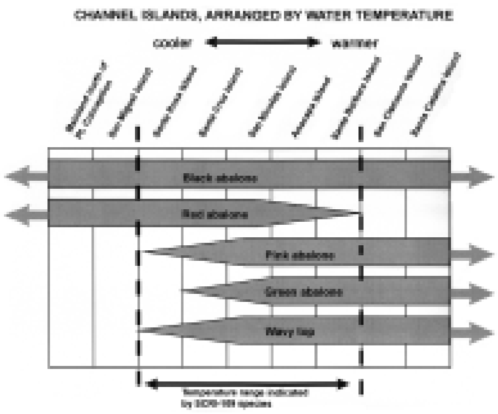


**Figure 4. Modern distribution of abalone in the Channel Islands and adjacent mainland. Wavy top is included here because of its prevalence in the CA-SCRI-109 deposits. Order of islands is after temperature data in Engle (1994). Sources for species distributions: Morris et al. (1980); Ault (1985); Parker et al. (1992); Tegner et al. (1992); Seapy and Littler (1993); Haaker (1994).**

This picture of relatively limited marine temperature change during the Middle Holocene contradicts the marine paleotemperature curve (Pisias 1978) on which earlier researchers have relied, but is in general agreement with a newer and higher-resolution curve recently constructed for the Santa Barbara region (Kennett and Kennett 1997). While the Pisias curve indicated Holocene temperature shifts as great as 11°C, the newer curve indicates maximum shifts of 6°C (Kennett 1998:124). This new evidence confirms the findings of faunal analysts, who had become increasingly puzzled over discrepancies between faunal assemblages and the temperature trends indicated by the Pisias curve (Walker and Snethkamp 1984:104; Glassow et al. 1988:73; Salls 1988, 1991, 1992; Raab et al. 1995).

Regarding the Middle Holocene, the new curve suggests that "Early and Middle Holocene conditions were relatively stable with inferred temperature variations from approximately 2 to 3°C" (Kennett 1998:124). The period represented by the Middle Holocene deposits at CA-SCRI-109 (approximately 5,000 to 7,000 BP) appears to have been average in terms of temperature and stability, with marine temperatures generally falling within a small range close to the 12,000-year trendline temperature.

It is unclear at this point how representative CA-SCRI-109 is of red abalone middens in general. Besides the unusual size and thickness of the deposit, the site also appears to be unique in the relatively high percentage of wavy top it contains (M. Glassow, pers. comm. 1998). This may be a result of sampling problems or of a local habitat which offered exceptionally ideal conditions for this species. It is important to note in this regard that the site's location on the southern side of Santa Cruz Island exposes the site to slightly warmer waters than most of the other red abalone middens documented so far in the Northern Channel Islands. Most of these deposits have been recorded on the cooler western end of Santa Cruz Island and on the cool-water islands of San Miguel and Santa Rosa.

The lack of evidence for significant climatic change prompts a re-examination of possible cultural reasons for the disappearance of the red abalone middens. Although a thorough treatment of this subject is beyond the scope of this paper (for good discussions see Salls 1991, 1992; Glassow 1993a; Glassow et al. 1994), two hypotheses are presented below with discussions of the implications of each and suggestions regarding future research.

The overexploitation hypothesis introduced by Glassow (1987) and subsequently advocated by Salls (1988, 1991, 1992) is certainly the most obvious cultural explanation for the absence of these sites after approximately 4,500 BP. Implicitly basing his arguments on optimal foraging theory (Jochim 1983; Bettinger 1991), and more specifically the diet breadth model, Salls (1991:73) interpreted the changes in species in the Eel Point sequence as a result of the site occupants "consuming these resources beyond the carrying capacity of the habitat…resulting in decreasing species size and abundance as well as the utilization of less desirable species." Salls noted that the large pink and green abalone present in the Early Holocene deposits at Eel Point became smaller through time, and were abruptly replaced by black abalone in deposits dated at 3,500 to 3,400 BP (it is unclear whether Salls documented or quantified these changes in shell size, however). As previously discussed, this scenario is similar in broad outline to the pattern observed by Glassow in the Northern Channel Islands.

The implications of this hypothesis are important; if it is correct it implies that the period around approximately 4,500 BP was a time of significant population growth on the islands. At present the nature of Middle Holocene demography in the region is difficult to address with the existing archaeological data. In the Santa Barbara area, the end of the Middle Holocene (5,000 to 3,500 BP) witnessed important technological changes such as the advent of the mortar and pestle and an increase in the use of projectile points, but it is unclear whether these changes were accompanied by significant population growth (Erlandson 1997; Glassow 1997). On the Northern Channel Islands, the Middle Holocene is generally seen as a period of significant population growth relative to the Early Holocene (Kennett 1998), but both Glassow and Kennett have interpreted the red abalone middens as short-term encampments used by relatively small groups of mobile foragers. Glassow (1997:84) actually notes indications of a population decrease in the Northern Channel Islands from approximately 4,000 to 3,600 BP. The temporal sequence from CA-SCRI-109, for example, suggests a period of site abandonment during this time (see Glassow, this volume). In the Southern Channel Islands, Raab (1997) acknowledges middle Holocene populations larger than those of the Early Holocene, but failed to see evidence of the resource stress which characterizes later periods.

Testing the overexploitation hypothesis will require more detailed studies of the nature, magnitude, and timing of the changes in these shellfish assemblages (for excellent examples, see Raab [1992]; Douros [1993]). When exactly did the red abalone middens disappear? Did they disappear gradually or across all of the Northern Channel Islands in a very short period of time? Did abalone become smaller through time, or did they suddenly disappear from the deposits altogether? Did smaller species gradually join the abalone, or did they suddenly replace them? In the case of overharvesting, we should see a decrease in abalone shell size and a gradual shift to smaller species in later deposits (Yesner 1984:121). The absence of these two signs of decreasing foraging efficiency may indicate other causes besides overexploitation for the observed changes in shellfish harvesting. Studies of this type would seem to be most fruitful in investigating the most recent red abalone middens, i.e., those which immediately precede the apparent disappearance of this site type at approximately 4,500 BP.

An alternate explanation offered here is that the changes in shellfish exploitation after 4,500 BP reflected a general abandonment of subtidal diving as part of broader changes in subsistence strategies, rather than as a response to the depletion of specific resources. This line of thought leads to larger questions well beyond the scope of this paper. One explanation is that the abandonment of subtidal diving after 4,500 BP signals the arrival of a different ethnic group without a diving focus. At present, such a hypothetical migration is only weakly supported by our limited knowledge of Middle Holocene faunal and technological assemblages. The seemingly gradual change in bead and ornament types during this period suggests that if such a migration did occur, it was from a nearby group which shared a similar coastal focus and a similar material culture (see Glassow 1997 for a good review of this topic).

Another explanation for the abandonment of subtidal diving is that shellfish diving was gradually replaced with other subsistence pursuits, most likely fishing. This hypothetical shift is most easily envisioned in a social and/or economic framework. While shellfish collecting has generally been portrayed as a demographically-inclusive activity in archaeological literature (Waselkov 1987; Jones 1991; McGuire and Hildebrandt 1994), subtidal abalone diving is a strenuous and dangerous activity (Hong and Rahn 1967; Plath and Hill 1987) more akin to hunting than collecting. It is likely that only some members of red abalone midden populations pursued subtidal species, probably while range-limited members (i.e., children and the elderly) collected the more accessible intertidal species which also make up a significant part of these Middle Holocene deposits. Whatever the cause, a shift towards fishing (another strenuous and relatively dangerous activity) would have the effect of occupying the strongest members of the group, i.e., those individuals capable of subtidal diving. Meanwhile, range-limited members of the group would still be left available to collect the more accessible intertidal species which completely dominate later shellfish assemblages.

Unfortunately, information regarding changes in Middle Holocene fishing in the region is limited at the present time. Although the available evidence suggests that changes in fishing technology and a general increase in fishing took place during this period, the timing and magnitude of these changes only loosely fit the hypothetical scenario described above. At Eel Point, "substantial quantities of fish do not appear in the assemblage until after about 5,000 RYBP [radiocarbon years before present]; indeed, fishing shows no clear tendency toward intensification until after 3,320 RYBP with the appearance of shell fishhooks " (Raab 1997:27). Salls (1991:73) also saw evidence of an increase in the use of watercraft in the Eel Point deposits dating to approximately 3,500 RYBP and later. In the Northern Channel Islands, Glassow (1993b) saw a dramatic increase in fishing in the Middle Period components he has analyzed from Santa Cruz Island, but all of these post-date 2,600 RYBP. On the Santa Barbara mainland, there appears to be a general trend towards an increasing use of fish and sea mammals during the Middle Holocene, but a lack of faunal data makes this increase, if it did occur, difficult to quantify (Erlandson 1997:108; Glassow 1997:88). Interestingly, Erlandson (1997:107) notes the appearance of notched cobbles resembling net weights in a Santa Barbara mainland deposit dated between 5,800 and 3,500 RYBP, approximately 1,000 years earlier than previous dates for these artifacts. The notched stones are associated with a fish assemblage thought to represent the use of beach seines.

Another problem with this hypothesis is that it posits the abandonment of large abalone as a result of economic decisions based on difficulties associated with diving. As Glassow (1993a:571-573) pointed out, red abalone is present sporadically in the intertidal zone of the Northern Channel Islands today, making it difficult to discern from the archaeological record between subtidal and intertidal collecting, even in the absence of climate change. While it is clear that the large abalone species (and wavy top) found at CA-SCRI-109 occur in greatest abundance at subtidal depths of three meters and more (Cox 1962; Ault 1985; Myers 1986; Parker et al. 1992; Tegner et al. 1992), biological studies in the Northern Channel Islands have encountered limited numbers of these species within the lower intertidal zone (Hewatt 1946; Seapy and Littler 1993). It is conceivable then that the red abalone middens represent occasional harvesting of a small standing crop of abalone appearing at the upper edge of their vertical range. This relatively small percentage of the total abalone population could have been collected intertidally, or by shallow water shore-picking as described historically by Eyles (1991:34). If this was in fact how the abalone were harvested, it is difficult to explain their sudden disappearance from the middens in any terms except overexploitation.

Elucidation of the question of diving versus intertidal collecting may require more extensive studies of human skeletal remains of Channel Islands populations. A condition known as auditory exostoses, a bony inner-ear growth resulting from prolonged cold-water exposure, has been identified in some prehistoric Channel Islands populations (see Glassow 1993a:573). Unfortunately, the existing data on the occurrence of this condition within Islands populations are limited, contradictory, and need to be more closely tied to specific temporal periods.

In summary, it seems likely that the disappearance of the red abalone middens was a result of cultural rather than environmental factors. The precise causes, mechanisms, and timing of these changes remain unknown, however. The most obvious explanation for the observed changes in shellfish harvesting is overexploitation, but at present there is little direct evidence to support this idea. Other possible cultural explanations include ethnic migration or a general abandonment of shellfish diving as part of larger subsistence changes. The predominantly subtidal ranges of the large abalone species (and wavy top) appearing in the red abalone middens suggest that they were procured through diving, although intertidal collecting and shallow water shore-picking cannot be ruled out at present. Future studies of these sites need to focus on changes in invertebrate species and shell sizes, without losing sight of the "big-picture" clues which may be present in technological assemblages and other faunal assemblages.

**ACKNOWLEDGMENTS**

First, I am most grateful to Michael Glassow for involving me in this project and for the remarkable level of intellectual support which he has provided. I am also grateful to lab directors Peter Paige, Steven Galbraith, and Brixen Reich, as well as the UCSB lab technicians who processed many of my samples. Paul Scott and Henry Chaney of the Santa Barbara Museum of Natural History generously lent their expertise in identifying some of the more difficult specimens. Conversations with Jack Engle, Doug Kennett, and Henry Chaney have similarly enlightened this paper. I must also thank Colin Hermans of the Biology Department at Sonoma State University, who skillfully deepened my understanding and interest in intertidal ecology. Finally, I thank Michael Glassow, Cassandra Hensher, and two anonymous reviewers for comments which have considerably improved this manuscript.

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