Late Holocene Sea Temperatures along the Central California Coast

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Mussel shells from central California coastal archaeological sites record changes in sea surface temperatures in the past 2000 years. Water temperatures, inferred from oxygen isotopes in the shells, were about 1°C cooler than present and stable between 2000 and 700 yr ago. Between about 700 and 500 yr ago, seasonal variation was greater than present, with extremes above and below historic levels. Water temperatures were 2–3°C cooler than today 500–300 yr ago. The interval of variable sea temperatures 700–500 yr ago partially coincided with an interval of drought throughout central California. A coincident disruption in human settlement along the coast suggests movements of people related to declining water sources. Quantities of fish bone in central coast middens dating to this same period are high relative to other periods, and the remains of northern anchovies, a species sensitive to changing oceanographic conditions, are also abundant. The continued use of local fisheries suggests that changes in settlement and diet were influenced more by drought than by a decrease in marine productivity, as fish provided a staple during an interval of low terrestrial productivity. © 1999 University of Washington.

Key Words: California coast; sea temperatures; drought; El Niño; oxygen isotopes; prehistory; fish.

INTRODUCTION

The late Holocene is increasingly recognized as a time of change in prehistoric North America. In central and southern California there is strong evidence for technological replacements, settlement shifts, changes in diet, altered exchange practices, and increases in interpersonal violence, particularly between ca. A.D. 1000 and 1400 (Arnold, 1992a, 1992b; Colten, 1993, 1995; Jones, 1995; Jones and Waugh, 1995; Kennett, 1998; Raab and Larson, 1997; Walker *et al.,* 1989). During this same time interval, broad-scale population shifts and increased interpersonal violence are evident in the American Southwest (Douglas, 1929; Fritts *et al.,* 1965; Haas and

Creamer, 1992; Larson *et al.,* 1996), and the apparent synchrony and suddenness of change across such a wide area has led to growing suspicion that climatic variability may have been at least a partial cause underlying many of the cultural transitions (Arnold, 1992a, 1992b; Colten, 1993, 1995; Jones *et al.,* 1999; Raab and Larson, 1997; Larson *et al.,* 1996). The interval of greatest cultural change corresponds with the Medieval Warm Period (Lamb, 1982) or Climatic Anomaly (Stine, 1994), a time of unusually warm, dry climate between ca. A.D. 800 and 1400, and some archaeologists have suggested that human populations in California were heavily impacted by drought-related declines in available food and water (Jones *et al.,* in press; Raab and Larson, 1997). Others have argued that warm seas off the coast of southern California (Pisias, 1978; Arnold and Tissott, 1993) reflected an extended El Niño-like decline in marine productivity (Arnold 1992a, 1992b, p. 132; Arnold and Tissott, 1993; Colten, 1993, 1995, p. 116) that, in combination with drought, impacted prehistoric human societies.

A major disruption in settlement occurred along the central California coast (Fig. 1) during the later part of the Medieval Warm Period. Most sites occupied prior to ca. A.D. 1200–1400 show signs of abandonment, while others were settled only after this interval (Fig. 2). This interruption, synchronous with changes in other regions, particularly the southern California coast, may reflect broad-scale environmental change, but paleoenvironmental variability coeval with this disruption is only partially documented. Graumlich (1993) and Stine (1994), working with tree ring and lake-level data, respectively, reported evidence of several major droughts during the Medieval Warm Period in the interior ranges of central California, with the most prolonged drought dating ca. A.D. 1200–1350. Preliminary studies of paleomarine conditions off the coast of southern California produced modest evidence for warm seas during the Medieval Warm Period (Arnold and Tissott, 1993; Pisias, 1978), but more recent and refined isotopic analyses suggest that cold seas were prevalent in the Santa Barbara Channel during this interval (Kennett 1998, p. 123).
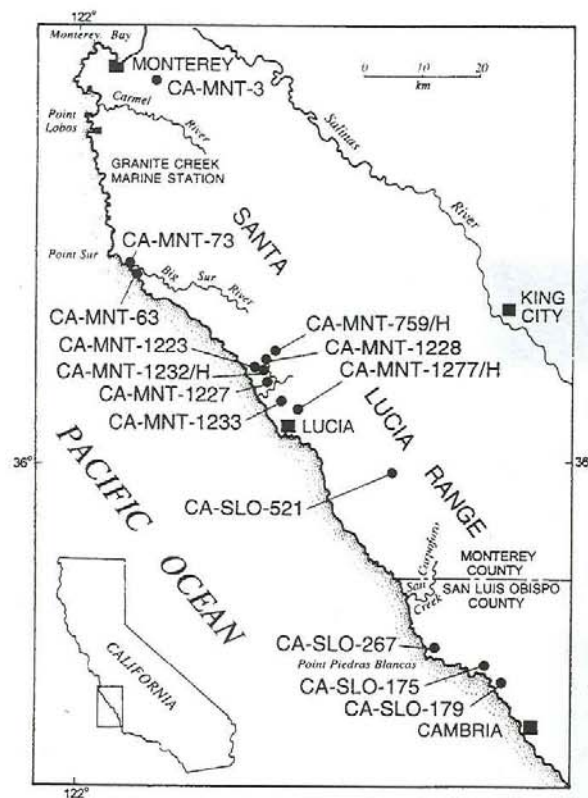
FIG. 1. Map of Central California Coast showing location of archaeological sites and study area.

In the current study, two sets of data from central California archaeological sites are examined: a paleo-sea-temperature sequence based on oxygen isotope measurements of mussel shells, and a suite of ichthyofaunal remains (particularly those from northern anchovies, *Engraulis mordax*). These data were used to assess the relative productivity of nearshore marine environments during the late Holocene and to evaluate the possibility that fluctuations in the availability of marine foods contributed to changes in human settlement and subsistence.

Oxygen isotopic analyses of archaeological mussel shells dating between ca. A.D. 1 and 1700, from the central California coast, show that sea temperatures were modestly cooler (1°C) than present ca. A.D. 1–1300; between A.D. 1300 and 1500, they were highly variable, reaching seasonal highs and lows of a greater amplitude than today, and between ca. A.D. 1500 and 1700 they were significantly cooler (2–3°C) than present. Quantities of fish bone in middens dating to the period of variable sea temperatures showed no decrease from earlier periods, however, and remains of northern anchovies also remained relatively stable. Northern anchovy populations off California are dependent upon seasonal upwelling (Baxter, 1967), and declines in their population have been linked with

El Niño events (Fiedler, 1984). The continued presence of the species suggests that local fisheries remained relatively productive, and that changes in settlement and diet were influenced more by droughts during the Medieval Warm Period than by decreases in marine productivity, with fish providing a dietary staple.

STUDY AREA

Archaeological data were obtained from 14 shell middens on the coast of Monterey and northern San Luis Obispo countries in central California (Fig. 1, Table S1[1]). Thirteen sites lay on the exposed, outer coast, and one (CA-MNT-3) was located within Monterey Bay. All but one (CA-MNT-521) were situated within a day's walk of the shoreline. Mussel shells were obtained from six late Holocene archaeological sites: CA-MNT-3, -1223, -1227, -1233, and CA-SLO-179 and -267. Samples of fish bone were recovered from these six sites and eight additional sites, CA-MNT-63, -73, -521, -759/H, -1228, -1232/H, -1277/H, and CA-SLO-175. Two or more radiocarbon dates were obtained from each deposit (Table S2). All shells discussed in this paper were directly dated. Nine sites have discrete occupational components dating between 600 B.C. and A.D. 1830; data from three other deposits dating 4400–1700 B.C. provide comparison with the late Holocene findings (Fig. 2).

The study area, encompassing the Monterey Peninsula and Big Sur coast, is one of the most rugged and diverse stretches of shoreline in California. Peaks >1500 m are present within 5 km of the shoreline, creating one of the steepest coastal gradients in the continental United States (Henson and Usner, 1993, p. 12). This coast has a mild Mediterranean climate with an average annual temperature of 12.8°C. Winters are cool and wet, and summers are warm, with frequent fog. Inland areas above 610 m have a more extreme temperature range owing to the absence of coastal fog. Higher elevations regularly receive snow in the winter and reach temperatures above 32°C in summer (Engles, 1984).

The shoreline, marked by steep cliffs and narrow isolated beaches, offered many littoral and offshore resources for prehistoric hunter-gatherers. These included shellfish, fish, sea mammals, and marine algae (kelp). The California mussel (*Mytilus californianus*), common in the mid to high littoral zone, is well represented in local midden sites, including those investigated. The most prolific fish habitats are rocky shelves and reefs associated with large, dense kelp beds. A variety of small- to medium-sized fish frequent the kelp beds all year. They include rockfish (*Sebastes* spp). lingcod (*Ophiodon elongatus*), cabezon (*Scorpaenichthys marmoratus*), and sardine and herring (Clupeidae). Northern anchovies (*E. mordax*) are most abundant in nearshore waters in the spring during sea-

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[1] Tables with the S prefix are available as supplementary data on the journal home page.
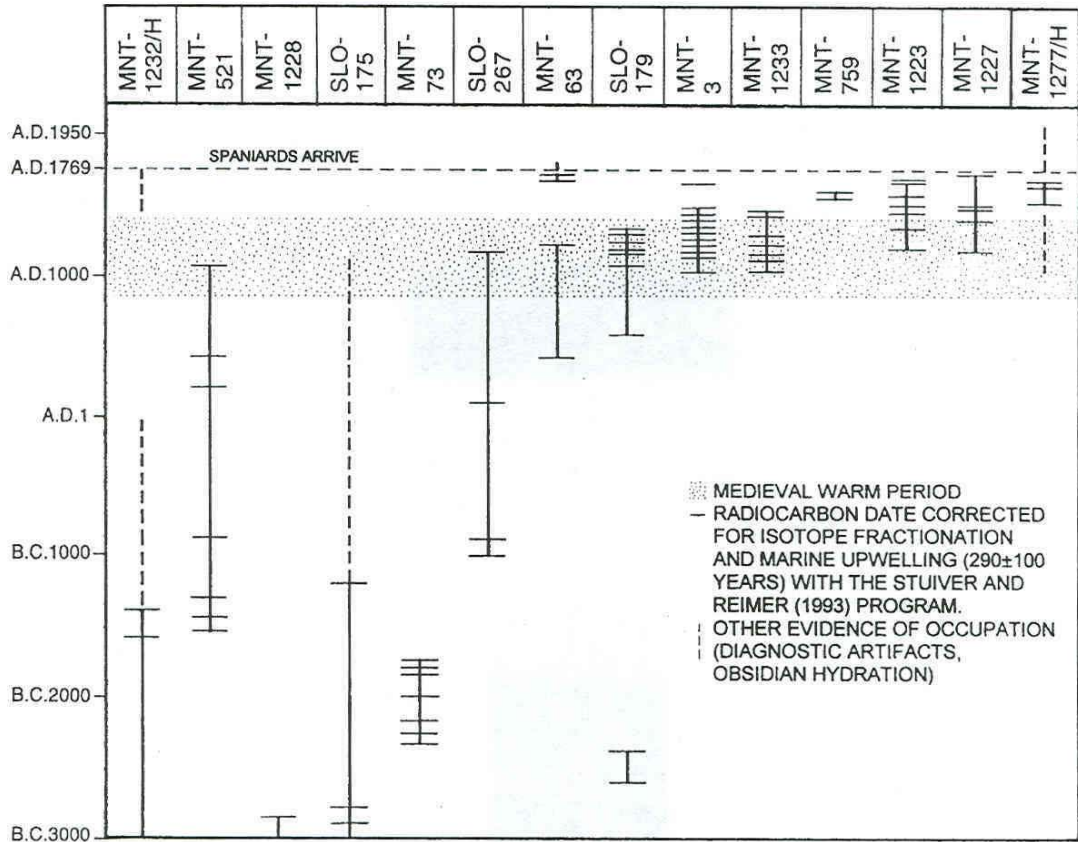
FIG. 2.   Occupational sequence for the central California coast showing the Medieval Warm Period and settlement disruption ca. A.D. 1200–1400.

sonal upwelling. During periods of warmer-than-average water temperatures, adult anchovies become less available (Baxter, 1967, p. 110). Recovery of shell fishhooks and stone net weights from the coastal middens indicates that fish were taken by hook and line and by nets.

CLIMATIC VARIABILITY ON THE CENTRAL CALIFORNIA COAST

Both long-term and short-term climate variability would have influenced prehistoric hunter-gatherers along the central California coast. Interannual variability in marine and terrestrial climate is often related to El Niño and the El Niño Southern Oscillation (ENSO), although the effect of El Niño on marine and terrestrial biomes is very different. Elevated sea-surface temperatures associated with the El Niño of 1982–1983 had widespread effects on the California coastal environment, including reduced upwelling, physical disturbances to kelp beds (Dayton and Tegner, 1990, p. 433; Tegner and Dayton, 1987, 1991), and reduction in northern anchovy populations due to reproductive failures (Fiedler, 1984). Many studies of California precipitation patterns based on historic records show correlations between ENSO events and rainfall

peaks (Michaelsen and Daily, 1983); Yarnal and Diaz, 1986). One study by Schonher and Nicholson (1989)) found the relationship to be regionally specific. Redmond and Koch (1991)) reported a meaningful correlation between ENSO events and rainfall on the southern coast and interior deserts. Hughes and Diaz (1994)), found that the ENSO cycle has been operative in the northern Pacific for at least the last millennium. In a study based on a 600-yr tree ring record, Haston and Michaelsen (1994)) concluded that the ENSO/rainfall relationship may be more equivocal than reflected historically, but that wet years associated with ENSO events tend to be exceptionally wet.

Historic records of rainfall and sea temperatures from Monterey Bay since 1919 generally show a positive correlation between precipitation and sea temperature (Fig. 3), and a stronger relationship is evident between ENSO events and rainfall. Between 1927 and 1987, there were 13 ENSO events with intensities varying between moderate ($N = 8$), strong ($N = 2$), and very strong ($N = 3$) (Quinn et al., 1987). Historic rainfall and sea temperature data show an unquestionable correlation between very strong ENSO events (1941, 1958, and 1982/83) and high rainfall. Of nine years associated with
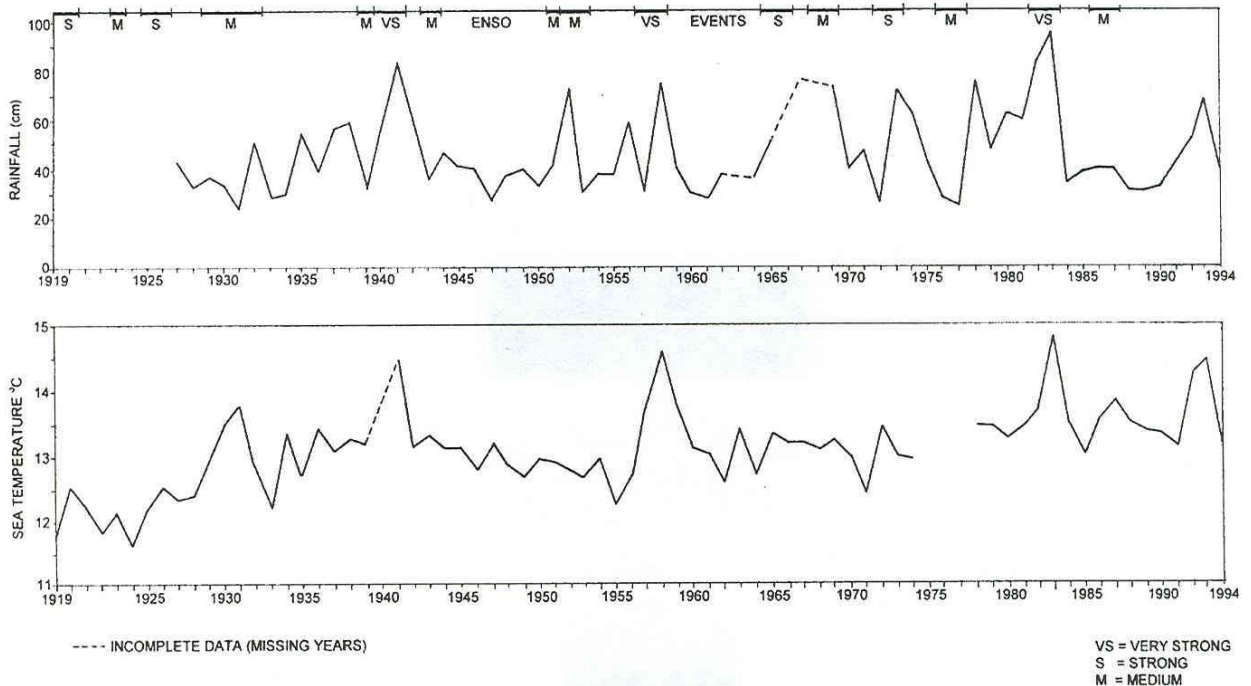
FIG. 3. ENSO events (from Quinn *et al.,* 1987) and mean monthly sea temperatures (°C) and rainfall (cm) for the Monterey Peninsula, Monterey County, 1927–1992.

strong or very strong events, seven show inordinately high precipitation. Intervals of non-El Niño conditions (e.g., 1932–1938, 1945–1950, 1960–1964) show moderate sea temperatures, and of 34 years during which there was no ENSO event, 22 (64.7%) show rainfall below the yearly mean. The overall pattern is consistent with ENSO events in Peru, where El Niño was originally linked with "years of abundance" and with heavy rainfall on the coastal deserts (Philander, 1990), p. 1).

Moderate ENSO events show marked variability in rainfall and sea temperatures, and some tendency toward an association with below-average rainfall. Of the 15 years with moderate ENSO events, 10 were associated with lower-than-average rainfall. The two lowest rainfall years of the century on the Monterey coast (1931 and 1977) occurred during moderate ENSO events. Rainfall records from the southern Sierra Nevada, at the same latitude as the Monterey coast and where Graumlich (1993)) detected Medieval-age droughts, show the same relationship between ENSO events and precipitation. Very strong ENSO events are marked by high rainfall, while non-ENSO years are drier. In general, at this latitude, the positive relationship between ENSO events and rainfall is felt at least as far inland as the interior ranges.

On an interannual scale, the relationship between rainfall, sea-surface temperatures, and upwelling intensity had important implications for coastal hunting and gathering groups who lived on the central California coast and subsisted on a mix of terrestrial and marine foods. Although El Niño events lower marine productivity, terrestrial productivity commonly increases during very strong El Niño years as a result of high rainfall. Very strong El Niño events would lower marine resource potential for hunter-gatherers, but the impact of these events would commonly be offset by enhanced terrestrial productivity. There would be no simultaneous deterioration of both marine and terrestrial resource bases.

El Niño events are brief phenomena, during which high sea temperatures persist for no more than 2 or 3 years. This time scale is essentially invisible in the archaeological record of mainland California, where midden deposits generally reflect occupation over several centuries, if not millennia, and where bioturbation disturbs vertical stratigraphy. Lack of precision in marine-shell-derived radiocarbon dates, based on varied corrections for upwelling (Ingram and Southon, 1996), further lessens time resolution, so that individual El Niño events cannot be identified. Nevertheless, relationship exists between ENSO events and climatic variability. One study (Anderson, 1994) suggests that warmer, drier conditions of the Medieval Period may be the result of the low-frequency and low-intensity of El Niño events.

Paleo-sea-temperature studies also indicate longer-duration patterns in sea temperature variability off the California coast during the Holocene. Kennett (1998, p. 123) reported evidence of cool, productive seas between A.D. 450 and 1150 off the southern California coast, and Koerper *et al.* (1985) reported isotopic support for sea temperatures 2–3°C below present

during the Little Ice Age (ca. A.D. 1400–1850). These long-term trends are different from the variability associated with the ENSO cycle, in that natural systems would have had time to respond gradually. A millennium of slightly warmer seas would not be synonymous with low marine productivity, but rather with a gradual latitudinal shift of habitats that would allow species to expand and/or contract their territories, altering the mix available to hunter-gatherers (Barry et al., 1995; Davenport et al., 1993), but not necessarily causing major problems in the overall availability of marine foods.

LATE HOLOCENE SEA TEMPERATURES INFERRED FROM OXYGEN ISOTOPE ANALYSIS

Studies of modern marine mollusks from known environments indicate that oxygen isotopic analysis is an effective method for reconstructing sea-surface temperature (e.g., Epstein et al., 1953; Killingley and Berger, 1979). The $^{18}O/^{16}O$ ratio of mollusk shells is sensitive to changes in water temperature (Epstein et al., 1953; Wefer and Berger, 1991). Incremental samples taken along a shell's growth axis permits measurement of oxygen isotopic ratios and, hence, of seasonal temperature change through the life of a mollusk.

Methods

A total of 196 oxygen isotopic measurements was obtained from 14 archaeological M. californianus shells (Table S3). All shells were cleaned and rinsed with deionized water to remove adhering midden soil and visible organic material. The outer surfaces of the shells were etched using a dilute solution of HCL (0.5 M) to remove any diagenetically altered carbonate. Calcite samples were extracted from the exterior prismatic layer of the shell in 2 mm increments along the shell's growth axis (0.5 mm drill). Powdered calcite samples (~0.3 mg) were heated at 400°C under vacuum for 1 h to remove organic compounds. After cooling to room temperature, samples were reacted with orthophosphoric acid at 90°C (Fairbanks auto-sample device). The oxygen isotopic ratio of the evolved CO_2 was measured using mass spectrometry (Finnegan/MAT251-Mass Spectrometer) at the Department of Geology, University of California, Santa Barbara. Water temperatures were calculated using the paleotemperature equation developed by Horibe and Aba (1972) for calcite, based on controlled experiments with Patinopecten yessoenis from Mutsu Bay, Japan:

$$T = 17.04 - 4.34(\delta c - \delta w) + 0.16(\delta c - \delta w)^2.$$

In this equation T represents temperature (°C). δc represents the $^{18}O/^{16}O$ of the carbonate, expressed as a deviation in parts per thousand from a standard carbonate, and δw represents the oxygen isotopic composition of the water expressed as deviation from standard mean ocean water (smow). We used a δw

value of −0.3, based on a water sample from the Monterey Peninsula.

When δw is constant, the $^{18}O/^{16}O$ ratio decreases by ~0.2‰ for every 1°C increase in water temperature. All measurements are expressed in δ (delta) notation, as a deviation from an internationally accepted standard (PeeDee Belemnite, a carbonate fossil from South Carolina). More-negative δ values indicate higher proportions of the lighter ^{16}O isotope compared with the heavier ^{18}O isotope, and vice versa. The precision of the oxygen isotopic ratios is +/−0.1.

After carbonate samples were extracted for oxygen isotope analyses, all shells were radiocarbon-dated by Beta Analytic, Miami, Florida, using standard radiometric techniques. Dates were corrected on a sample-specific basis for isotope fractionation, and the resulting ages were converted into calendric dates using the Stuiver and Reimer (1993)) CALIB program with a reservoir value (δR) of 290 ± 35 yr, developed by Ingram and Southon (1996) for northern California. Despite these procedures, there remains a degree of imprecision inherent in dates obtained from marine shells due to temporal and spatial variation in upwelling. As the effects of varied upwelling intensity cannot be controlled using available radiometric methods, it is important to recognize the 1-sigma probabilities associated with dates, although recent studies show evidence for occasional variation in δR greater than that encompassed by 1-sigma probabilities (Ingram and Southon, 1996).

Results

The number of incremental oxygen isotopic measurements for each shell ranged from 6 to 31 depending upon the length of each specimen. Midpoint, maximum, and minimum oxygen isotopic values from each shell profile are shown in Table 1 along with temperature calibrations based on Horibe and Oba (1972). During the period A.D. 1–1300 (180 B.C.–A.D. 1400, 1-sigma), represented by seven shells and 76 readings, oxygen isotopic values ranged from a minimum of 0.423 (13.99°C) to a maximum of 1.752 (8.81°C), with a midpoint of 11.40°C (Table 1). Midpoint values for all seven shells from this period are less than 12°C. The period from A.D. 1300–1500 (A.D. 1270–1520, 1-sigma), represented by three shells and 64 readings, shows a range between −0.716 (18.87°C) and 1.713 (8.95°C). All three shells have midpoints greater than 12°C. The period A.D. 1500–1700 (A.D. 1460–1860, 1 sigma), represented by four shells and 56 readings, shows a range from 0.490 (13.71°C) to 2.165 (7.31°C).

Twelve shells and 169 readings from the outer coast show variation with historic sea temperatures recorded at Granite Creek Marine Station in the Big Sur region (Fig. 4). The period A.D. 1–1300 shows maximum temperatures below those recorded historically, but lows are similar to those of the present. The midpoint of 11.40°C is lower than the historic midpoint of 12.38°C. Consistency in the midpoints and ranges from the

TABLE 1

Midpoint, Maximum, and Minimum Oxygen Isotopic Values of *M. californianus* Shells from Study Sites

Sample No.	Location	Unit/level (cm)	Calibrated ¹⁴C range[a]	Midpoint		Maximum		Minimum		N
				$\delta^{18}O$	°C	$\delta^{18}O$	°C	$\delta^{18}O$	°C	
A5	CA-MNT-1223	5/20–30	AD 1630 (1690) 1860	1.278	10.61	0.887	12.11	1.669	9.11	12
11	CA-MNT-3[b]	7/60–70	AD 1470 (1630) 1720	1.003	11.70	0.490	13.71	1.516	9.69	14
2	CA-MNT-1223	11/40–50	AD 1460 (1600) 1700	1.546	9.62	0.990	11.71	2.101	7.54	15
1	CA-MNT-1227	6/20–30	AD 1460 (1550) 1680	1.640	9.27	1.115	11.22	2.165	7.31	15
6	CA-MNT-1233	3/40–50	AD 1310 (1430) 1520	0.779	14.11	−0.716	18.87	1.607	9.35	20
3	CA-MNT-1233	2/70–80	AD 1300 (1400) 1470	0.877	12.27	0.040	15.58	1.713	8.95	31
12	CA-MNT-3[b]	7/50–60	AD 1270 (1360) 1460	0.433	13.98	−0.037	15.91	0.902	12.05	13
A3	CA-SLO-179	13/50–60	AD 1210 (1300) 1400	1.217	10.85	0.851	12.26	1.583	9.44	10
A8	CA-SLO-267	8/10–20	AD 1060 (1200) 1290	0.964	11.82	0.716	12.80	1.212	10.84	5
A2	CA-SLO-179	14/30–40	AD 1000 (1070) 1220	1.102	11.31	0.629	13.15	1.575	9.47	10
7	CA-MNT-1233	3/50–60	AD 980 (1060) 1220	0.963	11.86	0.423	13.99	1.503	9.74	12
A7	CA-SLO-179	9/60–70	AD 930 (1030) 1160	0.943	11.93	0.475	13.77	1.410	10.09	6
A6	CA-SLO-179	13/100–110	AD 390 (500) 630	0.975	11.80	0.530	13.55	1.420	10.05	13
A1	CA-SLO-267	12/30–40	180 BC (30 BC) AD 90	1.356	10.32	0.959	11.83	1.752	8.81	20
Total										196

Note. All oxygen isotopic values are expressed in delta (δ) notation, as a deviation from PDB. Oxygen isotopic values were calibrated using the Horibe and Oba (1972) equation for calcite. Maximum isotope values correspond with minimum water temperature values, and vice versa.

[a] Radiocarbon dates calibrated using Stuiver and Reimer (1993). One sigma range shown here.

[b] Samples are from Monterey Bay; all other specimens are from the open coast.

seven shells representing this period suggests that conditions were relatively stable and slightly cooler than present. The period A.D. 1300–1500 shows a range in temperatures greater than those in the other late Holocene intervals and in historic records, with peak sea temperatures greater than those today and seasonal lows lower than the present ones. The ranges in individual specimens and the combined sample marking this period also differ from those of a very strong El Niño event (represented by temperatures from 1983) in that both extreme highs and extreme lows are represented, whereas during El Niño events temperatures below 11°C do not occur (Fig. 3). The range (7.31–12.11°C) and midpoint (9.71°C) marking the period A.D. 1500–1700 are both decidedly lower than the present.

Two shells and 27 readings from Monterey Bay were treated separately because water temperatures within the bay are warmer than those along the open coast. Twenty-seven readings from two shells generally show similar directional trends relative to the historic record, but the limited sample does not exhibit the same extremes in range (Fig. 4).

THE ICHTHYOFAUNAL RECORD

Fish remains from the same coastal archaeological sites were evaluated under the premise that changes in the abundance of fish bones or in taxonomic representation might reflect changes in marine productivity related to variation in sea temperatures.

Methods

Fish remains were recovered from study sites by two methods. Samples were obtained with 3-mm (1/8 inch) mesh during standard excavation of 1 × 2 m units, and finer-mesh (1.5 mm (1/16 inch)) samples were also recovered from bulk soil columns processed in the laboratory. The larger-mesh samples (3 mm) were recovered from soil processed in the field through shaker screens, with fish bones being extracted along with artifacts and other faunal remains. Column samples were needed to recover anchovy and other small fish bones not retained in 3-mm mesh. They were collected as bulk samples from the field and were processed in the laboratory with soils washed through nested 6-mm, 3-mm, and 1.5-mm mesh. All fish bones from both types of samples were washed and segregated from other faunal materials. Elements were then identified to species using a reference collection at California State University, Bakersfield. Results were first tabulated by number of identified specimens (NISP), which were converted to NISP/m³ to account for site-to-site variation in the volume of deposit processed.

Results

A total of 4657 fish elements was recovered from 68.5 m³ of deposit processed with 3-mm mesh (Table S4). Taxonomic identification included 24 species, 4 sets of remains that could only be identified to the genus level and 10 representing the
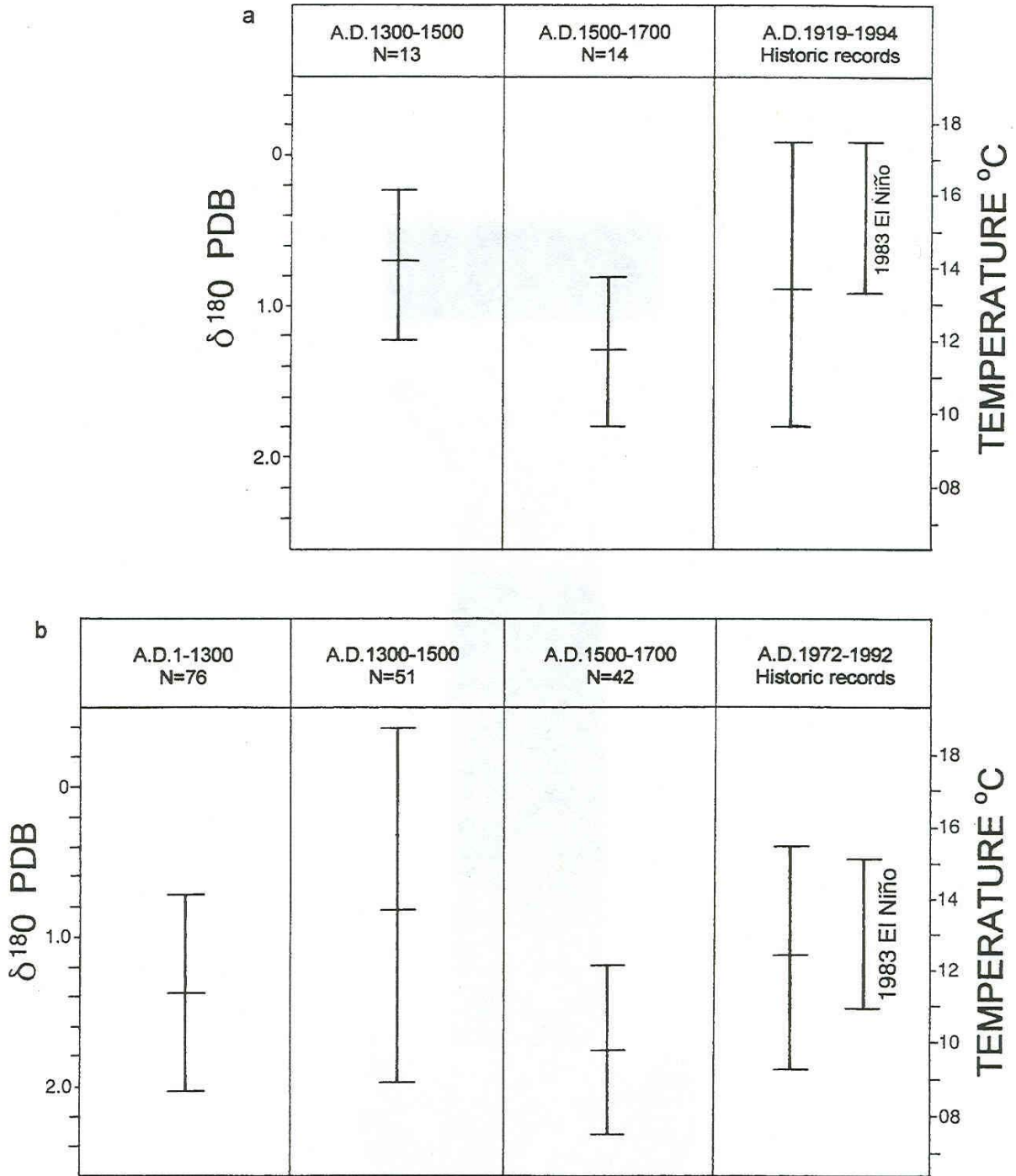
FIG. 4.   Range and midpoint of ¹⁸O values and inferred temperatures for 14 archaeological specimens of *Mytilus californianus,* compared with historic ranges and midpoints: (a)Monterey Bay; (b) outer coast of Big Sur and northern San Luis Obispo County. N is the number of individual isotopic readings.

family/order level. Thirty taxa are represented, with most assemblages dominated by rockfish, cabezon, and surfperches. The NISP/m³ values exhibit a considerable range. Sites occupied prior to 600 B.C. show relatively low frequency of fish

bone between 6.3 and 15.0 NISP/m³, and no anchovy bones (Table S5). Sites exhibiting the highest densities of fish remains were occupied 600 B.C.–A.D. 1250 (up to 360.0 NISP/m³) and A.D. 1000–1450 (up to 1253.1 NISP/m³). These were

also the only deposits to yield northern anchovy remains. Sites occupied between A.D. 1450 and 1850 showed relatively low frequency of fish bone between 0.3 and 79.7 NISP/m^3.

Fish remains from archaeological sites represent an imperfect index of the vitality of prehistoric fisheries, in that bones reflect directly the intensity of human fishing and not necessarily the abundance of fish in near-shore waters. The volumetric density of remains and the relative proportion of different taxa can also be influenced by seasonality of occupation and post-depositional taphonomic factors. Furthermore, some fish bone is deposited in sites secondarily arriving in the stomach contents of marine mammals and/or larger fish (Fitch, 1972). Such caveats notwithstanding, the frequency of fish bone in sites dating 600 B.C.–A.D. 1250 and A.D. 1000–1450 suggests that humans fished regularly, if not intensively, during these periods and that fish were abundant enough to warrant the effort. The presence of northern anchovy bones in deposits dating between 600 B.C. and A.D. 1450 suggests that fishing equipment included nets with small enough mesh to capture this diminutive species and that upwelling was regular and sufficiently intense to encourage the presence of these fish near shore.

DISCUSSION

Comparison of historic sea-surface temperatures with those inferred from oxygen isotopic profiles of prehistoric shells indicates variation in oceanographic conditions during the late Holocene off the central California coast. Oxygen isotope analysis of shells dating A.D. 1–1300 suggests stable conditions, with seas cooler than present. Between A.D. 1300 and 1500, the later portion of the Medieval Warm Period, temperatures reached peaks higher than present and also showed an unusually wide seasonal range. Mussel shells dating from A.D. 1500 to 1700 show colder, less-variable sea-surface temperatures, consistent with previous isotopic studies (Dunbar, 1983; Koerper et al., 1985). Compared with historic sea-temperature records, the oxygen isotopic profiles from the late Medieval Period are unusual in their suggestion of large-scale seasonal fluctuations in water temperature, with a range greater than any recorded historically. Single specimens from this interval, representing 1- to 2-yr temperature cycles, suggest seasonal flux of 8–9°C, whereas the modern range represented in a 20-yr period spans only 5.95°C. Sea-surface temperatures during the A.D. 1500–1700 period were, on average, lower than at present. However, the seasonal range was similar to that of the present, fluctuating 4–5°C. The seasonal range in temperatures between A.D. 1300 and 1500 is inconsistent with very strong El Niño conditions, which show warm temperatures throughout the seasonal cycle. As in Peru, very strong ENSO events off California are commonly "years of abundance" in the terrestrial environment due to high rainfall, but there is strong evidence for prolonged drought during this period in central California (Graumlich, 1993; Stine, 1994). Low incidence and low intensity of El Niño events may partially explain the extended warm, dry conditions in central California (Ander-

son, 1994), but the range of variation in sea temperatures between A.D. 1300 and 1500 suggests conditions not wholly accounted for by the ENSO cycle. They may contribute to Stine's (1994) characterization of the Medieval Period as somewhat anomalous relative to the rest of the Holocene.

Fish remains from middens suggest that fisheries remained relatively productive during the period of warm, variable seas. Sites occupied A.D. 1000–1450 show relatively high frequencies of fish bone, with no indication of a decrease from earlier periods. The continued presence of northern anchovy (E. mordax) remains further suggests that fisheries remained reliable. Large populations of anchovies are generally inconsistent with El Niño, and the presence of this species is compatible with a low incidence of very strong ENSO events. The small size of this taxon further suggests a measure of dietary stress—given the considerable investment of time and technology required to capture and process these small fish. Fish seem to have provided an important dietary staple during the Medieval droughts, and the marked disruption in human settlement on the central California coast is probably more a reflection of response to drought-related subsistence stress rather than to a decline in marine productivity. Disruption to the marine environment related to variable sea temperatures during the late Medieval Warm Period cannot be entirely ruled out, however, owing to the lack of chronological resolution associated with central California shell midden deposits.

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