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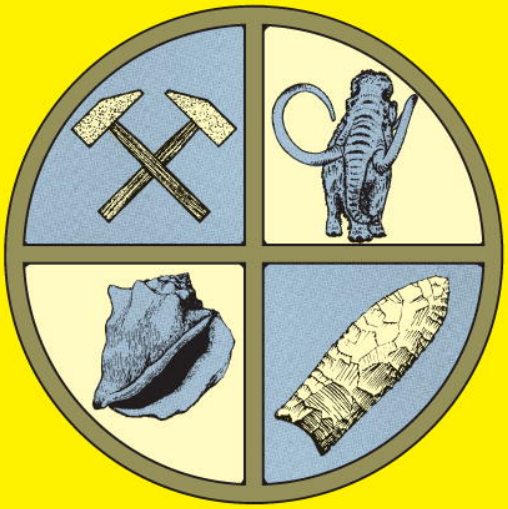

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Human responses to Middle Holocene climate change on California's Channel Islands

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Abstract

High-resolution archaeological and paleoenvironmental records from California's Channel Islands provide a unique opportunity to examine potential relationships between climatically induced environmental changes and prehistoric human behavioral responses. Available climate records in western North America (7–3.8 ka) indicate a severe dry interval between 6.3 and 4.8 ka embedded within a generally warm and dry Middle Holocene. Very dry conditions in western North America between 6.3 and 4.8 ka correlate with cold to moderate sea-surface temperatures (SST) along the southern California Coast evident in Ocean Drilling Program (ODP) Core 893A/B (Santa Barbara Basin). An episode of inferred high marine productivity between 6.3 and 5.8 ka corresponds with the coldest estimated SSTs of the Middle Holocene, otherwise marked by warm/low productivity marine conditions (7.5–3.8 ka). The impact of this severe aridity on humans was different between the northern and southern Channel Islands, apparently related to degree of island isolation, size and productivity of islands relative to population, fresh water availability, and on-going social relationships between island and continental populations. Northern Channel Islanders seem to have been largely unaffected by this severe arid phase. In contrast, cultural changes on the southern Channel Islands were likely influenced by the climatically induced environmental changes. We suggest that productive marine conditions coupled with a dry terrestrial climate between 6.3 and 5.8 ka stimulated early village development and intensified fishing on the more remote southern islands. Contact with people on the adjacent southern California Coast increased during this time with increased participation in a down-the-line trade network extending into the western Great Basin and central Oregon. Genetic similarities between Middle Holocene burial populations on the southern Channel Islands and modern California Uto-Aztecan populations suggest Middle Holocene movement of people at this time from southern California desert environs westward to the southern islands, a migration perhaps stimulated by increased continental aridity.

1. Introduction

Archaeologists working in coastal California have long been interested in climate change and its potential for shaping prehistoric societies (Arnold, 1987, 1991, 1992a, b, 1997, 2001; Glassow et al., 1988; Arnold and Tissot, 1993; Arnold et al., 1997, 2004; Raab and Larson 1997; Kennett, 1998, 2005; Jones and Kennett, 1999; Jones et al., 1999). This interest stems from the observation that coastal and terrestrial environments in California are highly sensitive to climate change (Moratto et al., 1978; Arnold, 1987; Glassow et al., 1988; Jones and Kennett, 1999), and the availability of high-resolution regional paleoclimate records beginning in the 1970s (LaMarche, 1973; Heusser, 1978; Pisias, 1978, 1979). Indeed, the increasing quality of climatic records clearly reveals this region's high sensitivity to climatic change (Stine, 1994; Ingram and Kennett, 1995; Kennett and Ingram, 1995a, b; Behl and Kennett, 1996; Heusser and Sirocko, 1997; Cannariato et al., 1999; Hendy and Kennett, 1999, 2000; Hughes and Graumlich, 2000; Benson et al., 2002, 2003; Friddell et al., 2003). Recent work also indicates that climatic instability seems to have been partly responsible for triggering sociopolitical and economic development on the southern and central California Coast between about 1.5 and 0.6 ka (Arnold

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et al., 1997, 2004; Raab and Bradford, 1997; Raab and Larson, 1997; Kennett, 1998, 2005; Jones and Kennett, 1999; Jones et al., 1999; Kennett and Kennett, 2000; Arnold 2001).

California's coastal environments changed drastically between the Early and Middle Holocene (10,000–3000 cal yrs BP; see Inman, 1983; Erlandson and Colten, 1991; Erlandson and Glassow, 1997; Graham et al., 2003; Kinlan et al., 2005). The configuration of the California coastal region continued to change with deglacial sea-level rise between 19 and 6 ka (Erlandson, 1994, 1997a, b; Glassow, 1997a, b; Masters and Gallegos, 1997), and with the infilling of estuaries that followed (Bickel, 1978; Inman, 1983; Erlandson, 1994). Potential effects of a distinct Middle Holocene warming episode have further stimulated archaeological interest in possible influences of climate on cultural change (Antevs, 1948, 1952, 1955; Glassow et al., 1988; Erlandson and Glassow, 1997). However, many Middle Holocene climate records have had insufficient chronological control, or adequate stratigraphic resolution to effectively explore potential associations between climatic and human behavioral change.

A wide range of paleoenvironmental data have revealed instability in global climate during the Holocene (Denton and Karlen, 1973; O'Brien et al., 1995; Alley et al., 1997; Bond et al., 1997; Sandweiss et al., 1999; Kennett and Kennett, 2000). Paleoclimatic data from the Greenland ice sheet, North Atlantic sediments, and sediment records from Santa Barbara Basin (ODP Hole 893A/B) all show a sequence of millennial-scale climate cycles through the Holocene (O'Brien et al., 1995; Bond et al., 1997; Kennett et al., 1997a, b; Kennett and Kennett, 2000; Friddell et al., 2003). Global temperatures appear to have been slightly warmer than today from ~9 to 6 ka, the so-called hypsithermal, altithermal, or climatic optimum (Kutzbach and Guetter, 1986; COHMAP, 1988; Gasse et al., 1991; Lamb, 1977). Coastal environments were continually being transformed by rapid sea-level rise until ca. 6 ka (Fairbanks, 1989).

Here we present a high-resolution Holocene marine paleoclimate record for the southern California Coast spanning the Middle Holocene at 50-year intervals. This record is based on oxygen isotopic analysis of planktonic foraminifera from ODP Site 893A/B, Santa Barbara Basin, superseding an earlier SST curve (Pisias, 1978, 1979), long employed by archaeologists working in California. Based on this high-resolution record, we explore the interrelationships between marine and terrestrial climate conditions in western North America and the potential role of Middle Holocene climate change on human cultural development on California's Channel Islands.

2. Santa Barbara Basin paleoenvironmental record

Changes in SST and marine productivity during the Holocene have been inferred using various marine sediment records from coastal California (Pisias, 1978, 1979; Heusser et al., 1985; van Geen et al., 1992) including an especially high-resolution Holocene record (Kennett and Kennett, 2000; Cannariato et al., 2003). This Holocene (11.5 ka to present) record represents the upper 17 m of a 200 m core, a late Quaternary sequence spanning the last 160 ka (Site 893A/B), drilled in Santa Barbara Basin as part of the Ocean Drilling Program (Ingram and Kennett, 1995; Kennett and Ingram, 1995a, b; Behl and Kennett, 1996; Cannariato et al., 1999; Hendy and Kennett, 1999, 2000) (Fig. 1). The sequence consists of laminated sediments deposited at an average rate of ~155 cm/1000 years. Climatic change through the Holocene is inferred from oxygen isotopic ($\delta^{18}O$) analysis of two planktonic foraminiferal taxa: *Globigerina bulloides*, a surface dweller, and *Neogloboquadrina pachyderma*, a species that lives near the base of the thermocline (~60 m below surface). Our Holocene age model is based on 20 AMS ^{14}C dates converted to calendar years using a reservoir age of 230 ± 35 years (Ingram and Southon, 1996; D.J. Kennett et al., 1997; see Roark et al., 2003 for chronological details). This has provided one of the highest resolution marine Holocene climate sequences in the world: 25 year intervals from 0 to 3 ka and 9 to 11 ka and 50 year intervals from 3 to 9 ka. The high quality of this climate record results from a combination of rapid sedimentation rates, lack of bioturbation, a continuous abundance of foraminifera for geochemical and faunal analyses, and high environmental sensitivity in this region (Kennett and Kennett, 2000). More details of the global climate correlations to the Santa Barbara Basin climate record and their implications for Holocene climate change mechanisms will be provided in a forthcoming paper (Cannariato et al., in preparation.).

This record reveals millennial-scale oscillations in SST during the Holocene (Fig. 2a). Compared with the previous glacial episode (Kennett and Ingram, 1995a), Holocene SSTs were warm (average of ~12.5 °C). Three distinct cycles are present in the Middle Holocene with warming between 8.2–6.3 and 5.8–3.8 ka, punctuated by a cool interval from 6.3 to 5.8 ka. The coldest SSTs during the Middle Holocene are centered on 6 ka (~12 °C). The warmest Middle Holocene interval occurred between 4.5 and 4 ka (~15 °C), in agreement with Friddell et al. (2003). SSTs between 5.8 and 5.2 ka were relatively moderate compared to these warm and cold cycles.

Inferred surface ocean productivity fluctuations occurred during the Holocene (Fig. 2b), often synchronously with changes in SST. Changes in marine productivity have been inferred using a marine productivity index. This index is based on temperature differences between surface waters (as measured by the oxygen isotopic composition of surface-dwelling *G. bulloides*) and waters at the base of the thermocline (as measured by the oxygen isotopic composition of *N. pachyderma* which inhabits the thermocline). Sediment trap studies within Santa Barbara Basin indicate that the isotopic difference between *G. bulloides* and *N. pachyderma* reflects the degree of surface ocean stratification, providing measures of upper water column

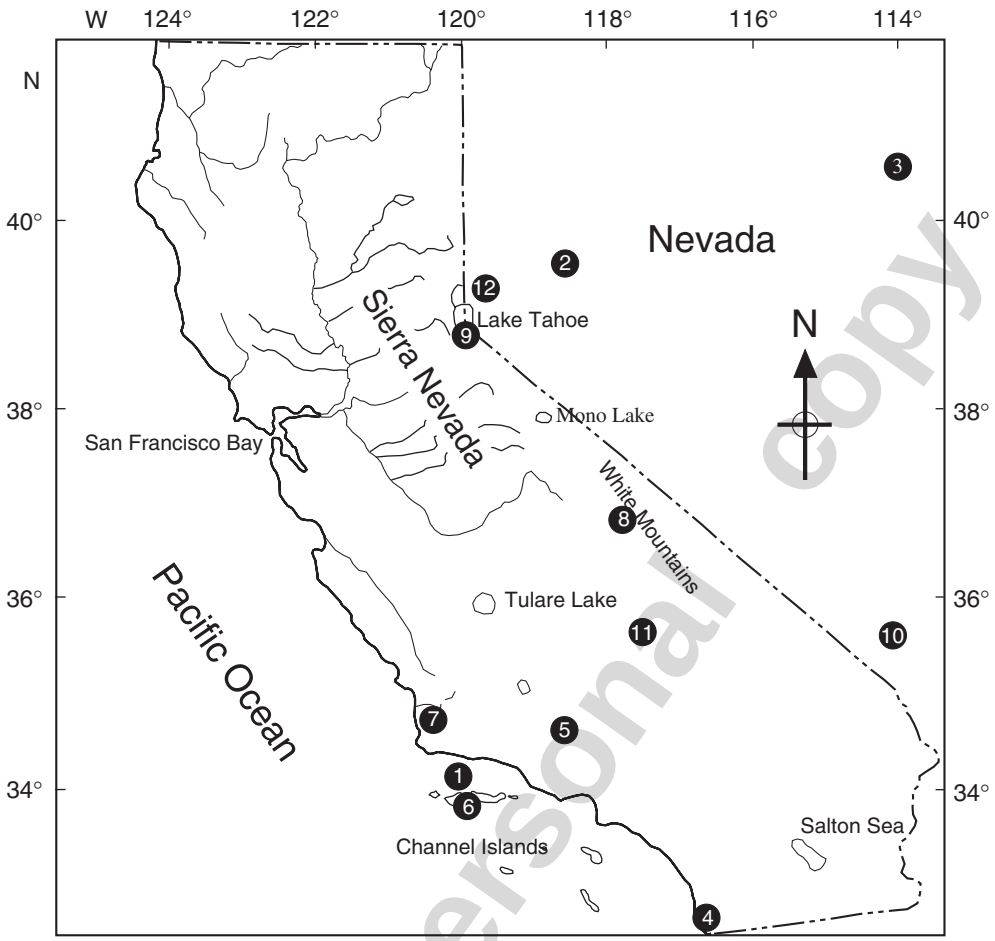

Fig. 1. Map of California and Nevada showing the locations of the main paleoclimatic records discussed in this contribution. (1) Ocean Drilling Project, Site 893A/B, Santa Barbara Basin (Kennett and Ingram, 1995b; Kennett and Kennett, 2000; Heusser and Sirocko, 1997; (2) Leonard Rockshelter pollen sequence (Byrne et al., 1979); (3) Ruby Valley pollen record (Thompson, 1992); (4) Archaeological pollen sequences (Masters and Gallegos, 1997); (5) Late Holocene tree ring record (Larson and Michaelson, 1989); (6) Santa Rosa Island pollen sequence (Cole and Liu, 1994); (7) Union pollen spectra (Morgan et al., 1991); (8) Bristlecone pine tree ring record (Hughes and Graumlich, 2000; LaMarche, 1973, 1974); (9) Lake Tahoe submerged tree stump record (Lindström, 1990); (10) Southern Great Basin black mat records (Quade et al., 1998); (11) Owens Lake sequence (Benson et al., 2002); (12) Pyramid Lake sequence (Benson et al., 2002).

stability, upwelling intensity, and magnitude of surface ocean productivity (Pak and Kennett, 2002). During the Holocene, inferred warming of surface waters was often associated with cooling at the thermocline, and vice versa, suggesting episodic variations in the intensity of upwelling. During cool episodes, little or no vertical temperature gradient existed between surface and thermoclinal species suggesting that upwelling of deeper, nutrient-rich waters was then especially intense during these intervals. Vertical mixing and inferred high productivity were greatest during the Middle Holocene from 7.5 to 6.8 and 6.5 to 5.9 ka. Reduced vertical mixing and lower marine productivity occurred between 6.8 and 6.5 ka, and again between 5.9 and 3.9 ka.

3. Associated terrestrial climate changes

High-resolution $\delta^{18}O$ and Total Inorganic Carbon (TIC) records from Pyramid and Owens Lake basins reveal at least five distinctive climatic episodes in western North America during the Holocene (Benson et al., 2002; Fig. 3; see Fig. 1 for locations). Younger Dryas cooling was followed during the earliest Holocene by drying (11.6–10 ka) except for a brief wet period between 10.4 and 10.2 ka. Relatively wet conditions occurred during the remaining early Holocene (10–8 ka). Under these conditions, Lake Tahoe fed Pyramid Lake via the Truckee River and a substantial body of water existed in the Owens Lake Basin (Benson et al., 2002). A drying trend between 8 and 6.5 ka is suggested as lake sizes declined in both basins. $\delta^{18}O$ and TIC records from Pyramid Lake suggest periodic wet intervals between 8 and 6.5 ka with the most pronounced isotopic excursion between 7 and 6.4 ka interpreted as a major influx of water from Lake Tahoe. Persistently warm and dry conditions occurred throughout the remainder of the Middle Holocene (6.4–3.8 ka). At this time Owens Lake dried completely and water flow from Lake Tahoe to Pyramid Lake was substantially reduced.

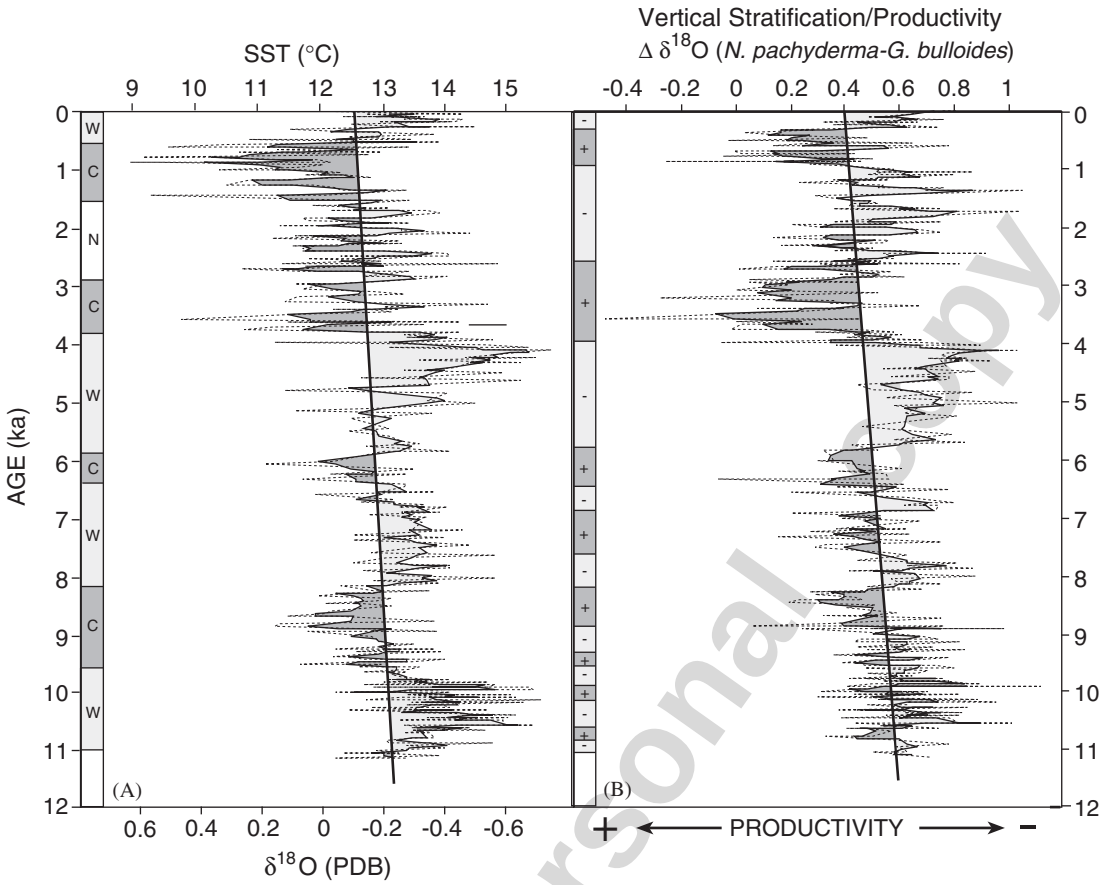

Fig. 2. Holocene $\delta^{18}O$ climate and inferred paleoproductivity records for Santa Barbara Basin (ODP Site 893A/B). (A) inferred sea-surface temperature curve is based on $\delta^{18}O$ of *G. bulloides* (surface-dwelling species of foraminifera) from varved sediments in Santa Barbara Basin. Sea-surface temperatures were calculated using the equation of Bemis et al. (1998). The Holocene (< 7 ka) $\delta^{18}O$ inferred SST estimates have been normalized by removing the oxygen isotopic component of ocean waters that resulted from ice volume changes. Bar at left represents warm (w) and cold (c) cycles through the Holocene; (B) inferred vertical stratification/productivity record is based on oxygen isotopic differences between *G. bulloides* (surface-dwelling) and *N. pachyderma* (deeper-dwelling) planktonic foraminifera. Bar at left shows intervals inferred as high (+) or low (−) productivity during the Holocene. General trends in inferred SST and productivity shown by straight lines, with generally cooler, more productive surface waters towards the Late Holocene.

Wetter conditions generally mark the Late Holocene after ~3 ka, but several short-lived major droughts are known to have occurred between 1.5 and 0.6 ka (Stine, 1994).

These new data are generally consistent with the early work of Antevs (1948, 1952, 1955) who argued that the Middle Holocene (~7–4.5 ka) was warm and dry across much of western North America, the so-called Altithermal or climatic optimum. This was preceded by the Anathermal (10–7 ka) and followed by the Medithermal (4.5 ka to present), intervals marked by generally cool and wet climatic conditions. Dry Middle Holocene conditions in the Great Basin are also suggested by decreased sedimentation rates in the Ruby Valley marshlands of western Nevada between 7.7 and 5.5 ka (Thompson, 1992), decreases in spring discharge indicated by the absence of black mats in the southern Great Basin between ~7.3 and 2.5 ka (Quade et al., 1998), and changes in the distribution of xeric flora (Hansen, 1947; Bright, 1966; Byrne et al., 1979; Mehringer, 1985; Madsen and Rhode, 1990) and associated fauna (Grayson, 2000). Axelrod (1981) argued that xeric (dry) vegetation expanded into the San Francisco Bay area in the Early and Middle Holocene and Moratto et al. (1978) identified several dry episodes in the Middle Holocene based on pollen records from California (Birman, 1964; Adam, 1967; Curry, 1969; Wood, 1975; Sercelj and Adam, 1975; Casteel et al., 1977) and correlated these with the bristlecone pine precipitation record from the White Mountains (LaMarche, 1973, 1974; Hughes and Graumlich, 2000) indicating a significant dry episode between 6 and 4.8 ka. This correlates well with the driest interval in the Middle Holocene as indicated by the Pyramid Lake $\delta^{18}O$ record (Benson et al., 2002) and is consistent with some of the most compelling evidence for severe Middle Holocene aridity based on submerged tree stumps in Lake Tahoe. Lindström (1990; also see Harding, 1965; Benson et al., 2002) documented ~20 tree stumps submerged up to 4 m below the current lake level. These trees have been radiocarbon dated to between ~6.3 and 4.8 ka and represent a low lake-level stand at that time.

Drought conditions appear to have been less severe in coastal California during the Middle Holocene compared with the interior. Relatively dry conditions in the Santa

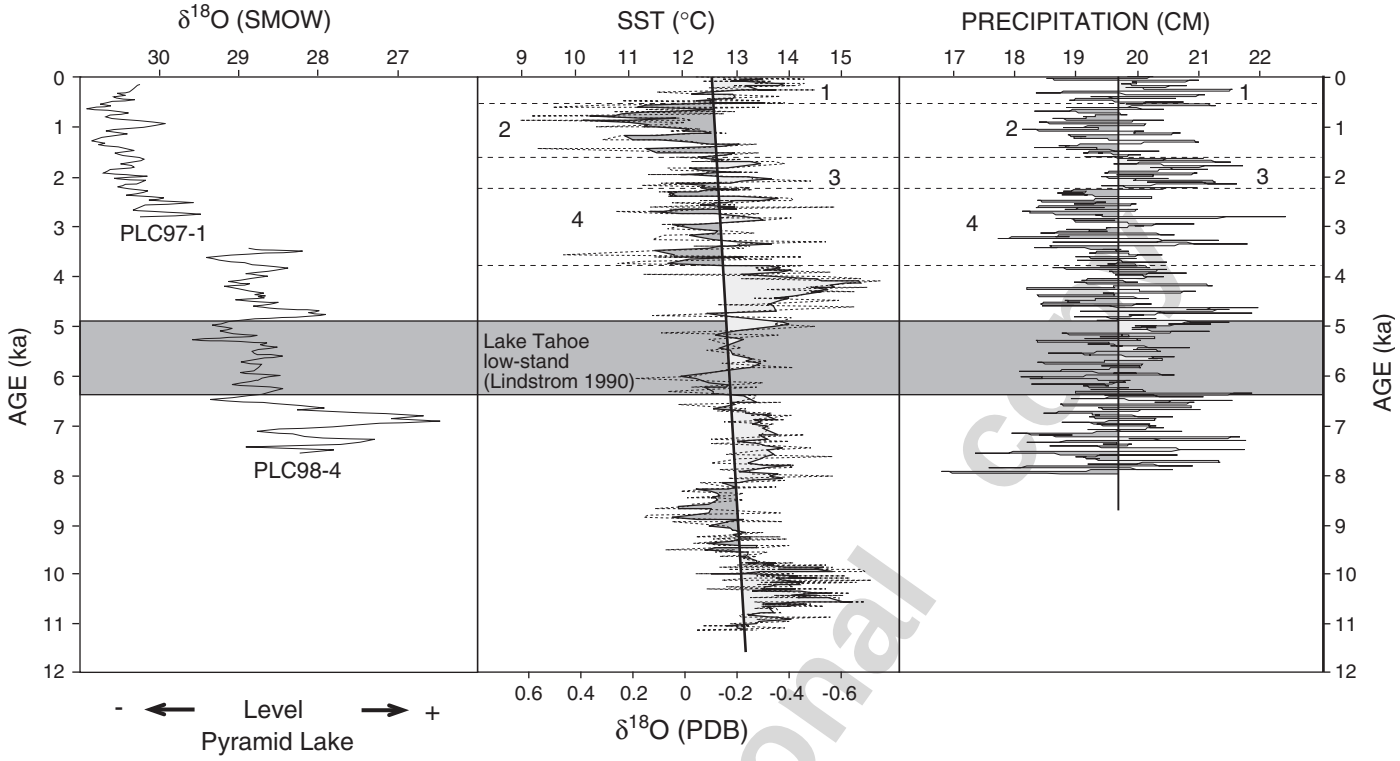

Fig. 3. Bristlecone pine inferred precipitation (8 ka-present) and Pyramid Lake $\delta^{18}O$ record compared with Holocene inferred SST from Santa Barbara Basin. (A) Smoothed (40-yr) $\delta^{18}O$ record for lake carbonates from Pyramid Lake (Cores PLC97-1 and PLC98-4), western Nevada (Benson et al., 2002). Oscillations in $\delta^{18}O$ interpreted to largely represent changes in freshwater input into lake in turn correlated to changes in lake size. Late Holocene high $\delta^{18}O$ values (PLC97-1) interpreted by Benson et al., 2002, as representing a phase of cooler, wetter climate. (B) Inferred SST record from Santa Barbara Basin, from Fig. 2; (C) Bristlecone pine record of inferred precipitation based on ring width measurements from trees in the White Mountains, California (data from LaMarche, 1973, 1974; Hughes and Graumlich 2000; see http://www.ncdc.noaa.gov/paleo/drought/drght_graumlich.html). Zones 1–4 denote cool/dry (2 & 4) and warm/wet cycles (1 & 4) exhibited by these SST and precipitation records.

Barbara region are suggested by high percentages of *Chenopodium* and *Ambrosia* pollen in estuarine deposits on Santa Rosa Island between 5.2 and 3.25 ka (Cole and Liu, 1994) and dune building became more widespread on San Miguel Island between 7 and 3.5 ka (Erlandson et al., 2005b). Pollen evidence from sediment records north of Point Conception also suggest dry conditions peaking in the Middle Holocene (7.6–4.8 ka) on the Santa Barbara Coast (Morgan et al., 1991). However, frequency changes in pine and oak pollen (Heusser and Sirocko, 1997) in Santa Barbara Basin (ODP Hole 893a) exhibit no distinct trends during the Middle and Late Holocene and thus climatic interpretations are inconclusive. Also, pollen spectra from estuarine and archaeological deposits in coastal San Diego County indicate relatively stable environmental conditions during the Holocene (Masters and Gallegos, 1997).

Relationships between marine and terrestrial climatic conditions on the California Coast are complex, but historical data suggest that these two climate systems are currently closely interrelated (Jones and Kennett, 1999). Late Holocene records indicate that intervals marked by cooler SSTs in Santa Barbara Basin were contemporaneous with low precipitation over parts of western North America (Kennett and Kennett, 2000; Graham et al., in review). A comparison of Santa Barbara Basin core data with the bristlecone pine record from the White Mountains of eastern California suggest correlation between cool SST and drier conditions during the last 4 ka (Fig. 3). During this interval, cool SSTs and low precipitation dominate between 4 and 2.3 ka and again between 1.5 and 0.5 ka; warm SSTs and higher precipitation are evident between 2.3 and 1.5 ka and again following 0.5 ka. Cool SSTs between ~1.5 and 0.5 ka also correlate with lower precipitation evident in a shorter tree ring record from the coastal ranges of southern California (Larson and Michaelson, 1989; Kennett and Kennett, 2000). Several other lines of evidence indicate dry conditions during this interval (Stine, 1994; Raab and Larson, 1997; Jones et al., 1999).

Middle Holocene relationships between inferred precipitation and SST are much less apparent. Prior to 4 ka correlations between SST in the Santa Barbara Basin and the bristlecone pine record, so evident in the Late Holocene, are largely absent, possibly reflecting a general shift in climate sensitivity in southern California at the end of the Middle Holocene. During the Middle Holocene dry conditions throughout western North America (Antevs,

1948; Benson et al., 2002) correspond to warm SSTs in Santa Barbara Basin. Similarly warm SSTs through the Middle Holocene recorded in another Santa Barbara Basin sequence have been interpreted as stronger El Niño-Southern Oscillation (ENSO) activity in the Pacific and implied generally wetter conditions in western North America (Friddell et al., 2003). This, however, is inconsistent with indications of widespread Middle Holocene aridity in western North America and evidence for relatively stable decadal-scale climate variability in Site 893A/B that are more in agreement with evidence for weaker ENSO activity during the Middle Holocene (Sandweiss et al., 1996, 1997, 2001; Overpeck and Webb, 2000; Tudhope et al., 2001). A corollary result is that generally warmer SSTs at the millennial-scale are not necessarily accompanied by more intense or frequent ENSO activity.

Although inferred relations between SST and precipitation are clearly more complex in western North America, the coolest SST interval (6.3 and 5 ka) corresponds with the onset of the driest interval during the Middle Holocene reflected in the bristlecone pine sequence (LaMarche, 1973, 1974), Pyramid Lake $\delta^{18}O$ record (Benson et al., 2002), and the submerged-stumps from Lake Tahoe (Lindström, 1990; Benson et al., 2002). This suggests that the climate during this interval operated similarly to that of the Late Holocene.

4. Channel Islands archaeological record

The Channel Islands off southern California geographically form northern and southern groups (Power, 1980). The northern group defines the southern boundary of the Santa Barbara Channel and consists of San Miguel, Santa Rosa, Santa Cruz, and Anacapa Islands. The southern Channel Islands (Santa Barbara, Santa Catalina, San Clemente, and San Nicolas) are each more isolated and located farther offshore (see Fig. 5). Isolation from the mainland during the Quaternary has led to low diversity of terrestrial flora and fauna. The largest extant land mammal found on these islands is the diminutive island fox and less than half the plant taxa found on the adjacent California mainland are endemic to the islands (Timbrook, 1993). Potable drinking water is limited, particularly on the smaller islands of San Clemente, San Nicolas, Santa Barbara, Anacapa, and San Miguel. In contrast, these islands have highly productive marine ecosystems, particularly the northern Channel Islands, because of their close proximity to extensive coastal upwelling of California Current waters. Patterns in the distribution and productivity of marine organisms near the islands are strongly related to variations in SST and primary productivity associated with relative importance of northern derived cool California Current waters to warmer southern countercurrent waters (Neushul et al., 1967; Murray et al., 1980; Seapy and Littler, 1980; Stewart et al., 1993; Engle, 1993, 1994).

4.1. Northern Channel Islands

Archaeological records on the northern Channel Islands provide some of the strongest evidence for human occupation along the west coast of North America between 13.5 and 7.5 ka (Erlandson, 1993; Erlandson et al., 1996a, b, 2005a; Johnson et al., 2000; Rick et al., 2001, 2005; Kennett, 2005). Most of the early sites are located on the westernmost islands of San Miguel and Santa Rosa, but the number of sites (~25) is still relatively small and dominant settlement and subsistence strategies are difficult to define because sea-level rise and coastal erosion have obscured the patterns. Population levels increased on the islands during the Early Holocene and many of the cultural features that became dominant during the Middle Holocene are evident in the record by ~7.5 ka. The north coast of Santa Rosa Island, particularly the Arlington Springs area, emerged as one important node of settlement by this time (Orr, 1968; Erlandson, 1994; Kennett, 2005).

Middle Holocene sites are more widely distributed compared with Early Holocene sites—occurring in a variety of coastal and interior settings. These sites differ according to function, intensity of use, duration of settlement, and post-depositional alteration. Here, we provisionally group sites into four categories for heuristic purposes: *primary villages*, *secondary villages*, *interior residences*, and *logistical encampments*. *Primary villages* were clearly occupied for extended periods of time and served as central locations for a variety of economic and social activities. These sites are large, contain deeply stratified or laterally extensive midden deposits, and are associated with cemeteries. The accumulation of domestic debris (middens) at *secondary villages* is similar to primary villages and isolated burials may be present, but cemeteries are apparently absent. This absence may be the result of insufficient archaeological work or may reflect different prehistoric site use (e.g., fewer people living at the site for shorter periods of time). *Interior residences* are often smaller than primary and secondary villages and positioned on ridges or small knolls away from the coast (Kennett, 1998; Clifford, 2001; Kennett and Clifford, 2004). These sites range from small ephemeral deposits, suggesting single usage, to large, deeply stratified sites representing repeated use or more permanent settlement. *Logistical encampments* are those sites that suggest special purpose activities, usually the collection and processing of a resource that is located far away from primary villages. The best-known logistical encampments on the islands are thin pavements of marine shell (usually abalone or California mussel) positioned near rocky promontories or along highly productive stretches of rocky, but accessible, coastline. Many of the ephemeral "interior residences" may be logistical encampments that were used periodically to collect and process plant foods (seeds and bulbs) from surrounding environs.

The distribution of known Middle Holocene sites on the northern Channel Islands is shown in Fig. 4. The

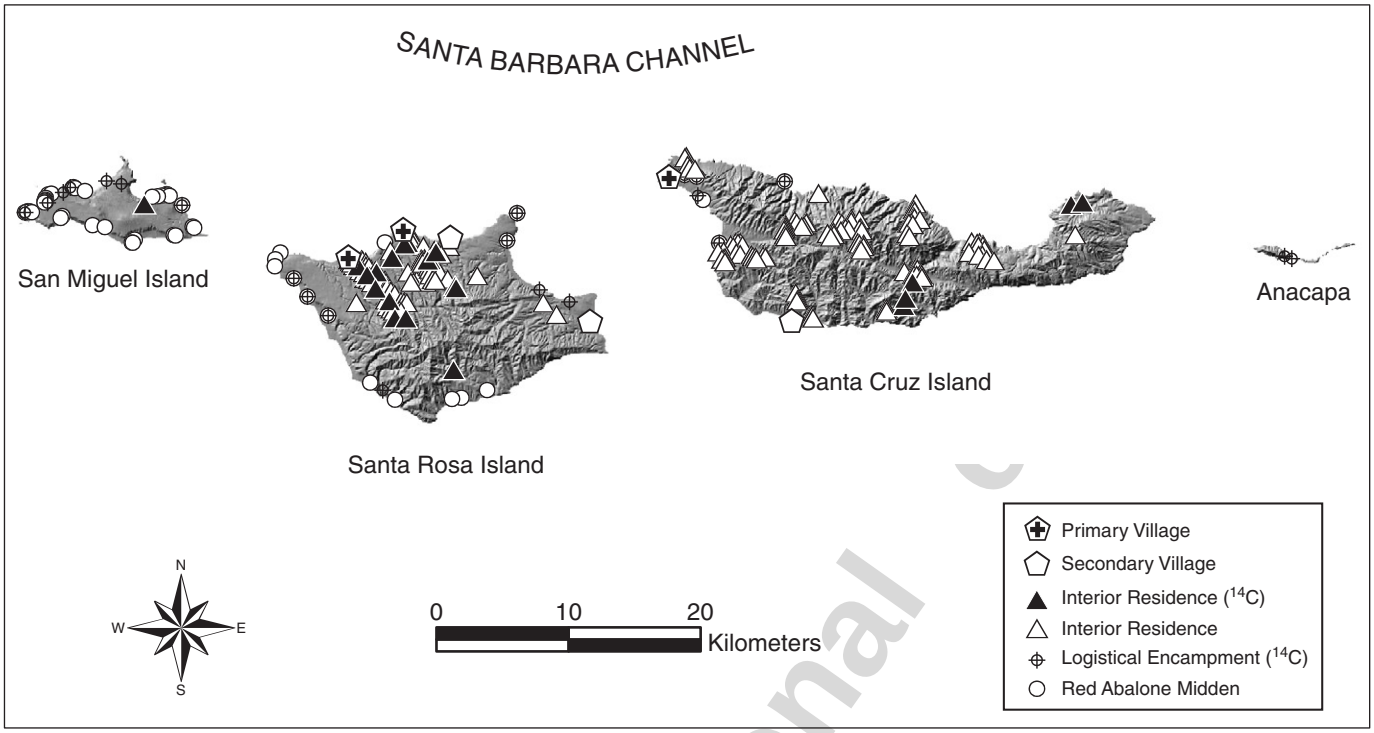

Fig. 4. Middle Holocene (7–3 ka) distribution of settlements on the northern Channel Islands (Kennett, 2005; Rick, 2006). This pattern was remarkably stable and persistent through the Middle Holocene.

chronological placement of some of these sites is verified using radiocarbon dating, but others are inferred to be of Middle Holocene age because of their location or faunal constituents (e.g., interior or red abalone sites; see Kennett, 1998, 2005 for rationale). The Middle Holocene age of the latter sites must be verified in the future. The north coast of Santa Rosa Island continued to be an important node of settlement, but the number of primary and secondary villages increased and expanded to several well-watered locations east of Arlington Canyon (Kennett, 1998; Orr, 1968). Primary and secondary villages are also present on the western and southern sides of Santa Cruz Island (King, 1990; Wilcoxon, 1993; Glassow, 1993a, 2000). Although extensive surveys were conducted on eastern Santa Cruz, large coastal middens suggesting primary or secondary village locations have not been identified along the coast (Kennett, 1998; Clifford, 2001; Perry, 2003), although one interior site may have served as a village (CA-SCrI-608). Interior residences are common on Santa Rosa and Santa Cruz (Kennett, 1998), and one site on San Miguel Island (CA-SMI-1) resembles these settlements and may be of Middle Holocene age (Erlandson, 1991). Logistical encampments and red abalone middens dominate on San Miguel Island, and are also common on the coasts of Santa Rosa and Santa Cruz.

Of the Middle Holocene site types on the northern Channel Islands, the most common are thin lenses of shell along the coast (Kennett, 2005; Rick, 2004), which we interpret as logistical encampments used for extracting and processing shellfish. Most of these sites are positioned on rocky stretches of coast or on headlands overlooking rocky intertidal habitats, and many consist of laterally extensive, but thin, pavements of abalone and California mussel shells. Fish and sea mammal remains are rare at these locations and tool assemblages are simple, usually consisting of expedient flakes manufactured from locally available volcanic rocks and chert. Red abalone middens are the most visible logistical encampments on the northern Channel Islands dating to between 7.5 and 4.5 ka (Glassow, 1993b). The shells of this species are large (15–25 cm long) and far less common in middens dating after 3.5 ka. Most of these sites are composed of a single component and represent short-term, but intensive, collecting and processing events. When red abalone shells are present within multi-component sites (e.g., CA-SCrI-333, CA-SRI-147; CA-SMI-528), they are often found in basal levels and are replaced in upper, more recent, strata by the smaller, black abalone (*H. cracherodii*) or more diverse shellfish assemblages typically including smaller species (Wilcoxon, 1993; Kennett, 1998, 2005; Walker et al., 2000). The cool waters surrounding San Miguel Island provided more favorable subtidal conditions for red abalone later in time and small shells of this species are found in the Late Holocene, sometimes associated with evidence for the manufacture of abalone shell fishhooks and beads (Walker et al., 2000; Rick, 2004).

Unlike today, it is possible that red abalone was more readily available in lower intertidal or upper subtidal

habitats surrounding the northern Channel Islands between 7.5 and 4.5 ka (Glassow, 1993b). The primary distribution of this species extends north into the cooler waters along the northern California Coast, where it currently lives in lower intertidal and subtidal habitats. Glassow (1993b) suggested that the presence of red abalone in Middle Holocene middens was indicative of cooler sea-surface temperatures during this interval. Oxygen isotopic analysis of California mussel shells (*M. californianus*) associated with one red abalone midden (CA-SCrI-333) indicated that water temperatures were 2 °C cooler when the midden formed (~5.7 ka; Glassow et al., 1994). These data are generally consistent with SST data for the region showing cool to moderate conditions between 6.3 and 5 ka. However, Middle Holocene conditions generally exhibit warmer than average sea-surface temperatures. Periodically warm SSTs are also suggested by diverse Middle Holocene shellfish assemblages at Punta Arena (southern Santa Cruz; Sharp, 2000). The persistence of red abalone in intertidal habitats between 7.5 and 4.5 ka may have resulted from less frequent El Niños during this interval (short-term warm water events not visible in lower resolution climate records), as suggested by some paleoclimatic records from the Pacific (Overpeck and Webb, 2000; Tudhope et al., 2001; Sandweiss et al., 2001; Masters, 2006). Reduced ENSO activity in the Middle Holocene is consistent with lower decadal variability during the Middle Holocene in Santa Barbara Basin (see Fig. 2) and evidence for arid conditions across much of Western North America. Another more plausible explanation is that this large abalone species was collected subtidally, perhaps in the upper subtidal zone during cold/productive intervals, by diving rather than in the intertidal zone (Sharp, 2000). The disappearance of red abalone shells from many middens on the northern Channel Islands was likely a product of changing environmental conditions (perhaps increased El Niño frequency), coupled with intensive predation. It is also possible that the secondary use of red abalone shells as raw material to produce fishhooks, beads, and other trade items partially contributes to their absence in Late Holocene middens.

The location of Middle Holocene settlements on the coast and in the interior suggests the complementary use of marine resources and plant foods. Fish, sea mammal, and bird bones are all found in residential middens of Middle Holocene age, but abalone and California mussel shells dominate in most of these deposits. Quantitative midden constituent data from coastal residences, temporary encampments, and interior settlements on San Miguel and Santa Rosa islands also indicate that shellfish provided the primary protein source (Kennett, 1998, 2005; Vellanoweth et al., 2000). The dietary importance of shellfish is also evident in coastal residential middens and interior sites on Santa Cruz Island (Glassow, 1980, 1993a; Clifford, 2001). The strategic position of interior settlements suggests the complementary use of coastal sagebrush and grassland communities. It is also possible that acorns and pine nuts were harvested from small stands of island oaks and pines on Santa Cruz and Santa Rosa.

Although significant changes in the distribution of plant communities occurred on the northern Channel Islands in the last 200 years, the current distribution provides some insight into the importance of different types of plants. Wind is one of the primary forces shaping plant geography, particularly on the outer islands of Santa Rosa and San Miguel, and widespread dune building during the Middle Holocene suggests that wind was a significant factor shaping island biogeography (Erlandson et al., 2005b). Coastal sagebrush occurs along drainage walls and behind hills, slightly sheltered from the wind, and grasslands predominate in more exposed portions of the island. Grasslands dominate on the northwest side of Santa Rosa and eastern San Miguel where the winds are stronger and the topography more gentle.

On Santa Rosa, small stands of oaks are only available in sheltered canyons in the interior. Middle Holocene hilltop/ridgeline sites in the Arlington Canyon area are distributed evenly along the rim of Arlington Canyon, apparently associated with grassland communities. Topographic relief in Cañada Verde is more variable and interior sites cluster on hills near coastal sagebrush communities. Large lithic scatters occur in the lee of these hills where coastal sagebrush communities persist today. Grasslands and coastal sagebrush both contain plants that produce edible seeds and tubers. Some of these plants were most productive during the spring (blue dick bulbs and seeds) and others were more productive in the fall (acorns). The importance of grasses and sagebrush during the Middle Holocene is revealed by the presence of milling equipment and digging stick weights with burials and sites in the interior (Orr, 1968; Kennett, 1998).

Osteological data from island burial populations also support the hypothesis that various plant foods were an important part of the Middle Holocene diet (6–3 ka; Walker, 1978; Walker and Erlandson, 1986). The abundance of dental caries in prehistoric skeletons is a proxy for the relative contribution in the diet of carbohydrates (plants) and protein (meat). Ethnographic and clinical studies indicate a direct link between high caries rates and carbohydrate-rich diets (Pederson, 1938). Middle Holocene people living on Santa Rosa Island had high frequency of dental caries (80%) compared with later peoples (Walker and Erlandson, 1986), suggesting that plant foods (e.g., roots and tubers) were important during the Middle Holocene. Stable nitrogen and carbon isotopic analysis of burial populations also provides information about Middle Holocene diet on the northern Channel Islands (Walker and DeNiro, 1986; Goldberg, 1993). Nitrogen and carbon isotopic composition of human bone reflects the relative proportion of marine and terrestrial food in the diets of prehistoric individuals (DeNiro, 1985). In general, island peoples exhibit enriched $\delta^{15}N$ and $\delta^{13}C$ isotopic values compared with those from the mainland, indicating greater dependence upon marine foods (Walker and DeNiro,

1986). The importance of marine foods also increased through time on the islands (Walker and DeNiro, 1986; Goldberg, 1993). Goldberg (1993) analyzed human bones from two Middle Holocene cemeteries on the northern Channel Islands: CA-SRI-41 and CA-SCrI-333. Both studies also found that statistically significant dietary differences existed between men and women during the Middle Holocene, probably because women had greater access to plant food than men.

The spatial patterning of archaeological sites on the northern Channel Islands suggests that people established villages on sections of rocky coastline near springs or well-watered drainages on Santa Rosa and Santa Cruz. The presence of cemeteries at some of these villages suggests that people were tied to these productive locations, yet foraged widely using interior residences and logistical encampments. In some instances this strategy required the temporary relocation of people, perhaps smaller family units, to residences in the interiors of the larger islands to exploit seasonally available plant foods. Seasonal shellfish harvesting based on $\delta^{18}O$ profiles from coastal villages, interior residences, and logistical encampments provide additional evidence for central place foraging during the Middle Holocene (see Kennett, 2005).

Although available data for Middle Holocene settlement and subsistence are limited, this generally supports the hypothesis that small groups of people (perhaps 50–100) had established semi-permanent villages by this time at optimal sites on the larger islands of Santa Rosa and Santa Cruz. The intricacies of ceremonial and social life in these villages remains largely unknown given the limitations of the archaeological record. However, if the nature of burial data is an indication of social differences between individuals, then it appears that some people in island Chumash society had become distinguished. Some burials are quite elaborate and contain hundreds of burial offerings including beads, spangles, and an array of shell and bone pendants (King, 1990; see also Erlandson and Rick, 2002). An absence of elaborate infant burials on the islands however, suggests that leadership positions were not inherited, but achieved during a lifetime. Island villages were likely tied together through marriage alliances, and materials from the coastal mainland suggest that trade and marriage alliances extended across the Santa Barbara Channel (Orr, 1968; King, 1990; Rick et al., 2001). What is clear from the record is that these people were skilled at crafting shell, stone, and bone items for ceremonial and subsistence purposes. They were also consummate fisher people, periodically fishing and hunting marine mammals, and using boats to forage widely through the island chain, intensively harvesting and processing shellfish for the primary villages. These maritime traditions appear to have been remarkably persistent through the Middle Holocene and established the foundations for later developments in island Chumash society.

4.2. Southern Channel Islands

The southern Channel Islands of San Clemente, Santa Catalina, San Nicolas, and Santa Barbara are more isolated, arid, and distant from the mainland compared with the northern islands. Cultural developments were significantly different on the southern Channel Islands during the Early and Middle Holocene. At historic contact, the southern Channel Islands were occupied by the Tongva (Gabrielino), Uto-Aztecan peoples linguistically and ethnically distinct from the Hokan people living on the northern Channel Islands (Bean and Smith, 1978; Raab, 1997). Interactions between peoples of the northern and southern Channel Islands during the Holocene appear to have been relatively limited, but steatite artifacts produced on the southern Channel Islands are occasionally found on the northern Channel Islands. Biological differences between these two island groups appear to have roots in the Middle Holocene with genetic data from human burials at the Eel Point site (CA-SCLI-43) indicating haplogroup frequency distributions most comparable to extant California Uto-Aztecan, rather than Chumash, peoples (Potter, 2004; see below). The first evidence for occupation of the southern Channel Islands is at Eel Point (Fig. 5), a large site on San Clemente Island with basal deposits of ca. 8.5 ka (Salls, 1990; Raab et al., 1995b; Raab, 1997). Other evidence for Early Holocene occupation of the southern Channel Islands is either rare or absent.

Occupations are more evident by the Middle Holocene on San Clemente and the other southern Channel Islands. In addition to the Early Holocene deposit, a substantial Middle Holocene component has also been described at Eel Point (Raab et al., 1995b). Other Middle Holocene occupations on San Clemente Island include Xantusia Cave (CA-SCLI-1178), the Nursery site (CA-SCLI-1215), the Columbus site (CA-SCLI-1492), and Big Dog Cave (Raab, 1997). Sites at Little Harbor (CA-SCAI-17) on Santa Catalina, and Bird Blind (CA-SNI-161), Thousands Springs (CA-SNI-11), and Celery Creek (SNI-351) on San Nicolas Island also have well-defined Middle Holocene components (Meighan, 1959; Vellanoweth, 1995; Raab, 1997; Rick et al., 2005; Vellanoweth and Erlandson, 1999). The reported size and depth of Middle Holocene middens on the southern Channel Islands suggests a greater degree of residential stability compared with sites of equivalent age on the northern Channel Islands. Saucer-shaped house depressions with prepared floors at the Nursery site on San Clemente Island suggest more sedentary behavior. Four house pits dated to the Middle Holocene (~5.5–4 ka) have been excavated and provide clear evidence for substantial structures with frames made of whale bone (Salls et al., 1993; Raab, 1997). Substantial deposits at Celery Creek (CA-SNI-351) on San Nicolas Island, positioned near a freshwater source, suggest that this site also served as a central place from which a range of activities were carried out (Rick et al., 2005).

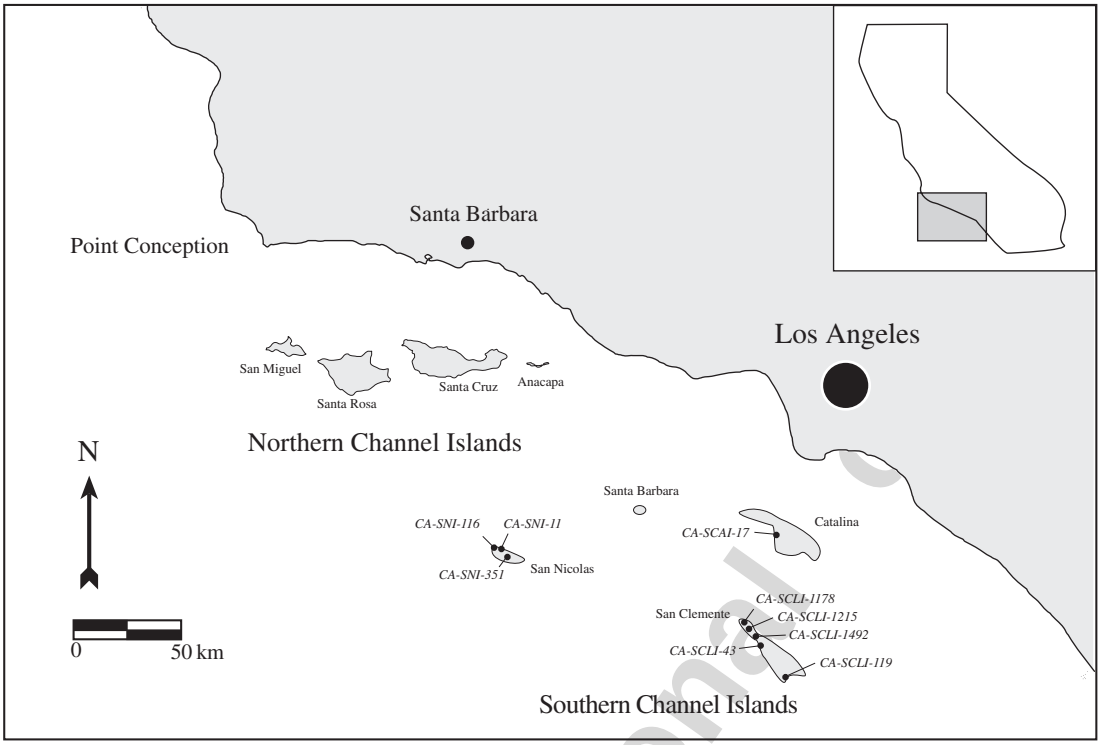

Fig. 5. Southern California and adjacent Channel Islands showing the position of known Middle Holocene sites on the southern Channel Islands.

The most comprehensive data related to subsistence change on the southern Channel Islands is from the Eel Point site (CA-SCLI-43) (Porcasi, 1995; Porcasi et al., 2000; Raab, 1992; Raab and Yatsko, 1990; Raab et al., 1995a, c). Early Holocene faunal assemblages at Eel Point indicate that the diet of the early inhabitants consisted primarily of shellfish and sea mammals, a pattern evident throughout the Holocene. However, fish became a more important component of the diet during the Middle Holocene. Fish bone became abundant in deposits younger than ~5.6 ka and there is clear evidence for intensified fishing by about 3.5 ka (Porcasi, 1995; Raab et al., 1995b, c), including some large pelagic species (*Mola mola*; Porcasi and Andrews, 2001). The Little Harbor site on Santa Catalina Island (Meighan, 1959; Raab et al., 1995a) and the Bird Blind site on San Nicolas Island (Vellanoweth, 1995; Vellanoweth and Erlandson, 1999) also provide evidence for expansion of fishing during the Middle Holocene. Intensified exploitation of fish continued into the Late Holocene, tracking the increasing importance of the circular shell fishhook, that first appeared on the southern Channel Islands about 3.5 ka (Raab et al., 1995b).

Early sedentism and intensified fishing on the southern Channel Islands parallel increased exchange and interaction with the adjacent mainland and the participation in a down-the-line exchange system that extended through the western Great Basin as far north as central Oregon (Vellanoweth, 1995; Jenkins and Erlandson, 1997; Raab, 1997; Raab and Howard, 2000). Between about 5.5 and 4.5 ka, evidence exists for developing cultural interaction extending from the southern Channel Islands to Los Angeles and Orange counties and the Great Basin. The best indicator of increased interaction between these spatially disparate areas is the distribution of *Olivella* (shell) grooved rectangle (OGR) beads produced on the southern islands or the adjacent mainland coast (Fig. 6). Howard and Raab (1993; also see Raab, 1997) were the first to point out the presence of this rare bead form on the islands. Vellanoweth (1995) documented the presence of OGR beads on San Nicolas Island (CA-SNI-161), along with *Olivella* bead manufacturing debris. Outside of southern California, Jenkins and Erlandson (1997) documented OGR beads in the northwestern Great Basin (central Oregon). Beads of this kind have also been found at other sites in the western Great Basin (Bennyhoff and Hughes, 1987; Raab and Howard, 2000; Vellanoweth, 1995, 2001).

Most of these beads were undoubtedly produced on the southern California Coast or offshore islands where purple olive shells (*Olivella biplicata*) are common. OGR beads have not been found on the northern Channel Islands and only a few have been documented in historic Chumash territory (Honda Beach, CA-SBA-530; Lebow et al. 2002; Rincon Point, CA-SBA-119, Bennyhoff and Hughes, 1987; Xonxon'ata, CA-SBA-3404, Hildebrandt, 2004, p. 64). Stable oxygen and carbon isotope analysis of another *Olivella* shell bead type (A1; spire-removed) from Middle Holocene (6.5–4 ka) archaeological assemblages in central Oregon also suggest manufacture somewhere on the southern California Coast (Bottman, 2006). The isotopic

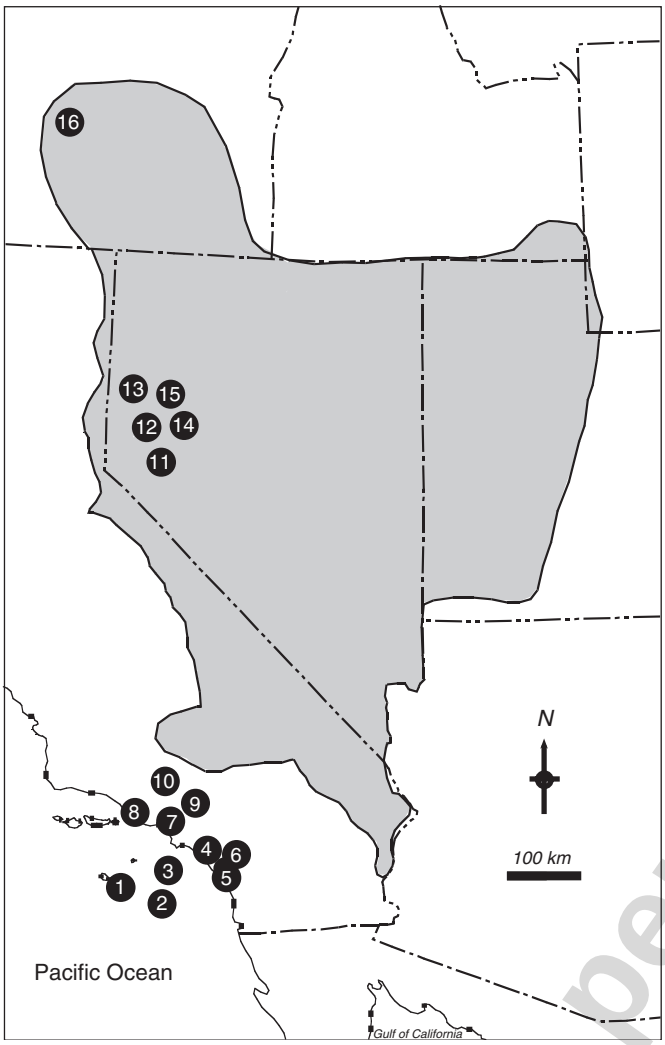

Fig. 6. Map of western North America showing the boundaries of the Great Basin (gray) and the known distribution of OGR beads that date to between ~5.9 and 4.7 ka. 1 = Celery Site, San Nicolas Island (CA-SNI-351); 2 = Nursery Site, San Clemente Island (CA-SCLI-1215); 3 = Little Harbor, Santa Catalina Island (CA-SCAI-17); 4 = CA-ORA-368; 5 = CA-ORA-667; 6 = CA-ORA-665; 7 = Encino Village (CA-LAN-43); 8 = CA-SBA-119; 9 = Vasquez Rocks (CA-LAN-361); 10 = Stillwater marsh; 11 = Hidden Cave (Ch16); 12 = Silverwater Marsh; 13 = Lovelock Cave (Ch18); 14 = Shinners Site F; 15 = Kramer Cave; 16 = DJ Ranch (35LK2758) (Data points from Bennyhoff and Hughes, 1987; Howard and Raab, 1993; Jenkins and Erlandson, 1997; King, 1990; Raab and Howard, 2000; Vellanoweth, 1995, 2001).

ratios of some of these beads indicate warm SSTs outside the range of the comparative dataset from the Santa Barbara Channel region and were likely manufactured on the southern Channel Islands, another indicator of the importance of down-the-line exchange connecting southern islanders with people living in the western Great Basin at this time. A recent study of ancient mtDNA of San Clemente Island skeletons dating to the Middle Holocene (Eel Point; CA-SCLI-43; Potter, 2004) indicates that they had the closest genetic affinities with extant California Uto-Aztecan people rather than Chumash or Northern Uto-Aztecan groups. However, the low frequency of one haplogroup (Group A) testifies to some admixture with the Chumash. These data suggest that the ancestors of the Tongva likely moved to the southern Channel Islands during the Middle Holocene (Potter, 2004). If this pattern is upheld, such a migration from the interior of California may have fostered the movement of *Olivella* beads from the southern Channel Islands via down-the-line exchange networks extending into the western Great Basin.

5. Discussion

Marine climate data from Santa Barbara Basin indicates that SSTs oscillated during the Middle Holocene between warm and cold states. In general, SSTs were relatively warm during the Middle Holocene, supporting interpretations of Friddell et al. (2003), except for one distinct cold interval between 6.3 and 5.8 ka. More moderate SSTs are evident in this record from 5.8 to 5 ka. Inferred high marine productivity between 6.3 and 5.8 ka corresponds with the coldest SSTs during the Middle Holocene. Climatically influenced changes in terrestrial environments along the coast during the Middle Holocene appear to have been less drastic than in the interior, particularly in central and northern California (Jones and Waugh, 1997). Dry climatic conditions persisted throughout much of the Middle Holocene in eastern California and the Great Basin (Benson et al., 2002) with the driest interval occurring between 6.3 and 5 ka (LaMarche 1973, 1974; Lindström, 1990).

The small number of primary and secondary villages on the northern Channel Islands suggests low population densities during the Middle Holocene. Faunal assemblages and settlement locations indicate that plant foods from the interior of the islands complemented the protein-rich marine foods, particularly shellfish. People appear to have aggregated in large coastal villages and seasonally splintered into smaller groups (Kennett, 1998). These economic strategies were relatively stable and persistent through the Middle Holocene, even when severe dry conditions between 6.3 and 5 ka likely limited terrestrial productivity and water availability. Cold and biologically productive marine conditions, partly synchronous with these dry conditions (6.3 and 5.8 ka), favored an emphasis on marine resources, particularly certain cooler-water forms such as red abalone. However, the persistence of red abalone in middens throughout the Middle Holocene suggests their availability was modulated by other environmental parameters (e.g., frequency of El Niños) or that they were being harvested from the lower intertidal or upper subtidal zones. Overall, we suggest that shortfalls in terrestrial resource availability and drinking water minimally impacted northern Channel Islanders because of their low populations relative to resource availability.

On the more arid southern Channel Islands, dry conditions between 6.3 and 5.2 ka coupled with cold/productive marine conditions (6.3–5.8 ka) appear to have had a greater impact on cultural development compared

with the northern islands. Currently available data suggest that people were more sedentary during the Middle Holocene. The evidence for substantial houses at the Nursery site on San Clemente Island is most convincing in this regard (Salls et al., 1993). In general, sustained and intensive use of fisheries also appears to have developed on the southern Channel Islands earlier than on the northern Channel Islands (Kennett and Kennett, 2000). The small size and limited nature of intertidal and terrestrial resources, particularly on the smaller islands of San Clemente and San Nicolas, could account for some of these developments. However, drought conditions between 6.3 and 5 ka would have exacerbated these inherent problems in resource availability. On some of the smaller and more isolated southern islands, populations may have reached the carrying capacity of local environments more rapidly, a context favoring economic intensification and technological innovation (i.e., the circular fishhook).

The distribution of OGR and spire-removed (Type A) beads from the southern Channel Islands across southern California and into the western Great Basin suggests increased interaction among these peoples between 5.9 and 4.7 ka. This exchange may have reduced the risk of resource shortfalls associated with dry environmental conditions during the Middle Holocene (see Larson et al., 1994; Kennett and Kennett, 2000 for Late Holocene examples of this phenomenon). The distribution of these beads seems to reflect the establishment of a new trade conduit, perhaps related to the inferred migrations of people from southern California desert environs to the southern Channel Islands (Grenda and Altschul, 1995; Potter, 2004; also see Warren, 1968; Mikkelsen et al., 2000 for more generalized idea of Middle Holocene movement from the interior to the coast). Persistently dry conditions in western North America between 6.3 and 5 ka would have expanded desert environments of southern California, displacing some groups to more humid and productive coastal regions. Increased interaction and migrations to the southern Channel Islands had a profound effect on the human evolutionary trajectories in this region and are fundamental in explaining the differences observed at historic contact between peoples of the northern and southern Channel Islands.

6. Conclusions

High-resolution archaeological and paleoenvironmental records from California's Channel Islands provide the opportunity to explore linkages between climate and culture change. Current evidence suggests persistently dry conditions in western North America during the Middle Holocene with the most severe aridity occurring between 6.4 and 4.8 ka. This was coupled with cold, productive marine conditions between 6.2 and 5.8 ka. On the northern Channel Islands these dry conditions had relatively little direct impact on cultural developments. Archaeological data suggest that population densities were low during much of the Middle Holocene. People periodically moved between the coast and the interior of the larger islands, supplementing a diet rich in shellfish with seasonally available plant foods. These settlement-subsistence strategies were relatively stable through the Middle Holocene. Residential mobility appears to have been the primary strategy for reducing the risk of resource shortfalls caused by inferred persistent drought between 6.4 and 4.8 ka.

Inferred climatically influenced cultural changes are more evident on the southern Channel Islands between 6.3 and 5 ka. A small number of large, Middle Holocene sites, one with substantial domestic features, suggest that residential mobility was more limited than on the northern Channel Islands. More intensive fishing strategies also developed on the southern Channel Islands after ~5.6 ka and could be related to population pressure and declining subsistence yields. The distribution of *Olivella* shell beads (OGR and Type A) from the southern Channel Islands into the western Great Basin suggests increased interaction between spatially disparate peoples between 5.9 and 4.7 ka. It is possible that migrations of people from the interior of California to these southern islands partially account for newly established down-the-line exchange networks that extended up the western fringe of the Great Basin. Such migrations may have been stimulated by persistent drought in the interior of California between about 6.4 and 4.8 ka.

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