SYNTHESIZING PALEO-ENVIRONMENTAL PROXIES FOR THE CENTRAL BAJA CALIFORNIA AREA IN THE LATE HOLOCENE

DEBORAH V. ROMAN AND ISABEL CORDOVA
CALIFORNIA STATE UNIVERSITY AT NORTHRIDGE

A profusion of proxies exist for the Santa Barbara Basin (SBB) in the Holocene period which infer previous environmental conditions. This paper summarizes a new synthesis of proxies for the central Baja California Pacific coast region for the Late Holocene and evaluates their validity in the ongoing debates regarding the environmental perturbations which may have occurred in the southwestern North American region during the Medieval Climatic Anomaly (MCA). Consideration will be given to the different proxies from Alta (Channel Islands and SBB) versus Baja California; integrated into this discussion will be a comparison of the marine and terrestrial environmental contexts of both locations. New proxies currently in development will be discussed.

The Pacific coastal region of central Baja California was investigated for paleo-environmental proxies in conjunction with a faunal analysis which was conducted for the Late Holocene port site of Campo Quintero (PAIC 36) on Cedros Island, Mexico. The faunal analysis, which is described in more detail in this issue by Roman and Des Lauriers, yielded anomalous results of predominating species for the time period on the Pacific coast, namely an abundance of chiton, including *Stenoplax conspicua* and *S. magdalenensis* (Cordova et al. n.d.; Des Lauriers 2005; Roman 2010). Many of the shell species which were typically procured from island Pacific coastal sites in the Late Holocene in the southern California bight were in very short supply or absent from the remains at PAIC 36, including *Mytilus californianus* and certain *Haliotis* species (Braje 2007; Braje et al. 2007; Erlandson and Jones 2002; Glassow 1992, 1993; Glassow and Wilcoxon 1988; Raab and Yatsko 1992; Rick 2008).

Further, there were limited terrestrial faunal remains, suggesting that increased reliance was placed upon the near-shore rocky intertidal zone as well as on pelagic sources during this time. As with most Pacific coastal Late Holocene sites, an expansion of procurement of pelagic species was noted at Campo Quintero.

As this site included dates from the MCA (A.D. 900-1300), one interpretation of this unusual result was the suggestion of local and regional environmental perturbations in central Baja California at this time. In order to assess the degree of relevance to this site for proxies that were previously developed for the SBB, Roman developed a synthesis of proxies which are applicable to the Pacific coastal central Baja California area.

In terms of the shell anomaly, additional hypotheses were developed to explain this occurrence. One suggested that the chiton were used as bait for pelagic fishing, as has been noted in modern Baja California communities (Des Lauriers 2005). However, against this argument, burnt chiton fragments were found within the apron midden surrounding habitation sites.

Another hypothesis involved the important nutritional contributions that chiton would have provided for island residents who were dealing with environmental perturbations during the MCA. These included iron, which is chelated by the chiton from rock surfaces, and the highest kilocalories of any rocky intertidal-zone dweller in this ecotone: 234 kcal (Erlandson 1988; Jones 1985). In one ecological experiment, Irons et al. (1986:1469) found that avian foraging for chiton yielded as much as 2,153.9 kJ/hr., versus urchins which yielded 606.7 kJ/hr.

Thus, an attempt was initiated to synthesize possible evidence for environmental impacts on the rocky intertidal zone during this period in central Baja California.

HISTORY OF PALEO-PROXIES FOR PACIFIC COASTAL BAJA CALIFORNIA

Proxies which were synthesized for comparative purposes drew upon studies performed in the local area of central Baja California, those from areas within 800 km of the Pacific coast location of Cedros Island, relevant proxies for western North America, and, finally, proxies developed for the SBB.

In formulating proxy syntheses for this coastal site, numerous factors that impact marine and terrestrial conditions must be considered. These include sea surface temperatures (SST), a proxy for marine productivity and along-shore wind forcing (Field, Baumgartner, Charles, Ferriera-Bartrina, and Ohman 2006; Takesue et al. 2007); terrestrial temperatures, reflected in local precipitation patterns, palynology, and dendrochronology for the area; local and global wind patterns; upwelling studies and salinity studies as a proxy for marine productivity; geomorphology of the area of the coastal site; coastal kelp bed demography; solar irradiance measurements which impacted wind patterns and heat convection in the marine environment; and climate simulation models.

Not included in this brief synthesis are the recent studies focusing on the preceding period of the Middle Holocene and their climate proxies (e.g., Kennett et al. 2007).

The first research on marine environmental contexts developed for the central Baja California region was published in the 1950s, as a product of research performed by staff members of the American Museum of Natural History. Dawson (1952:427) argued that the upwelling zones that abut the Cedros area, Kellett Channel, and Vizcaíno Bay were intensive, due to the convergence of the Humboldt and California currents. "The prominent occurrence of low temperatures due to upwelling effected by the prevailing northwest winds has been well documented" (Dawson 1952:428). Cedros, located at 28º 5' north latitude and 115º 11' west longitude, is located in the center of this intensive upwelling area.

Emerson, another researcher from the Museum, stated that studies of the Pacific coastal "upwelling areas of the Baja California coast serves to demonstrate the advisability of utilizing thermophilic…species as indices for the interpretation of former climatic conditions of fossil faunal assemblages" (Emerson 1956:397). He paved the way for later studies that examined thermophilic tolerances of various shell species that were located in this area. Table 1 summarizes the studies that are relevant to the Baja California area.

In 1977, two groups of researchers studied the California bight in the Baja California area in a marine research vessel by plotting upwelling intensities and also utilized the water meter readings along the Baja California Pacific Coast, culminating at Punta San Hipolito. Some of the meters were located close to Vizcaíno Bay (Blasco 1977; Walsh et al. 1977). Each group discovered some intriguing differences between the scales of upwelling noted in Baja and Alta California.

First, the intensity of upwelling appeared to be impacted by three factors: diel, seasonal, and event factors (Walsh et al. 1977). Daily factors could include cases of three hours of intensive upwelling, followed by long calm periods. Seasonal factors included such things as the probability of increased upwelling in early spring. Event factors included local storms, larger-scale El Niño-Southern Oscillation (ENSO) events, and occurrences such as red tides and hurricanes (Walsh et al. 1977). The conclusions were that upwelling in Baja California, particularly around the Vizcaíno Bay, was more intensive than in Alta California. Further, they noted that the average SSTs were more variable, from 11.75 to 14. 32ºC.

Blasco (1977) also studied the Pacific coastal/Punta San Hipolito hydrology readings, as well as plotted dynoflagellate volumes along the length of the Baja California peninsula. She focused on aspects of the red tide phenomena, and discovered that the red tide was intimately associated with cooler water temperatures. Further, she noted that the upwelling was associated with a lower salinity factor than

Table 1. Charting central Baja California proxies.

AUTHORS	RAW SOURCES	INFERENCES	VALIDITY FACTORS
Burnett et al. 1988	Chiton hemocyanin	11-25ºC SST	Complicated by trophic factors
Burnett et al. 1988	Abalone hemocyanin	~25-35ºC SST	As above
Walsh et al. 1977	Water meters	Different scales of upwelling than Alta California	Retested?
Blasco 1977	Dynoflagellates	Red tide connected cooler SST; seeding factor Vizcaino Bay?	Accepted red tides/cooler SST region
Emerson 1956	Vizcaíno Bay	Upwelling factors- use shell for proxies	Foundation for later work
Dawson 1952	Upwelling in Vizcaíno Bay	Upwelling intense: convergence of currents	Accepted
Barber and Chavez 1983	Impact El Niño	Reproductive failure	Accepted
Stott 2002	Mg/Ca paleotemperature	Zonal temperature gradients	A.D. 900-1000 west Pacific confirmed
Tegner and Dayton 2000	Kelp demography Pt. Loma	La Niña most productive	Accepted
Diaz et al. 2001	*Pinus lagunae*, Baja California	High precipitation Late Holocene southern Baja California	Less correlation central Baja California
Ortiz et al. 2004	Sediment core, Magdalena Bay	Warm climate/high productivity correlates with cool SST	Confirmed by other studies in Northern Hemisphere southwest
Biondi et al. 2001	Tree rings/precipitation sites	PDO variability	Confirmed by other studies
Minnich et al. 2000	Water gauges	La Niña: drought/SST changes	Appears confirmed
Stahle et al. 1998	Tree rings/SST	Western North America correlates drought/SST	Confirmed many studies
Sankey et al. 2001	*Neotoma* sp. midden	Annual temperatures of 18.4ºC in interior Baja California	See Ortega-Rosas et al. 2008
Zaytsev et al. 2003	Baja California Pacific shelf upwelling	Coolest SST at bottom slope, shelf width, etc.	Not yet confirmed by other studies
Barron and Bukry 2006	Silicoflagellates Gulf of California	High productivity A.D. 1050; solar forcing?	Studies continuing
Takesue et al. 2007	Salinity, nutrients, surface pressure Baja California	Large shifts nearshore measurements; ENSO	Good proxy for past ENSO patterns
Ortega-Rosas et al. 2008	Pollen sequences	More variable during MCA for climate/vegetation	Still ongoing studies in those areas
Herguera et al. 2009	Summer SST/organic C	Cool summer SST/higher organic C MCA	Continuing studies?
Barron et al. 2005	Biogenics, diatoms; Gulf of California	Wind shifts: late Holocene ENSO	Correlates with other studies
Herweijer et al. 2007	Tree rings/global proxies	Medieval droughts forced by La Niña-like tropical Pacific SST	Multiple proxies confirm correlation

Source: Roman 2010; no Santa Barbara Basin proxies are included in this table.

normal, and a 33.8 per thousand isopleth. In particular, she suggested that Vizcaíno Bay contained a type of "seeding mechanism" for the extraordinary upwelling that occurred in the region.

Both of these studies confirm what members of the fishing community of the Kellett Channel have long known: that the extraordinary diversity of species drawn to the area is related to the SST, and the timing results in seasonal patterns in the size of schools or groups of fish that enter the bay. All of this may be influenced by the factors noted above, such as red tides, ENSO, and local climatic events. If the studies are valid, we may extrapolate that during drier climatic periods (such as during the MCA), there was intensive productivity with high levels of upwelling.

In the 1960s, the first legs of the Deep Sea Drilling Project (DSDP) included an area near Cedros: core 470 was evaluated for micro-palenotological remains from the upper Miocene (Bukry 1981). This site was east of Isla Guadalupe and west of Cedros, and was rotary-cored. According to John Barron (personal communication 2010), the Holocene sediments are softer and harder to collect, and no data were reported from this leg. However, this area was recently redrilled, and updated results are anticipated from Leg 167.

Cores from the DSDP and Ocean Drilling Program (ODP) have been analyzed since the 1960s. Their early focus was on geologic "deep time." More updated use of proxy cores has included consideration of the recent Holocene (Fisler and Hendy 2008; Kennett and Kennett 2000). The SBB has been the focus of numerous multi-proxy studies utilizing foraminifera from cores, but less has been done the central Baja California region. However, recent work by Takesue et al. (2007) and Heguera et al. (2009) has addressed this concern more directly.

In fact, certain general proxy markers were developed from the ODP that continue to be used and reviewed for validity. These include silicoflagellate proxies, such as *Octatis pulchra*, for cooler SST and thus higher marine productivity (Barron and Bukry 2006); diatom and silicoflagellate assemblage variations (*Fragilariopsis doliolus* and *Nitzschia interrupteseriata)* from the SBB, to confirm that there were generally cooler SSTs (Barron and Bukry 2006); and oxygen isotope records of near-surface-dwelling *Globigerina bulloides*, a planktonic foraminifer for the SBB (Kennett and Kennett 2000). A further discussion of the updated concerns for relevance and validity of these proxies will be considered below.

Strub et al. (1987) found that the North Pacific High system "influences coastal winds during both winter and summer off southern California (south of 33 degrees N) and Baja California, resulting in year-round equatorward winds with weak seasonality" (Strub et al. 1987:1507; Takesue et al. 2007). This type of wind pattern significantly impacts coastal upwelling, providing enriched waters for all levels of marine trophic systems during these seasons.

In another study, Biondi et al. (2001:58) reconstructed a Pacific Decadal Oscillation (PDO) record for the climate of the Pacific coast region of southern California and northern Baja California from A.D. 1661 to the mid-1800s. This is generally considered an indicator of Pacific climate variability, with PDO reflecting the relative warmth or cooling of SST north of 20º latitude.

Biondi et al. (2001) utilized a combination of networks of precipitation-sensitive sites and tree rings. In this multisource reconstruction, the authors studied temperature and hydrology, and found a broad range of variability over the Pacific coast sites. In particular, they discovered that the PDO variability was associated with ENSO and with climatic "teleconnections." This is usually a term that covers "simultaneous physical variations in climate over distant parts of the globe" (Stenseth et al. 2003:2088). These are phenomena often labeled by archaeologists as environmental perturbations.

In essence, this study suggested that warmer SST in one region does not imply the same pattern in an area a few hundred kilometers away. The focus of interest in this article is the eco-tropical north Pacific, as ENSO anomalies originate in that locale. However, the Pacific North American systems, and specifically the Baja California area, are connected with this anomaly, as positive PDOs (or El Niño-like phases) exhibit warm SSTs in the northeast Pacific, and La Niñas exhibit reversed conditions (MacDonald and Case 2005). This is ultimately driven by the North American Oscillation current (Fagan 2008; Mantua 2009). This study confirmed the trend of past climatic variations noted particularly in 12-28+ year phases on the Pacific coast region. The chances that ENSO operated cyclically during the occupation of PAIC 36 would have been good, with the PDO bringing sea surface temperature changes and salinity changes on this phased type of cycle (Zaytsev et al. 2003).

MacDonald and Case (2005) examined the dipole pattern of PDO and its impact on MCA climate conditions. They utilized *Pinus flexilis* tree ring data from southern California and Alberta, Canada (at the dipoles). They found that

> ...the reconstruction provides evidence for the persistence of a strongly negative PDO state, suggesting a cool northeastern Pacific, during the medieval period (~AD 900 to 1300). This…corresponds to a period of severe and prolonged dry conditions evident throughout western and central North America. There is also additional evidence for cooler northeastern Pacific SST's, higher rates of upwelling and increased marine productivity along coast during this general time period [MacDonald and Case 2005:3].

Recently, more investigation on the California Current and its relationship to factors such as SST, salinity, and impacts on marine trophic systems were investigated by Takesue et al. (2007) in California, Baja California and Chile; by Herguera et al. (2009) at 25º north; and by Field, Cayan, and Chavez (2006), Field (2004), and Barron et al (2008), focusing first on the SBB and then extrapolating to other locales in the California Current. Takesue et al. (2007:1) maintain that their data indicate that "such large shifts in nearshore water properties suggest it may be possible to reconstruct past ENSO patterns from geochemical paleo-nutrient/paleo-salinity proxy records in nearshore archives such as mollusk or foraminifera shells." They found that three currents which impact the marine productivity of the Pacific coastal Baja California area: the California Current (surface flowing); the California Undercurrent, transporting saline "nutrient rich, oxygen deficient" water (Takesue et al. 2007:6); and the Davidson Current, with a fall/winter surface flow (Takesue et al. 2007:5). In fact, the entire North American coast has, according to these authors, spring and summer cadmium-enriched (nutrient-enriched, with cooler temperatures and more saline) waters in a band about 50 km wide.

Herguera et al. (2009:abstract), in their reconstruction of summer SST and organic carbon content in the current, suggested that "the variability of both processes during the spring to summer season are inversely linked with centennial to multi-decadal changes in Northern Hemisphere continental temperatures." Their records suggested cool summer SSTs and increased organic carbon in the sediments abutting the shore area during the MCA.

Zaytsev et al. (2003) reported that the correlation between winds from the northwest to north impacted the strength of upwelling on the Pacific shelf of the Baja California peninsula. The greatest intensity was recorded from April to June; with remote sensing imagery analysis this revealed that coldest "SST anomalies were closely related to the bottom slope, shelf width, and coastline orientation relating to wind direction" (Zaytsev et al. 2003:abstract). As PAIC 36 lies on the southeast coast of Cedros near the Kellett Channel, it is subject to these longshore winds from northwest to north (Dawson 1952; Zaytsev et al. 2003).

Barron and Bukry (2006) investigated the warmer Gulf of California on the eastern side of Baja California and found correlations with cooler SSTs in diatom and silicoflagellate records (*Octactis pulchra* abundance) in the Late Holocene:

> Regularly spaced cycles (~100 year duration) of *Octatis pulchra*, a silicoflagellate proxy for lower SST and high productivity, and *Azpeltia nodulifera*, a tropical diatom, occur between ~ AD 400 and ~1700 in the more nearshore Carmen Basin zone, NH01-21 (26.3

> degrees North), suggesting a possible solar influence on coastal upwelling [Barron and Bukry 2006:abstract].

Their findings suggest that the MCA had periods of reduced productivity, meaning warmer SST, and "an intervening high productivity (cool) interval centered at ~ AD 1050" (Barron and Bukry 2006:abstract). As this date closely coincides with radiocarbon dates obtained from well-defined stratified samples, and this area is less than 240 km from the western Pacific Baja California coast, local inferences may apply (John A. Barron, 2010 personal communication).

Minnich et al. (2000) studied precipitation fluctuations from 30 water gauge stations on both coasts of Baja California. They found that with the El Niño cycle, as expected, there was consistent rain, but that subsequent La Niña brought drought and SST changes.

This pattern is corroborated by the studies of Ortiz et al. (2004), which reported that over the last 52,000 years there was a well-verified correlation between drought and lower SST in this region. Their study was centered on cores from Magdalena Bay, about 500 km south of the Cedros area. This finding may have a regional relevance to the results of the PAIC 36 faunal analysis.

However, utilizing multiple pollen Plant Functional Types (PFTs) from sources in northern Baja California and northwest Mexico, Ortega-Rosas et al. (2008) suggested that these data involve a more nuanced interpretation. They stated that late Holocene terrestrial temperatures show three periods of rapid change, not always involving warmer, drier conditions. During the period "between 1500 and 900 cal yr BP [terrestrial temperatures] increased again…the last warming correlates in time with the so-called 'Medieval Warm Period'" (Ortega-Rosas et al. 2008:261). Different regions demonstrate differing interpretations, however, and they hypothesize that "the large variations of temperature and precipitation during the last 3000 yr. can also be a response to the ENSO phenomenon" (Ortega-Rosas et al. 2008:261).

Conversely, some researchers (Cobb et al. 2003) have reported that this period between A.D. 800 and 1250 was one of weak El Niño systems. However, Ortega-Rosas et al. (2008:261) still suggest that ENSO may have been a main forcing agent affecting climate variability during this time.

Barber and Chavez (1983:1208) provided provocative evidence that there was a distinct connection between El Niño sequences, SST, local intensity of upwelling, and broad-scale biological changes to trophic levels affected by this pattern. They studied the sequelae of the 1982-83 El Niño to confirm anecdotal evidence that there were multiple biological consequences of the influx of warm water on the coasts and in the equatorial ocean off Peru (where the system originates). As Baja California experiences numerous effects of ENSOs, this report reflected the important impact of these systems on the Pacific west coast (Takesue et al. 2007).

Evidence was abundant for destruction of trophic levels:

> For most species of the higher trophic levels, we believe that the major effect of the 1982-1983 El Niño was an absolute decrease in growth and reproductive success caused by disruption of the normal food web. The specific change was a *five-to-twenty fold reduction of primary productivity* [emphasis added] [Barber et al. 1983:1208].

If indeed ENSO cycles or other local perturbations were operating during the Late Holocene at Cedros Island, this would suggest an explanation for changes in food preferences or availability leading to anomalous results in the faunal analysis.

Stahle et al. (1998) established a close correlation between drought-sensitive tree ring data and SST over western North America, utilizing tree ring data local to the Baja California area. This should further bolster claims regarding the relationship between cooler SST and terrestrial temperature regimes (see also Takesue et al. 2007; Zaytsev et al. 2003).

In terms of specific SST, a source related to shell-tolerances of water temperatures provides us with a range of possible proxy marine paleo-temperatures for the area during certain Late Holocene stages. Burnett et al. (1988:154) studied the hemocyanin components of such shells as *Stenoplax conspicua* and *Haliotis corrugata*, which are species found in our analysis. Their results indicate direct correlation of water temperature tolerances with these species based upon hemocyanin properties. For the chiton, the inferred temperature tolerated was between 11 and 25ºC. If the La Niña phase (or negative PDO) was operative, as indicated by many of these studies, chiton would have tolerated cooler SSTs well.

For the abalone species, which were more abundant in certain levels, the inferred temperatures were from about 25º to 35ºC, inferring warmer SST (Burnett et al. 1988:155). These proxies provide us with potential answers to questions about why certain species were depleted in various levels from the PAIC 36 midden analysis. If the extrapolations are correct, then we can assert with some confidence that the local SST at the time of procurement for the chiton species was between 11º and 25ºC. Dr. Douglas Eernissee (personal communications 2007, 2008, 2009, 2010), a renowned expert on chiton morphology and ecology, has indicated that this is an acceptable proxy for the Late Holocene time period.

However, Raab and Larson (1997), in a lengthy treatment of the proxies utilized for thermophilic species, suggest that one must consider these extrapolations with caution due to the "noise" generated by multiple interdependent factors on species' acclimation to a given area of the sub-tidal zone. These concerns were also voiced by Eernissee regarding extrapolations on chiton species. A particular shell species may have annual variations in density in a given ecological context based upon factors which impact spawning capacities, as well as inter-annual variations based upon salinity, SST, red tides, etc. Earlier studies of shell temperature tolerance often reflected controlled lab testing conditions, rather than the more recent on-site studies at the coast that collect samples from sub-tidal environments and thus measure more realistic thermal constraints shown by these species (Roberts et al. 1997; Tomanek 2002).

Finally, in an effort to track activity in the movements of pelagic fish in central Baja California, Robinson et al. (2006:abstract) noted that anchovy abundance was greatest nocturnally in "deep offshore oceanic and intermediate slope zones" off the coast. The movements of these pelagic schools were positively correlated with diel changes: the schools moved offshore during the daytime and clustered in much deeper depths. These kinds of diel changes appear to correlate directly with the changes noted by Walsh et al. (1977) in terms of salinity and SST factors that operate in this area.

Tegner and Dayton (2000) studied near-shore kelp demography from Point Loma, about 500 km north of the Cedros area. They reported that 1) drier periods terrestrially were associated with increased marine upwelling, and 2) cold water cycling (SST and upwelling) has a major impact on kelp maintenance and health. Thus, as we associate kelp bed maintenance with productivity of near-shore species, this evidence supports the pattern of combined high productivity, high upwelling, and low SST (Barron et al. 2008; Takesue et al. 2007).

Further evaluation of precipitation patterns has been supplied by Diaz et al. (2001) with their assessment of *Pinus lagunae* tree ring data from the Baja California area. These data record higher rain levels in the south of Baja California during the Late Holocene period, and show less correlation with northern areas of Baja California. As the location of Cedros is opposite the central region, more clarification is needed for extrapolation from this data set.

In terms of central Baja California terrestrial habitats and climate, Sankey et al. (2001) have investigated a *Neotoma* sp. (woodrat) midden and found palynological remains that suggest an average annual temperature at Catavina of 18.4ºC for the Late Holocene. They suggest that the floral regimes of that time resembled those of contemporary Baja California, but that the location and extent of certain plant patches had often migrated. Often the contemporary patches were also not as large as during the Late Holocene.

Ortega-Rosas et al. (2008:245) studied PFTs to establish correlations with paleo-environments of the Holocene under the influence of the North American monsoon, which included northwest Mexico and a few sample sites on Baja California. The Late Holocene record revealed that an increase in temperatures is recorded at the end of this period (last 1000 yr) (Ortega-Rosas et al. 2008:258). As with many patch studies, the results from higher altitudes generally reveal more tolerance to drought conditions than in the lower biome regions (Ortega-Rosas et al. 2008; Millar et al. 2006).

Examining Late Holocene forest dynamics from the southwestern North American perspective (the San Joaquin Ridge in the United States), Millar and colleagues (2006) also found that during the MCA, climate was warmer and drier, but their study highlighted the effects of volcanism from this region. Evidence of volcanic eruptions during this time period suggests that not only decreased precipitation and changing wind patterns impacted the Southwestern area (Millar et al. 2006:273). In fact the Glass Creek vent from Inyo Craters appears to have erupted; deadwood adjacent to these areas was dated to A.D. 815-1350. The issues surrounding evidence for volcanic impacts on climate have been well documented in the past 30 years. However, the extent of the region covered by ash has yet to be fully characterized.

Two general reviews of the validity of current environmental proxies assist us to assess these criteria in perspective. Stenseth et al. (2003) provided a list of caveats that specifically concern the relationship between local environmental variables and global phenomena. First, they caution that there is great spatial variation in response to climate patterns (Stenseth et al. 2003:2092). Thus, the proxies invoked for both Alta and Baja California may still require broad ranges of estimates, as it is well known in climatology circles that there are periods of “lack of correspondence” between tree-ring data, for instance, and a warming trend (Stenseth et al. 2003:2093). Second, according to Stenseth and colleagues, seasonality is difficult to read in the evidence, just as the concept of non-stationarity renders the analysis more difficult. Non-stationarity refers to the awareness that climate indices and local weather may vary over time and so also would the ecological responses.

Ecological studies also demonstrate that nonlinearity applies to many studies that attempt to correlate a specific species’ response to local weather: “Changes in climate may indeed mean that for a given variable under study, there may be a ‘lack of correlation’ between the climate index chosen and the species’ spawning habits” (Stenseth et al. 2003:2093; Eernissee, personal communication 2006).

The fact that so many variables should be considered still confounds ecologists today, many years after Robert M. Netting wrote “A Trial Model of Cultural Ecology” (1965). He advised caution regarding interpretations of the impact of what he labeled the “effective environment” on human subsistence activities; he noted that many variables impact foraging choices such as “soils, rainfall, temperature, flora and fauna” (Netting 1965:82)

In another global survey, Jones et al. (2009) also reviewed multiple proxy sources for the Holocene. Their team created a series of recommendations to implement the highest resolution of proxy validity: “multi-proxy reconstructions are critical to a variety of climatic science studies. They provide a large-scale context with which to compare regional climate variability as reconstructed by single proxy records” (Jones et al. 2009:4). In their review of marine sedimentary archives, they stressed that “a critical assessment of these spatially based transfer functions indicates that some early claims of this accuracy of this approach were overstated. The optimal reproducibility of transfer function estimates appears to be at best ±1 degree C” (Jones et al. 2009:5). They note that the best progress has been made in constructing SST based upon composition of shells of planktonic species. Still, their contention is that there is an uncertainty “on the order of ±0.5-1 degree C” for this method (Jones et al. 2009:5).

Herweijer et al. (2007) evaluated multiple proxies for the global impact of the MCA and stated that “a survey of existing paleoclimatic reconstructions for the MCA largely supports our proposition that the North American medieval megadroughts are part of a global hydroclimatic regime linked to persistent La Niña-like conditions in the tropical Pacific” (Herweijer et al. 2007:1369). They utilized a gridded network of tree rings from the North American continent plus a consideration of other studies from around the world to reach their conclusions. They also stated that medieval tropical Pacific SST patterns correlate with “greater solar irradiance and reduced volcanism than in previous centuries” (Herweijer et al. 2007:1370).

In a general overview of cultural responses to Late Holocene climate changes in the Americas, de Menocal (2001:667) asserts that numerous examples exist to testify to “population dislocations, urban abandonment, and state collapse” particularly during the period of the MCA. He states that there is ample evidence of “megadroughts” during this period (de Menocal 2001:671). He reports that “variations in solar irradiance and volcanism” contributed to the magnitude of the drought (de Menocal 2001:658). Further he notes that during the years A.D. 1572-1593, the persistence of drought was greater, equaling at least 22 years in duration. As this was shortly after Ulloa’s expedition encountered the inhabitants of Cedros Island and during the radiocarbon-dated period for the site, this type of long-term environmental perturbation surely impacted these island dwellers.

To reassess the state of numerous environmental proxies, Mann et al. (1999, 2003, 2005) reviewed data on the northern hemisphere with multiple proxy sources. They submitted that the results are often less conclusive for the western Pacific area in the period before A.D. 1400.

Barron (personal communication 2010) recently stated that “the character of North Pacific SSTs during the Medieval Warm Period is open to considerable debate…The Santa Barbara Basin is the only nearby area where the MWP has been studied in detail.”

Validity of proxies is, of course, directly related to the types of raw materials utilized for generation of the extrapolations and the ability to apply such inferences locally (Mann et al. 2000). In the case of central Baja California, Table 1 suggests specific proxies which are more valid, due to extrapolation for the MCA period of the Late Holocene.

COMPARISONS TO SBB PROXIES FROM THE LATE HOLOCENE

Cores from the ODP program were more recently utilized by Kennett and Kennett (2000) for the SBB, and by Field et al. (2006) and Fisler and Hendy (2008) for ODP 893 in that basin, with updated results. These results may only be cautiously extrapolated for the more southerly central Baja California area to date. Problems with the extrapolations of each of these markers have emerged from continued studies on many cores. Fisler and Hendy (2008) reported extrapolations of warmer SSTs during the late Holocene than were originally cited by Kennett and Kennett (2000) from ODP 893. Fisler and Hendy (2008:4) state:

> We argue that the isotopic record is complicated by regional changes in salinity and water mass. Specifically the low frequency variability in the isotopic record, i.e., the interpreted “warming trend” from 1200 to 1700 years AD exhibited in both the [*Neogloboquadrina*] *pachyderma* and [*Globigerina*] *bulloides* Delta Oxygen 18 records is not reflected in the faunal record. We suggest differences between the faunal and geochemical records indicate a more complicated interpretation of surface water conditions than previously presented.

Thus, they attribute factors such as the North Pacific High and Aleutian Low wind patterns to increased PDO in southern California; they also cite droughts associated with cool PDO events (Fisler and Hendy 2008:4). These results utilized varve chronology, as there was variability noted in the C14 reservoir age in SBB (Fisler and Hendy 2008).

Due to the expanded types of silicoflagellate proxies examined, this report contained some differing results from the high-resolution proxy published by Kennett and Kennett in 2000. *G. bulloides* is a predominant species in late Holocene abundance according to Fisler and colleagues; they consider this to be accompanied by high-nutrient, low-chlorophyll water mass. They do agree with the conclusions reached by Kennett et al. (2007) for the drought conditions for the mid-Holocene: they report that these were independent of SSTs and driven by large-scale orbital forcing (Fisler and Hendy 2008:2). Thus, the interpretations of SBB foraminiferal paleo-proxies are ongoing and represent consideration of many interacting factors (Field, Baumgartner, Ferriera-Bartrina, and Ohman 2006).

Both Field and Baumgartner (2000) and Fisler and Hendy (2008) found that after 1,500 and 800 years ago, more intervals of *N. pachyderma,* abundance were recovered, which is extrapolated for cooler SST as *N. pachyderma* tolerates 13-17ºC. The researchers correlate late Holocene cool events with higher-latitude cooling that was reported by Reyes and Clague (2004) for the Cascades and the Sierras. This seems to suggest a generally similar cooling of SST during non-ENSO years. El Niño extrapolations also have been made with presence of warm tropical species such as *Globigerinoides ruber and Globigerina rubescenes*, "indicating that anomalously warm annual events such as El Niño occurred within intervals when SST's were generally cooler than the Holocene average" (Fisler and Hendy 2008:3).

Field, Cayan, and Chavez (2006) studied the impact of warming on the contemporary California Current and the north Pacific via investigation of multiple California Cooperative Oceanic Fisheries Investigations stations' SSTs, including in the SBB. They assert that the PDO along all stations "accounts for 18-48% of the variability in these SST series....Near surface temperature variations throughout the California Current System are similar between regions," including the SBB (Field, Cayan, and Chavez 2006:92). They also qualify their extrapolations from foraminifera: "just as different planktonic foraminifera vary in response to interannual and decadal variations that depend on the life history and unique relationship with particular environmental variables, so do other zooplankton and marine taxa" (Field, Cayan, and Chavez 2006:106).

Finally, in an overarching study which examined global as well as local proxies for environmental change during the MCA, Graham et al. (2006:2) conclude that "the dry MCA in the western US resulted (at least in part) from tropically forced changes in winter [northern hemisphere] circulation patterns like those associated with modern La Niña episodes." They concluded that the core of this phenomena occurred between ca. A.D. 800 and 1200; they also cited "severe centennial-scale drought" (Graham et al. 2006:2). This correlation between cool coastal waters and drought in the western United States was confirmed via proxies such as coral fossil records, marine sediment cores, fire-related proxies, and others. This, along with the work of Herweijer et al. (2007), is perhaps the most comprehensive attempt to examine evidence for global "fingerprints" of the MCA (Graham et al. 2006:14).

A compelling argument is made for the validity of these multi-proxy sources with raw materials drawn from areas around the globe. However, the authors also note that there are some inconsistencies in records from such areas as Quelccaya and Pallcacocha, as these "appear inconsistent or ambivalent with the idea of a cool MCA tropical Pacific" (Graham et al. 2006:14). However, this evidence only serves to demonstrate the complexity of the phenomena that operated – and still operate – in the teleconnections of the northern hemisphere climate and the Pacific fronts from Bering to Baja California and beyond (Etnoyer et al. 2003).

ENDURING RELEVANCE OF PALEO-PROXIES

In addition to the importance of comparative data sets for faunal analyses versus other environmental proxies, inferences that can be made along similar temporal scales, in this case the Late Holocene, provide us with much needed context for our evaluations of subsistence strategies in this crucial period of emerging social complexity of groups along the Pacific coast (Altschul and Grenda 2002; Des Lauriers 2006; Erlandson and Jones 2002; Gamble 2005; Glassow and Wilcoxon 1988; Kennett 2005; Rick 2007).

This abbreviation of a synthesis performed in partial completion of Master's thesis has attempted to generally suggest sources of and studies on relevant proxies in the central Baja California area, in the vicinity of the site of Campo Quintero on Cedros Island. The continued interest in this area will provide new data sets and proxies as more studies reach culmination through research funded by the Centro de Investigación Científica y de Educación Superior de Ensenada (CICESE) and others.

One measure of the relative importance of the Vizcaíno Bay/Cedros area is the designation of the Vizcaíno Desert as well as the bays adjacent to it as a UNESCO heritage site (Etnoyer et al. 2003). In a study commissioned by the Baja California to Bering Sea Marine Conservation Initiative, this area was designated a "priority conservation area." "The Baja California Frontal system (BCFS) is the largest concentration [of temperature fronts] found within the multi-national federal waters" (Etnoyer et al. 2003: 94-95).

> We define the BCFS not as a persistent front, but as a dynamic region characterized by a persistent high concentration of frontal features generated by the confluence of the cool south-bound California Current and warmer northbound Davidson Current (a.k.a. the California counter-current) [Etnoyer et al. 2003:93].

This commission recommended two spatially discrete areas for this type of conservation: the Channel Islands and the Baja California Frontal System (Etnoyer et al. 2003:95). The recognition of the uniqueness of these exceptional marine upwelling spheres by the committee serves to reinforce our awareness that both areas had numerous similarities in environmental context:

1- abutting intense upwelling zones;
2- part of the PDO bipolar region;
3- island environments in which some areas were xeric abutting the marine zones;
4- impacted according to this evidence by ENSO systems during the MCA;
5- climate influenced by North Pacific High winds as well as the Aleutian Low;
6- located within 30 km of the mainland;
7- similar faunal subsistence strategies reported during Early to Mid Holocene on Cedros versus some of the Channel Islands (Des Lauriers 2005; Erlandson and Glassow 1997; Glassow 1993; Jones and Richmond 1995; Raab and Yatsko 1992; Rick et al. 2005); and
8- evidence of elaboration of a maritime collector society in the Late Holocene period (further detailed by Roman and Des Lauriers in this volume).

Another measure of relevance for these proxies lies in the importance of the relationship between cooler SST, increased upwelling, and marine productivity. Roemmich and McGown (1995:1324) measured more recent zooplankton distribution at stations at Point Conception and in the southern California bight. Their results demonstrate that with modern warming of SSTs, the volume of zooplankton has been reduced. Hence, decreased zooplankton production can translate into decreased marine productivity in the near-shore areas that were tested. Therefore, the ultimate impact of the cycles of warm versus cooler SSTs continues to impact us, the contemporary inhabitants of Pacific coastal California.

SUMMARY

The most parsimonious statement at this time is that the climate of western North America in the Late Holocene, particularly in the last 2,000 years, was highly variable. Extrapolations regarding the MCA are made more complex when systems such as ENSO and the impact of solar irradiance are added to the equation (Barron and Bukry 2006; Field, Cayan, and Chavez 2006; Graham et al. 2006; Takesue et al. 2007).

Evidence presented here suggests that, like the SBB, the Cedros Island area and the channels and Vizcaíno Bay abutting it experienced significant environmental fluctuations during the MCA (ca. A.D. 900-1300). Data sets presented suggest that at least during part of this period, SSTs were significantly cooler than during the Little Ice Age, terrestrial regimes were arid with warm temperatures, and upwelling factors produced intense marine productivity in the near-shore zones adjacent to the port site of Campo Quintero.

Variability still remains a hallmark of these studies, as noted by Graham et al. (2006). It appears that currently our data sets present at least three periods of fluctuations in temperature and SST, as cited above. The range of variability may be one of the many factors that has not been adequately explained; debates focus on whether "decadal-scale variability is likely related to a combination of oceanic integration of white noise weather, tropical forcing and mid-latitude feedbacks" (Field, Cayan, and Chavez 2006:92).

As more studies emerge from the Pacific Baja California region, we will have excellent opportunities to draw inferences about the exciting sites that are being investigated in this "forgotten peninsula" (Laylander and Moore 2006).

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