University of Nevada, Reno

# 3000 years of environmental change at Zaca Lake, California, USA

A thesis submitted in partial fulfillment of the
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By
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## Abstract

Climatic variations of the last few millennia can reveal patterns of variability beyond that recorded by the instrumental record. These variations may have had a profound influence on the culture of the Chumash people who lived in the region. This study uses pollen and sediments to generate a high resolution 3000 year record of vegetation and climate along the southern California coast, and discusses the implications for the study of anthropology in the region. An increase in *Pinus* and *Quercus* pollen found in the top 100 years of the record is a result of known planting and fire suppression. In the pre-historic record, a period of high *Salix* percentages and high pollen concentration from 500 to 250 cal yr BP represents the wettest period of the record and coincides with the Little Ice Age. There is also evidence for 3 warm periods between 1350 and 650 cal yr BP which are identified in the record by the presence of *Pediastrum boryanum* var. *boryanum*. The latter two of these periods, dating from 1070-900 and 700-650 cal yr BP correspond to Medieval Climatic Anomaly droughts identified in other records. This period corresponds with a period of profound change in Chumash culture. In addition to these events, a multi-centennial drought between 2700 and 2000 cal yr BP is identified in Zaca Lake, corroborating evidence from across the Great Basin and extending the regional spread of this drought to southern California. Corresponding wetter conditions in the northwest indicate that the modern ENSO precipitation dipole also occurred during this persistent drought. Today this dipole is associated with La Niña conditions, and a coincidence with evidence for a change in ENSO dynamics from marine records in the tropical Pacific is noted. This dry period is remarkably persistent and has important implications for understanding the possible durations of drought conditions in the past in California. This period also corresponds with key changes in Chumash culture, and adverse environmental conditions may have played an important role in cultural evolution beginning around 2500 cal yr BP. The role played by this extended dry period is examined and a new model of the impacts of climate on Chumash cultural evolution is suggested.

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## 1. Introduction

The potential for persistent century-long droughts in California has been well documented. Submerged stumps in lakes and rivers have been interpreted as evidence for epic droughts between 1000 and 600 cal yr BP (Stine 1994). Additional research has supported the interpretation of a dry (Meko et al., 2001; Cook et al., 2004; Herweijer et al., 2007; MacDonald et al., 2008; Kleppe et al., 2011) or warm (Graumlich, 1993; Scuderi, 1993; Millar et al., 2006) climate during this period, confirming that extended droughts are a part of California's climatic history and raising the concern that should such conditions return in the future, it would have serious economic consequences for the region. Despite the interest in developing a better understanding of the climate history of California, there are still a limited number of high-resolution paleoclimate studies that span the last few millennia, a period sufficiently long to identify droughts of a century or more in time. This is particularly true of Southern California where natural undisturbed sediment deposits are rare.

Paleoclimate studies (Figure 1) take advantage of natural recorders of environmental conditions, such as tree-rings, lake levels, and sedimentary records in lakes. Such records are unevenly distributed across the landscape, meaning that our ability to develop a network of paleoclimatic reconstructions is limited to the availability of suitable natural sites, including permanent natural lakes. In the dry climate of California, natural lakes are rare outside of mountain environments, and the number of paleoclimate reconstructions remains sparse for much of the state, especially in Southern California, where the majority of the population lives. Therefore, it is critical to take

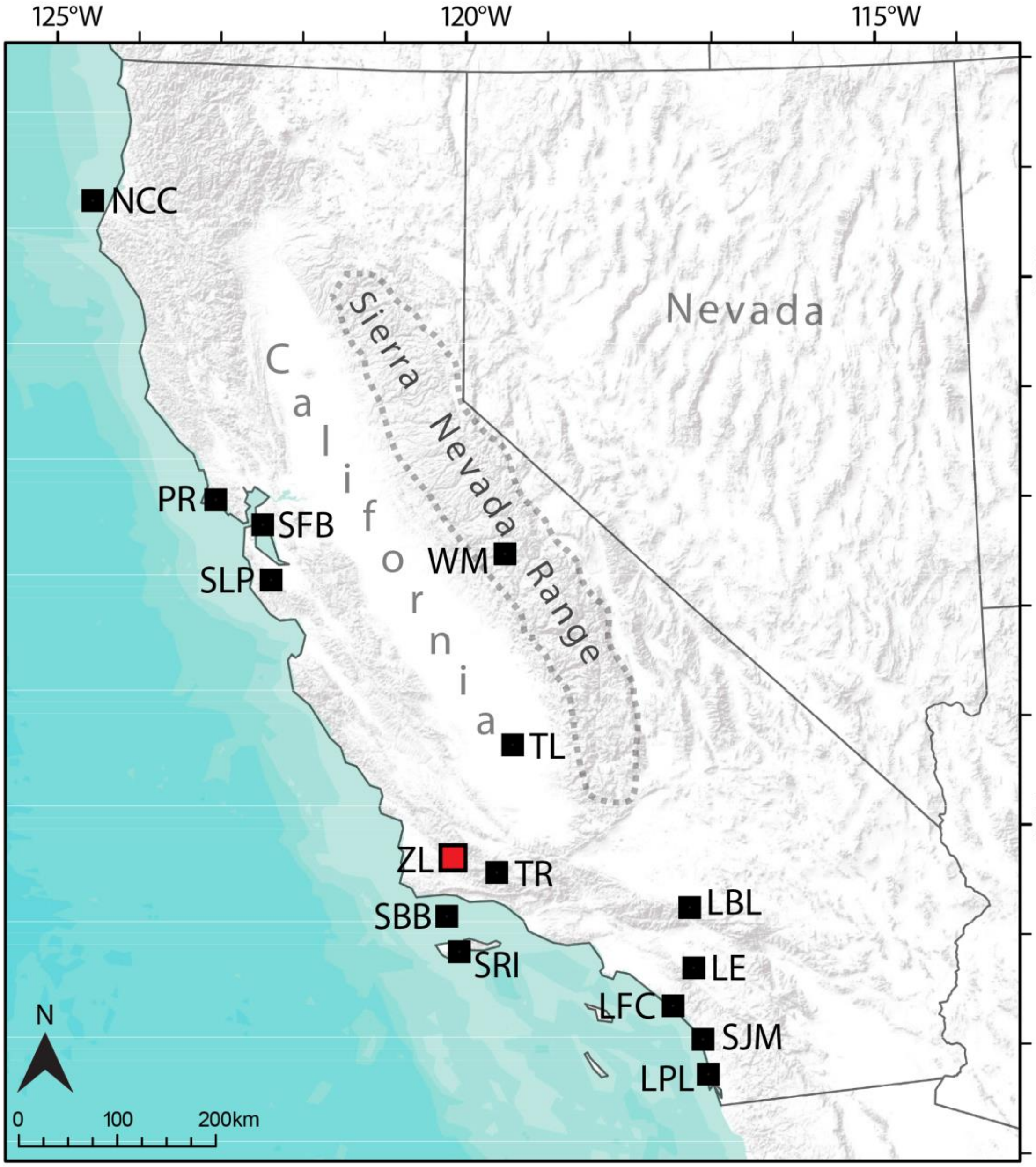

**Figure 1.** Map of California and Nevada with locations referenced in the text. The geographic extent of the Sierra Nevada Range is marked by the dashed line. Zaca Lake location marked with a red square; other sites referred to in the text marked with black squares. LBL (Lower Bear Lake), LE (Lake Elsinore), LFC (Las Flores Creek), LPL (Los Peñasquitos Lagoon), NCC (North coast California), PR (Point Reyes), SBB (Santa Barbara Basin), SFB (San Francisco Bay), SJM (San Joaquin Marsh), SLP (Skylark Pond), SRI (Santa Rosa Island), TL (Tulare Lake), TR (Transverse Ranges), WM (Wawona Meadow).

advantage of each natural site available for expanding our understanding of the long-term climate history of California.

The purpose of this thesis is twofold: to present a 3000-year high-resolution climate reconstruction inferred from pollen and sediments from a core recovered from Zaca Lake, Santa Barbara County, California, and to examine Native American cultural evolution in the region. Zaca Lake is ideal for creating a high resolution paleoecologic record because it has a rapid and constant sedimentation rate that allows for frequent sampling at regular time intervals. The Zaca Lake watershed is small and records local vegetation that responds relatively quickly to changes in climate. In addition, the study site is located only 55 km from the Santa Barbara Basin (SBB), a varved coastal marine basin with an extensive paleoclimatic record, allowing for comparison between terrestrial and marine environments. Finally, Zaca Lake is located in a region with a well-established anthropological record, allowing for comparison between environmental and cultural records to assess the role changing environment may have played on culture.

## 2. Background

### 2.1 Environmental Background

A handful of important paleoenvironmental studies in the region have been published (Figure 1). Holocene reconstructions of stream flow and lake level have been developed using grain size and geochemistry at Lake Elsinore and Lower Bear Lake, southern California (Kirby et al. 2007; 2010; 2012). A chronology of lake level was developed for Tulare Lake, central California by locating paleo-shorelines (Negrini et al., 2006). In the central California Coast environmental conditions were reconstructed using pollen and charcoal going back 3300 years at Skylark Pond (Cowart and Byrne, 2013). Just north of the San Francisco Bay Area pollen and charcoal were used to create a 6200-year record from Glenmire, Point Reyes Peninsula (Anderson et al., 2013). Previously at Zaca Lake, Mensing (1998) developed a pollen and charcoal record from a 3 m core, and Feakins et al. (2014) identified changes in precipitation source over the past 3000 years using fluctuations in the leaf wax D/H ratio from the same core used in this study.

Pollen and charcoal in sediment cores recovered from tidal estuaries, marshes and the SBB have been used to reconstruct fire and vegetation along coastal California. Changes in moisture and vegetation were reconstructed over the past 7000 years at San Joaquin Marsh (Davis 1992), and over the past 5000 years on Santa Rosa Island (Cole and Liu, 1994), at Los Peñasquitos Lagoon (Cole and Wahl, 2000), and at Las Flores Creek (Anderson and Byrd, 1998). High resolution records of vegetation and climate change from the SBB span the last 600 years (Mensing, 1998; Mensing, et al. 1999) as well as the Holocene (Heusser, 1978) and late Pleistocene (Heusser and Sirocko, 1997). Freshwater input into the San Francisco Bay over the last 3000 years has been reconstructed from sediment cores (Byrne et al., 2001; Malamud-Roam et al. 2006).

Tree rings play an important role in providing high-resolution records of precipitation and temperature over the past few centuries. A 600-year tree-ring reconstruction of precipitation for the Transverse Ranges, near Zaca Lake, was developed from big-cone spruce (*Pseudotsuga macrocarpa*) (Haston and Michaelsen, 1994). Unfortunately, long-lived tree species appropriate for building lengthy chronologies are absent from low elevations across most of central and southern California, limiting the usefulness of dendrochronology in the region.

High resolution reconstructions of sea surface temperature (SST), upwelling, and the strength of the California Current exist for the Holocene (Pisias, 1978; Kennett and Kennett, 2000; Roark et al., 2003; Fisler and Hendy, 2008) and at higher resolution for the last 1000 to 2000 years (Field and Baumgartner, 2000; Zhao et al., 2000; Barron et al., 2010; Li et al., 2011). Efforts to correlate marine records with terrestrial climate during the past 1000 years have been moderately successful (Pisias, 1979; Huguet et al., 2007; Grelaud et al., 2009), but relationships, such as cool SST associated with dry terrestrial conditions, are weaker earlier in the record  (Kennett et al. 2007). In addition, interpretations differ as to how conditions such as SST and upwelling changed over time, complicating our understanding of marine conditions during the late Holocene. New terrestrial paleoecologic records may help to clarify the paleoclimatic history of the region.

### 2.2. Cultural background

In the Santa Barbara region studies of the relationship between Native Americans and the environment have generally focused on two aspects. The extent to which Native Americans modified the landscape, particularly though the use of fire (Timbrook et al., 1982; Keeley, 2002; Anderson, 2005), and the influence of climate on the location, size, and culture of Native populations (Raab and Larson, 1997; Kennett and Kennett, 2000; Kennett et al., 2007).

At the time of European contact in the 16th Century, the Chumash of the southern California coast possessed a socioculturally complex society (Erlandson and Rick, 2002; Arnold, 2004) with a leadership system based on heredity and a well-developed class system, traits not often found in hunter-gatherer societies. A form of currency made from shell beads and an ocean-going watercraft, the *tomol*, facilitated a large and well developed trade network that connected mainland settlements with those on the northern Channel Islands (King, 1990; Arnold, 2007). At the time of contact the Chumash inhabited the California coast from Malibu to San Luis Obispo, the four northern Channel Islands, and a large swath of the California interior (Figure 2)(Arnold, 2001). Estimates put the total population at around 20,000 at contact, with the vast majority living close to the ocean (Arnold, 2001).

The Chumash have been the subject of substantial archaeological and anthropological study for several reasons. First, the lack of rodents on the Northern Channel Islands means that middens from the islands often have intact stratigraphy. Second, amongst California Native American groups the Chumash have almost uniquely deep cultural roots, with continuous inhabitance of the Santa Barbara region since at least

**Figure 2**. Map of the Chumash cultural region and surrounding Native American groups.

8000 BP (Kennett, 2005). That Chumash culture developed entirely *in situ* is a great aid to the study of its evolution. Third, a complex culture and hunter-gatherer subsistence is a somewhat unusual combination that interests scientists who want to explore the relationship between the two (Arnold, 2001). These factors have combined to make the Chumash one of the best-studied Native American sociolinguistic groups in California.

Much of the research done on the Chumash over the past two decades has focused on the relationship between cultural evolution and environmental change (Arnold, 1992, 2001; Raab and Larson, 1997; Jones et al., 1999; Kennett and Kennett, 2000; Kennett, 2005; Kennett et al., 2007). Of particular interest has been the relationship between environmental conditions over the past 3,000 years and a series of cultural changes, including the development of sociopolitical complexity. The record from pollen and sediments at Zaca provides a valuable new high resolution record of environmental change over this period.

### 2.3. Archaeology and anthropology in the region of Zaca Lake

While the coastal and island Chumash have been extensively well studied, much less is known about the population of the interior sections of the Chumash range. Ample evidence from surface archaeology, accounts from early Spanish explorers, and records from Mission Period (Johnson, 1988) indicate that the region was home to a significant population of Chumash (1000-1800 total population [King, 1975; Glassow, 1979]) during and just prior to the Historic Period (AD 1782-1802 [King, 1990]). The interior Chumash population which inhabited the Santa Ynez valley and its surroundings, including Zaca Lake, were known as the Inezeño Chumash. A number of archaeological sites from the region, particularly along the Santa Ynez River, indicate year-round habitation during the past 1000 years. Archaeological surveys from around Zaca Lake (SBa-1296 to SBa-1299) indicate that the site was used during this period. Historical accounts from the Spanish indicate that the Chumash used Zaca as a seasonal deer hunting camp and that there is not clear evidence of extended or year-round occupation (Glassow, 1970). Glasssow (1970) argues that based on midden depths nothing at the site indicates occupation prior to 1100 AD. Additionally, a site near the end of Zaca Canyon (SBa-140) contained several burials and evidence of a village which archaeologists identified as dating from the Canalaro period, which encompasses the past 2000 years. Unfortunately no excavation of the site has been undertaken. Further, a number of manos and metates used for seed processing have been recovered from the region around Zaca. Unfortunately, these tools have been in use continually in the region for 5000+ years (Glassow, 1970), so their diagnostic usefulness as an age control is limited. Overall, ample evidence from surface archaeology around the Zaca site, more substantial work from the region, and accounts from early Spanish settlers indicate that interior populations were substantial at the time of contact. Unfortunately, our knowledge of settlement and use patterns prior to the last ~1000 years is almost entirely absent.

As a result of lack of information about interior Chumash occupation and lifeways, particularly prior to ~1100 AD, the extent to which Chumash activities may have altered the vegetation at Zaca is unknown. For example, while it has been established that Chumash along the coast regularly burned grassland and chaparral to facilitate the gathering of plant foods and improve hunting yields, it is unknown to what extent interior populations practiced vegetation burning (Timbrook, 1982).

Therefore, it is not possible to ascertain with any kind of confidence to what extent Chumash may have modified the vegetation around Zaca Lake. As a result, the usefulness of Zaca Lake pollen record in an anthropological context must focus on its potential to help inform our understanding of the relationships between environmental change and the evolution of Chumash culture over the past 3000 years.

### 2.4. The Zaca Lake record in Context: 3000 years of Chumash cultural evolution

There are two primary chronologies of Chumash culture that are used in the literature. The first, developed by King (1990) divides Chumash cultural history in three: the Early (prior to 2440 BP), Middle Period (2440-570 BP), and Late Periods (570-150 BP). Arnold (1992) developed an alternative chronology which adds a Transition Period (800-650 BP). Once the radiocarbon dates on which the chronologies were based were calibrated, the two sequences emerged as very similar, and most of the literature over the past two decades use the chronologies interchangeably (Kennett, 2005).

The vast majority of data concerning cultural changes over the past 3,000 years comes from northern Channel Island sites because their stratigraphy is generally better preserved than mainland sites, and there has been minimal modern construction done on the islands that would cover up or otherwise disrupt the integrity of sites (Kennett, 2005). These sites are primarily middens, but sometimes also include burials or villages. There are a few good sources with comprehensive lists of archaeological sites that have been excavated on the Channel Islands, including Arnold (2001), Kennett (2005), and Rick et al. (2005). These give a good indication of the kind of sources of data that are used in the archeology and anthropology of the Chumash.

Settlement patterns during the late Holocene evolved with both cultural and environmental conditions. The period 3000–1500 BP saw an increase in settlement locations near the ocean and a reduction in interior Channel Island sites (Kennett, 2005; Glassow et al., 2006). This trend was mirrored by an increase in the importance of marine food resources and a reduction in the importance of terrestrial food sources. Settlements from this period also became larger and show evidence of increased sedentism (Kennett, 2005). This suggests an increasing population that was occupying larger villages year-round. Settlements continued to expand and become more permanent during the late Middle Period, and were primarily located on easily defended promontories or hills that provided good surrounding views (Kennett, 2005). During the Transition Period, settlement patterns evolved rapidly. Large villages built satellite villages, possibly to help defend territory and more effectively exploit the region’s resource base. This was part of a larger redistribution of settlements that saw villages spread evenly along the coastline with each village controlling the surrounding territory.

These increases in territoriality are mirrored by an increase in interpersonal violence. Villages were also increasingly found at locations that possessed a source of perennial fresh water, which indicates that access to fresh water resources had increased in importance, and was possibly a response to increasing late Holocene aridity (True, 1990). Arnold (1992, 2001) found that the Transition Period from 800–650 BP was also marked by the abandonment of a number of village sites on the northern Channel Islands, and postulates that this was due to severe environmental stresses. These abandonments appear contemporaneous with the mega-droughts of the MCA and have been interpreted as evidences of their effect on the Chumash.

The health of the Chumash population evolved over the late Holocene and mirrored the changes in settlement patterns. Osteological evidence from the Channel Islands suggests that overall health slowly declined throughout the Middle Period and then declined sharply during the late Middle and Transition Periods between 1300 and 600 BP (Lambert, 1993). The evidence for this decline comes from analysis of remains that show a decline in average height and an increase in the rate of infectious disease. These findings suggest that population levels increased during the Late Middle and Transition periods and that people became more sedentary. The decline in stature and health of the population closely mirrors what scientists have found when hunter-gatherer populations transition to sedentary agriculture, but in this case it developed during a transition to increased exploitation of marine resources (particularly fish) and an increasingly sedentary population (Lambert, 1993; Erlandson, 1997; Erlandson and Rick, 2002). People in more dense, permanent settlements are more susceptible to infectious disease, and their diet often becomes less diverse, resulting in a reduction of stature. The peak in disease and poor health during the Transition Period has been linked to subsistence stress due to a lack of terrestrial food resources (Lambert and Walker, 1991), and a less diverse diet (Rick et al., 2005). This decline has been interpreted as a possible result of drought conditions present during much of the MCA and possibly deteriorating marine resources (Lambert, 1993; Raab and Larson, 1997; Kennett, 2005).

The history of warfare and conflict can be traced though the analysis of osteological remains that show evidence of violence. In particular the frequency of cranial fractures and projectile point injuries indicates interpersonal violence. These data show that there was an upward trend in violence over the late Holocene. The period between 2500 and 1300 BP shows an increase in sub-lethal violence, possibly tied to some kind of ritual non-lethal fighting (Kennett, 2005). The late Middle period and Transitional period between 1300 and 600 BP saw a significant spike in lethal projectile point injuries (Lambert, 1993; Raab and Larson, 1997; Kennett, 2005). Both Lambert (1993) and Raab and Larson (1997) argue that this increase is a result of three primary factors: the increasing population, the declining environmental conditions, and the introduction of the bow and arrow sometime around 1500 BP.

Overall the osteological data tells a similar story to that of the settlement patterns. Chumash were moving into more permanent settlements along the coast, and village size and density were increasing throughout the late Holocene. At the same time, health was getting worse and warfare was increasing. Both began shifting around 2500 BP and show significant changes during the 1300 to 600 BP period that seem to indicate subsistence stress. Warfare increased, as evidenced by the increase in territoriality and projectile point wounds. Health also declined at the same time that villages were being abandoned.

Diet is particularly important for tracing the relationship between environment and culture because what is eaten is closely tied to what is available and what is available is influenced by environmental conditions. Chumash diet consisted of both marine and terrestrial resources. Over the late Holocene, Chumash diet was overwhelmingly made up of marine resources, which included shellfish, fish and marine mammals (Kennett and Kennett, 2000). This reliance on marine resources was tied to changes in settlement patterns that saw people increasingly living almost entirely in coastal villages during the late Middle, Transitional, and Late Periods. Kennett (2005) suggests that dry climate conditions between 3000 BP and 650 BP was a driver of the increase in importance of marine food resources. While the general reliance on marine resources as a whole did not vary much over the late Holocene, the species being exploited did. The dominant trend over the past 3,000 years was a change from a diet focused primarily on shellfish to one dominated by fish. This change occurred across the entire Chumash cultural region, and has been documented in numerous places, including Walker and Erlandson (1986), Kennett (2005), Glassow et al. (2006), and Braje et al. (2007). Along with a general decline in shellfish exploitation, the species and size of those being consumed also changed. The late Holocene saw a decline in the presence of large meat-rich species in shell middens, such as red abalone (*Haliotis rufescens*), black abalone (*H. cracherodii*), and California mussel *(Mytilus californianus*). Smaller species, such as turban snail (*Tegula spp.*), sea urchin (*Strongylocentrotus spp.*) and platform mussel (*Septifer bifurcates*) saw their percentages increase (Braje et al., 2007). The size of the specimens being taken also declined over the past 3,000 years. Additionally, it is important to note that changes in shellfish exploitation do not show much of a response to climatic or SST changes (Kennett, 2005; Braje et al., 2007), but are mostly likely indicative of changes due to subsistence stress.

Two factors are mostly likely responsible for the increase in the exploitation of fish during the late Holocene. The first is the increase in intensity of marine resource usage due to dietary changes, settlement location changes, and population growth. People were forced to catch fish when the shellfish resources became increasingly depleted. The second factor is the development of better technology that allowed Chumash fishermen to better hunt fish species that were previously prohibitively difficult to catch. Of primary importance was the development of the plank canoe sometime around 1500 BP (Arnold, 2001; Arnold, 2007), which allowed Chumash fishers to hunt pelagic and reef fish more easily. A second important innovation was the circular shell fishhook, which appeared around 3200 BP (Rick et al., 2005). Finally, the development of better fishing nets and toggling harpoons (Kennett, 2005) also improved the capability of hunters to exploit fish resources. The fish species being exploited primarily varied spatially rather than temporally, though there are a couple of important trends over time. The first is a general move toward exploiting smaller species such as anchovies, sardines, kelp-bed dwellers, and bottom fish (Walker and Erlandson, 1986). The second is an increased focus on pelagic fish during the Transitional Period between 800 and 650 BP (Kennett, 2005). The focus on smaller fish is another example of subsistence stress and increased exploitation of more costly-to-produce food resources due to population increases and marine resources exploitation intensification.

One final marine resource that was exploited by the Chumash during this period are pinnipeds. The Channel Islands are home to one of the largest populations of marine mammals in the world (Kennett, 2005), and the presence of pinniped bones in archeological middens suggest that they were hunted by the Chumash. In particular, Colten (2001) notes that pinniped exploitation peaked around 1,500 BP and declined shortly after, most likely due to over-hunting driving the animals to offshore rookeries that were much more difficult to access. The story of pinniped exploitation is indicative of marine food sources in general in that dietary changes are generally more closely linked to subsistence stress and population pressure rather than SST or terrestrial climate.

The story of terrestrial food resources is largely a story of trade, because many of the foods eaten by the Channel Island Chumash were imported from the mainland via the late Middle, Transitional, and Late Period trade network. Food resources such as acorns (from *Quercus* spp.), walnuts (*Juglans californica*), and prickly pear (*Opuntia* spp.) were traded from the mainland to the Northern Channel Islands while shellfish and other marine resources such as shell beads were traded to the mainland (Martin and Popper, 2001). Along with the terrestrial food resources imported from the mainland, island Chumash also ate roots and tubers that grew on the islands (Walker and Erlandson, 1986). Mainland coastal Chumash diet relied more on terrestrial resources such as acorns, however, their diet was still heavily reliant on fish and shellfish. Overall, terrestrial food resources provided diversity to the Chumash diet, however, on the islands they still represented a small portion of a diet that was dominated by marine food sources. The trade network that allowed terrestrial food resources to make it to the northern Channel Island was facilitated by the introduction of the plank canoe.

The development of the plank canoe or *tomol* greatly facilitated the development of vast trading networks that came to dominate much of Chumash culture over the past 1,500 years. It helped facilitate the transfer of food and other goods between the mainland and the Channel Islands, and played a potentially important role the development of a complex political system. The plank canoe was typically built out of scavenged redwood (*Sequoia sempervirens*) driftwood because there are no trees in the region appropriate for creating the necessary planks (Arnold, 2007). Before its development, travel between the islands and the mainland had to be done in small tule reed boats called *balsas* (Arnold, 2001). A *tomol* required over 500 man-hours of labor to create, and the workers responsible for building them were in a guild called the Brotherhood of the Tomol (Arnold, 2001). The *tomol* also became synonymous with high status and wealth, and control over the best driftwood beaches became important (Johnson, 2001). This development of a status symbol and way to control and possess wealth may have been important to the development of cultural and political complexity during the transition period (Arnold, 2001).

Over the late Holocene, and particularly after the development of the plank canoe, a complex and well developed trade between the northern Channel Islands and the mainland appeared. This trade not only helped redistribute food resources throughout the Chumash cultural region but also allowed other goods such as stone tools and luxury goods from outside the region to make their way throughout the region (Arnold, 2001). This trade was aided by the development of a shell bead currency that used *Olivella biplicata* shells (Arnold, 2011). This allowed for easier trade and added substantially to the economy of the Channel Islands, where most of the beads were produced.

### 2.5 Models of Chumash cultural evolution

The concentration of power amongst elites is a key indicator of sociopolitical complexity, although its precise definition is very contentious, with several definitions used by anthropologists working on Chumash culture. Arnold (1992, 2001) focused on control of non-kin labor and the hereditary inheritance of leadership positions as the necessary components of complexity, while others focused solely on political leadership and the accumulation of wealth by high status individuals (Raab and Larson, 1997; Kennett and Kennett, 2000). However it’s defined, evidence from the Santa Barbara region indicates that at the time of contact with Spanish explorers during the 16th century Chumash society showed clear evidence of complexity, with a number of chiefs controlling major sections of both the mainland and the northern Channel Islands (Arnold, 1992). The debate over complexity has focused on two major questions: when did complexity arise, and what factors led to its development?

The first of these questions, when did complexity arise, has generally focused on the period between 1500 and 600 BP, although evidence from burials indicates that some stratification of society was occurring going back to the late Early Period, which ended approximately 2440 cal yr BP (King, 1990). Arnold (1992, 2001) has argued for between 800 and 650 BP as the period of emergent complexity based on increases in trade good manufacture and specialization. She sees these as indicative of control of production, and thus non-kin labor, by elites. Kennett and Kennett (2000) and Raab and Larson (1997) have argued for a longer window for complexity development from about 1300 to 650 BP. Burial data from the mainland (Gamble et al. 2001) provides evidence for an earlier and potentially longer time scale for the development of complexity, similar to the one proposed by King (1990).

The second area of debate surrounding Chumash cultural complexity addresses the question of what factors led to its development. There is a lively debate surrounding the question, and the four different schools of thought presented below represent the most common theories in the literature.

Arnold (1992; 2001; 2011) argues for a model of emergent complexity based on the control of labor by elites. In particular, she sees an increase in trade and the production of increasingly complex trade goods by specialists on the northern Channel Islands as evidence of the development of chiefs or other tribal leaders. Her evidence comes primarily from an increase in the bead-making industry and its resulting detritus in shell middens on Santa Cruz Island during the transitional period between 800 and 650 BP and the increase in trade over the period after the development of the plank canoe around 1500 BP. Arnold also argues that reduced marine productivity due to warm SSTs led to the abandonment of some villages during the Transitional Period and further encouraged increased trade as a way to cope with more difficult environmental conditions through economic redistribution. Overall, her model focuses on the influence of entrepreneurs and trade in the context of climate change and how each of these factors contributed to the development of increased social complexity.

Raab and Larson (1997) present an alternative hypothesis for the driving force behind the development of cultural complexity. They argue that rather than trade increase and the control of production by elites, complexity arose as a coping mechanism for dealing with severe climate conditions. In particular, they argue that the severe droughts of the period between 800 and 650 BP were the driving factor behind a host of cultural perturbations including increased warfare, abandonment of villages, reduction in health of the population, increased territoriality, and the development of complexity. Their theory is that tremendous environmental stress leads to a need for leadership to help plan things such as food and water rationing and finding new resources, and from that need develops a hereditary leadership class and social complexity.

A third hypothesis, put forward by Kennett and Kennett (2000), argues that complexity is a result of more long-term Chumash trends over the previous 2,000 years. They argue that an increasingly large and sedentary population led to increasing competition for marine and terrestrial resources. This competition was the catalyst for the development of a complex trading network as well as increased inter-village warfare during the period between 1500 and 600 BP. They argue that the slow process of intensification was accelerated by a highly variable and dry climate during the period between 1500 and 650 BP along with a general trend of increasing aridity across much of the late Holocene. They see this intensification and increase in competition for resources as the primary catalyst for the development of sociopolitical complexity.

Finally, King (1990) sees Chumash cultural evolution as a much longer and slower process without the kind of punctuated changes suggested by other models. Based on a comparative study of artifacts used for social system maintenance, he argues for gradual development of complexity beginning in the late Early Period and extending over the entire Middle and late Periods. The development and evolution of complex social systems was primarily a response to increasing population and a result of competition between groups (King, 1990 p199).

It is important to review the role played by changing environmental conditions in the four models presented above. Arnold (1992, 2001) sees environmental conditions as secondary players in her model. A need to counteract adverse marine conditions may have helped encourage trade, but overall she sees trade and the control over the production of trade goods as the primary drivers of cultural complexity. Raab and Larson (1997) argue for climatic conditions as the primary driver of complexity, with MCA mega-droughts not only responsible for the development of complexity but also increased violence, territoriality, and the abandonment of some villages. Kennett and Kennett (2000) see environmental conditions as playing an important role in the development of a number of late Holocene Chumash cultural features including complexity, but they see it operating on much longer time scales and in combination with population pressure.

Finally, climate does not play a role in King's (1990) model, which instead sees competition as the key driver of cultural complexity.

The lack of high resolution climate records from the region has been a hindrance to our ability to evaluate these models. To understand the relationship between culture and environment reliable records of both are required. Previous efforts to evaluate this relationship have noted that our understanding of environmental conditions in the region is lacking (Gamble, 2005). It is this gap in our knowledge that the record from Zaca Lake can help fill. The following sections will describe the record of environmental change from Zaca Lake, reevaluate the four previously mentioned models of Chumash cultural evolution in light of the new record, and suggest an alternative model.

## 3. Study Area

Zaca Lake (34º 46' N, 120º 2' W) is a rare low-elevation (730 m) natural lake formed by a Quaternary landslide (Hall C.A., 1981), located in the San Rafael Mountains, 50 km from the Pacific Ocean and 200 km northwest of Los Angeles (Figure 3). The lake covers 8.2 ha with a maximum depth of ~12 m, and a small, steep sided catchment of 900 ha. Complete mixing occurs once a year, generally in January and February, and otherwise anaerobic conditions persist below ~7 m water depth (Caponigro, 1976). The lake sill is ~9 m above modern lake level, making outflow rare.

Southern California has a Mediterranean climate and receives almost no summer precipitation. Mean annual precipitation at Zaca Lake is ~740 mm (PRISM data, 1895-2011; Daly et al., 2008), which comes primarily from a handful of major winter storms typically originating in the north Pacific (Cayan and Rhodes, 1984).

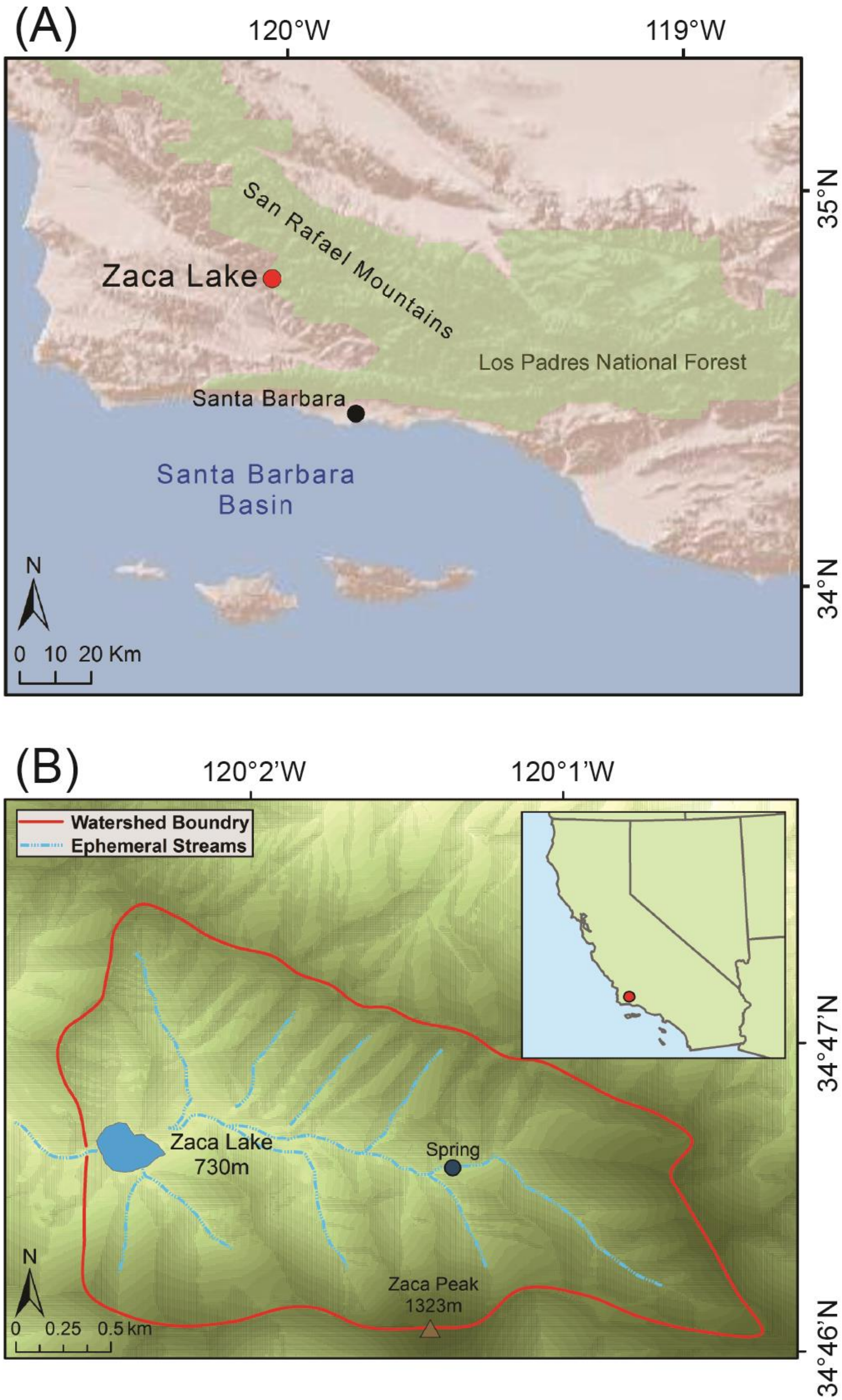

**Figure 3**. Map of Zaca Lake location. **A:** Santa Barbara Region **B:** Zaca Lake watershed.

The lake lies within a belt of folded Monterey Miocene Formation bedrock, a sedimentary rock of marine origin rich in calcium carbonate (Behl, 1999). Zaca Lake has an actively flowing spring complex located ~2 km upstream, characterized by large calcium carbonate tufa deposits (Ibarra et al., 2014). Currently no surface water reaches the lake except during rain events.

Vegetation in the Zaca Lake watershed can be broadly separated into three categories: pine-oak woodlands, chaparral, and riparian. Pine oak woodlands are dominated by coast live oak (*Quercus agrifolia*) and coulter pine (*Pinus coulteri*) but ponderosa pine (*P. ponderosa*), grey pine (*P. sabiniana*), interior live oak (*Q. wislizenii*), canyon live oak (*Q. chrysolepis*) and valley oak, (*Q. lobata*) are present. Small stands of big-cone spruce (*Pseudotsuga macrocarpa*) and incense cedar (*Calocedrus decurrens*) grow at higher elevations. Pines and oaks are found throughout the Zaca Lake watershed, except on south facing, dry, rocky or steep slopes, where chaparral dominates. Chaparral, including California lilac (*Ceanothus* spp.), manzanita (*Arctostaphylos* spp.), *Yucca* spp, sage (*Salvia* spp.), and California sagebrush (*Artemisia californica*) grow on exposed slopes and in openings between the pines and oaks. Riparian species include sycamore (*Platanus racemosa*), big leaf maple (*Acer macrophyllum*), California bay (*Umbellularia californica*), and willow (*Salix* spp.). Rushes (*Juncus* spp.), tules (*Scirpus* spp.) and cattails (*Typha* spp.) grow along the lake shoreline.

The modern vegetation may not be representative of the site during the pre-Euro-American period. Many of the mature coulter pines result from a massive planting operation beginning ~AD 1900 (Norris and Norris 1994). Additionally, historical photographs from the turn of the 20th century suggest that there were many fewer trees at that time (Mensing, 1998). The increase in forest cover over the past century is likely the result of a combination of fire suppression and organized planting.

## 4. Methods

### 4.1. Core recovery and subsampling

An 8.5 m core (core Z-1C) was recovered in July 2009 by Matt Kirby and Sarah Feakins, and is described in Feakins et al. (2014).The team used a combination of Bolivia and Livingstone piston corers for successive drives from a four-way-anchored, small boat-based coring operation provided by the National Lacustrine Core Facility (LacCore). Coring efforts ceased when further drives could not be obtained with the equipment available. Core Z-1C was stored in a cold room at California State University, Fullerton (CSUF). Subsamples for pollen analysis were taken on site in 2011 and 2013.

### 4.2. Dating

The chronologic control for the Z-1C core comes from sixteen radiocarbon dates of terrestrial macrofossils as well as additional exotic pollen and $^{137}$Cs events (as reported in Feakins et al., 2014). A total of twenty-one radiocarbon dates were obtained on materials found in the core (Table 1). Of these, three dates on material from 778.5, 800.5 and 806.5 cm depths returned statistically identical ages younger than the overlying strata at 642 cm depth, implying instantaneous deposition of >1 m of sediment. Variation in sediments in this section, as well as the δD data (Feakins et al., 2014), argue strongly against this interpretation, therefore, these dates were excluded from the age model. The remaining dates were input into the R-based statistical program BACON v2.2 (Blaauw and Christen, 2011) to develop an initial age model using the IntCal13 calibration curve

**Table 1**. Dates obtained for developing the age model. CAMS# = sample identification number from measurements at the Center for Accelerator Mass Spectrometry, Lawrence Livermore National Laboratory (LLNL). No[a]: Identified as an outlier by the age model and not used. No[b]: identified as an outlier by the authors. s/w interface = core top sample that captured the sediment water interface without disturbance. FO = first occurrence. Historical = historical markers are the $^{137}$Cs peak (1963), measured by D. Hammond at the University of Southern California (USC). Pollen = historical dates from invasive species. Pollen counts (by L. Reidy at UC Berkeley) are assigned dates based on first appearance [Mensing and Byrne 1998] of *Erodium* (1755-1760), *Eucalyptus* based on planting date (Norris and Norris, 1994a) and estimated maturity. Age uncertainty on pollen dates are estimates.

| Type | Depth (cm) | CAMS# | Material dated | In age model | Mass of C (mg) | d$^{13}$C (‰) | $^{14}$C Years BP | σ |
|---|---|---|---|---|---|---|---|---|
| Core top | 0 | n.a. | sed./water | Yes | n.a. | n.a. | n.a. | 0 |
| Historical | 42.5 | n.a. | Cs peak | Yes | n.a. | n.a. | n.a. | 0 |
| Pollen | 73 | n.a. | *Eucalyptus* FO | Yes | n.a. | n.a. | n.a. | 10 |
| $^{14}$C | 95.5 | 144842 | Twigs | Yes | 1.07 | -25.00 | 180 | 35 |
| Pollen | 135 | n.a. | *Erodium* FO | Yes | n.a. | n.a. | n.a. | 14 |
| $^{14}$C | 164.5 | 144843 | Bark and twigs | Yes | 0.71 | -25.00 | 325 | 35 |
| $^{14}$C | 208.5 | 144844 | Twig, organics | Yes | 1.08 | -25.00 | 460 | 30 |
| $^{14}$C | 244.5 | 147067 | Single twig | Yes | 0.35 | -25.00 | 550 | 30 |
| $^{14}$C | 244.5 | 147068 | Single twig | Yes | 0.15 | -25.00 | 440 | 40 |
| $^{14}$C | 244.5 | 147070 | Stem | No[a] | 0.05 | -25.00 | 5210 | 110 |
| $^{14}$C | 275.5 | 144845 | Twigs | Yes | 1.01 | -25.00 | 725 | 30 |
| $^{14}$C | 305.5 | 144846 | Twig, bark, leaf | Yes | 0.58 | -25.00 | 835 | 30 |
| $^{14}$C | 344.5 | 144847 | Twig, leaf | Yes | 0.54 | -25.00 | 1115 | 30 |
| $^{14}$C | 377.5 | 147071 | Stem, charcoal | Yes | 0.32 | -25.43 | 1070 | 30 |
| $^{14}$C | 400.5 | 147072 | Stem, charcoal | Yes | 0.06 | -25.00 | 1100 | 90 |
| $^{14}$C | 400.5 | 147073 | Mixed organics | Yes | 0.28 | -26.68 | 1430 | 40 |
| $^{14}$C | 444.5 | 144848 | Root, grass, leaf | Yes | 0.20 | -25.00 | 1335 | 35 |
| $^{14}$C | 525.5 | 144849 | Wood | Yes | 1.16 | -25.00 | 1595 | 30 |
| $^{14}$C | 577.5 | 144850 | Leaf, grasses | Yes | 0.96 | -25.00 | 1840 | 30 |
| $^{14}$C | 585.5 | 147074 | Stems, charcoal | No[a] | 0.17 | -25.00 | 2370 | 40 |
| $^{14}$C | 642 | 144851 | Seed, organics | Yes | 0.80 | -25.00 | 2040 | 30 |
| $^{14}$C | 778.5 | 144852 | Organic fibers | No[b] | 0.23 | -25.00 | 1905 | 35 |
| $^{14}$C | 800.5 | 144853 | Twigs and bark | No[b] | 0.41 | -25.00 | 1905 | 30 |
| $^{14}$C | 806.5 | 144854 | Charcoal, twigs | No[b] | 0.18 | -25.00 | 1910 | 35 |
| $^{14}$C | 839.5 | 147076 | Stems, charcoal | Yes | 0.129 | -25.00 | 2680 | 40 |

(Reimer et al., 2013). BACON uses a Bayesian approach to accumulation histories by separating the core into many sections and then estimating accumulation rate for each through millions of Markov Chain Monte Carlo iterations. The program calculates the probability density function for all dates as well as identifying outliers, $^{14}$C dates that lie outside of the 95% confidence interval. Outliers likely represent $^{14}$C ages on reworked material out of stratigraphic context. Two outliers were identified (244.5 and 585.5 cm) and these ages were also removed from the age model calculations. The final Bayesian age model for Z-1C was calculated using the dates identified in Table 1 with the following parameters: estimated accumulation rate set to 5 yr/cm to make calculating accumulation rate faster and maximum depth set 873m, so that ages were calculated for the total length of the Z-1C core. Remaining elements used default parameters.

### 4.3. Sediment and Pollen analysis

Core Z-1C was sampled at 1 cm contiguous intervals for loss-on-ignition analysis at the CSUF Paleoclimatology and Paleotsunami Laboratory. Percent total organic matter (%TOM) and percent total carbonate (%TC) were determined by weighing samples after two hours in a furnace at 550°C and then reweighing them after an additional two hours at 950°C (Dean, 1974; Heiri et al., 2001).

Subsamples were processed for pollen at the University of Nevada, Reno (UNR) Paleoecology Laboratory. Sample sizes were either 0.625 or 1.25 cm$^3$ depending on pollen concentration, and were processed using standard pollen preparation procedures (Faegri and Iversen 1985). A known quantity of an exotic tracer (*Lycopodium* spores) was added. Following potassium hydroxide (KOH) treatment, samples were sieved using a

125 µm mesh to remove the large organic fraction. Processed samples were mounted on glass microscope slides and counted at 400x magnification. Pollen was identified to the lowest possible taxonomic level using the UNR Palynology Laboratory reference collection and published keys (Moore and Webb, 1978; Kapp et al., 2000).

Samples from the Z-1C core were counted at intervals of ~20 cm. We were unable to count samples between 651 and 691 cm depth due to poor pollen preservation and low concentration. A total of 400 terrestrial pollen grains were counted per slide except for twelve samples between a depth of 641 and 801 cm. In this section, due to low pollen concentration, we counted 300 terrestrial grains per slide. Pollen zones were interpreted from a constrained single-link dendrogram created using ConSLink in the PolPal plotting program (Nalepka and Walanus 2003). Data input included the six most common taxa plus indeterminate pollen, total pollen concentration, %TOM and %TC.

Three surface samples were collected from the land around Zaca Lake; one soil sample from within several meters of the lakeshore, and one soil sample and moss pollster from a hillside approximately 50 m from the shoreline. These samples were treated with 5% KOH for 4 hours, sieved using a 500 µm mesh, and then processed in the same manner as the Z-1C pollen samples. Surface samples were scanned to assess the type and extent of pollen deterioration.

## 5. Results

The basal age of the Z-1C core age model (Figure 4) is 3000 cal yr BP (calendar years before present). The sediment accumulation rate for the top 1m was 5.8 mm $yr^{-1}$, while the sedimentation rate for the remaining 7.7 m of core was 2.7 mm $yr^{-1}$. The overall

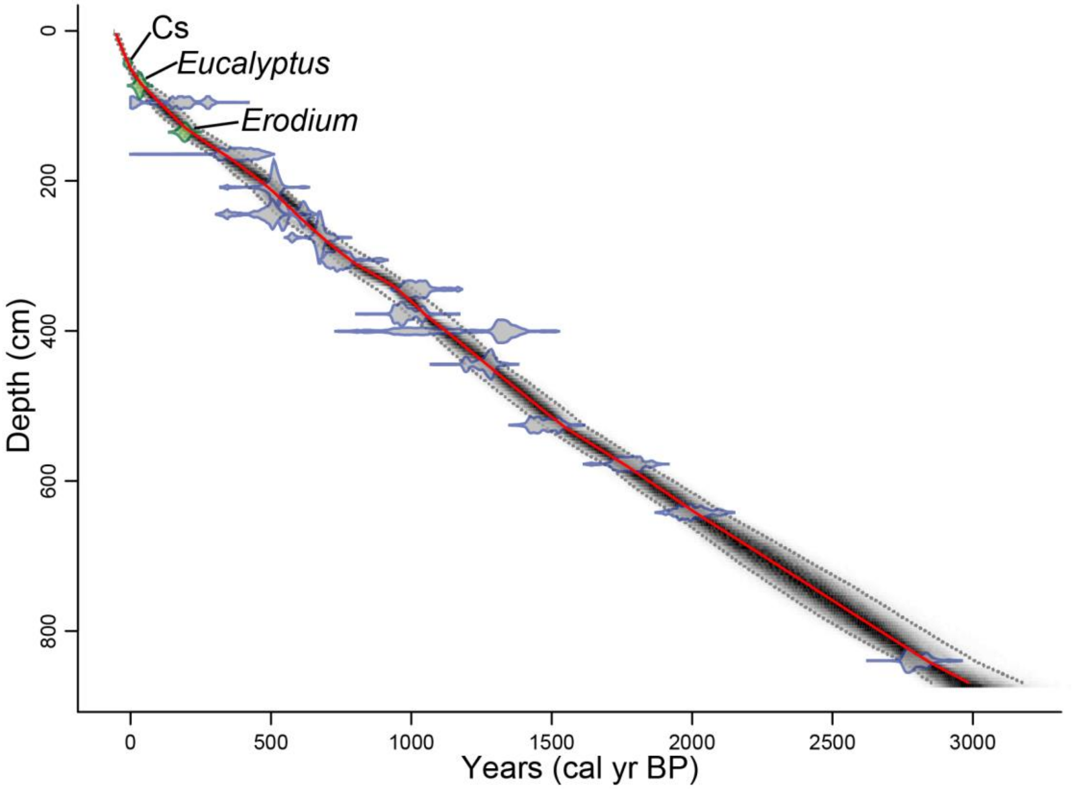

**Figure 4.** Age model for core Z1C. Best fit age for each depth (red line), the probability calculation (darker color indicates more likely calendar age), and 95% confidence interval (grey dotted line). Calibrated $^{14}C$ dates (blue), and exotic pollen and $^{137}Cs$ dates (green), all with their 2-sigma error range.

sedimentation rate was 2.9 mm yr$^{-1}$ and the bottom 7.7 m of the core had a nearly linear sedimentation rate.

Total core length was 873 cm. Sediments showed color variations including dark gray, brown or black often alternating on the scale of 1–2 cm throughout most of the core (Figure 5). A noticeable exception was a 160 cm-thick section from 805 to 645 cm depth that consisted of a light brown material. Occasional very fine laminations (mm-scale) of white calcium carbonate were present, typically in the upper section of the core.

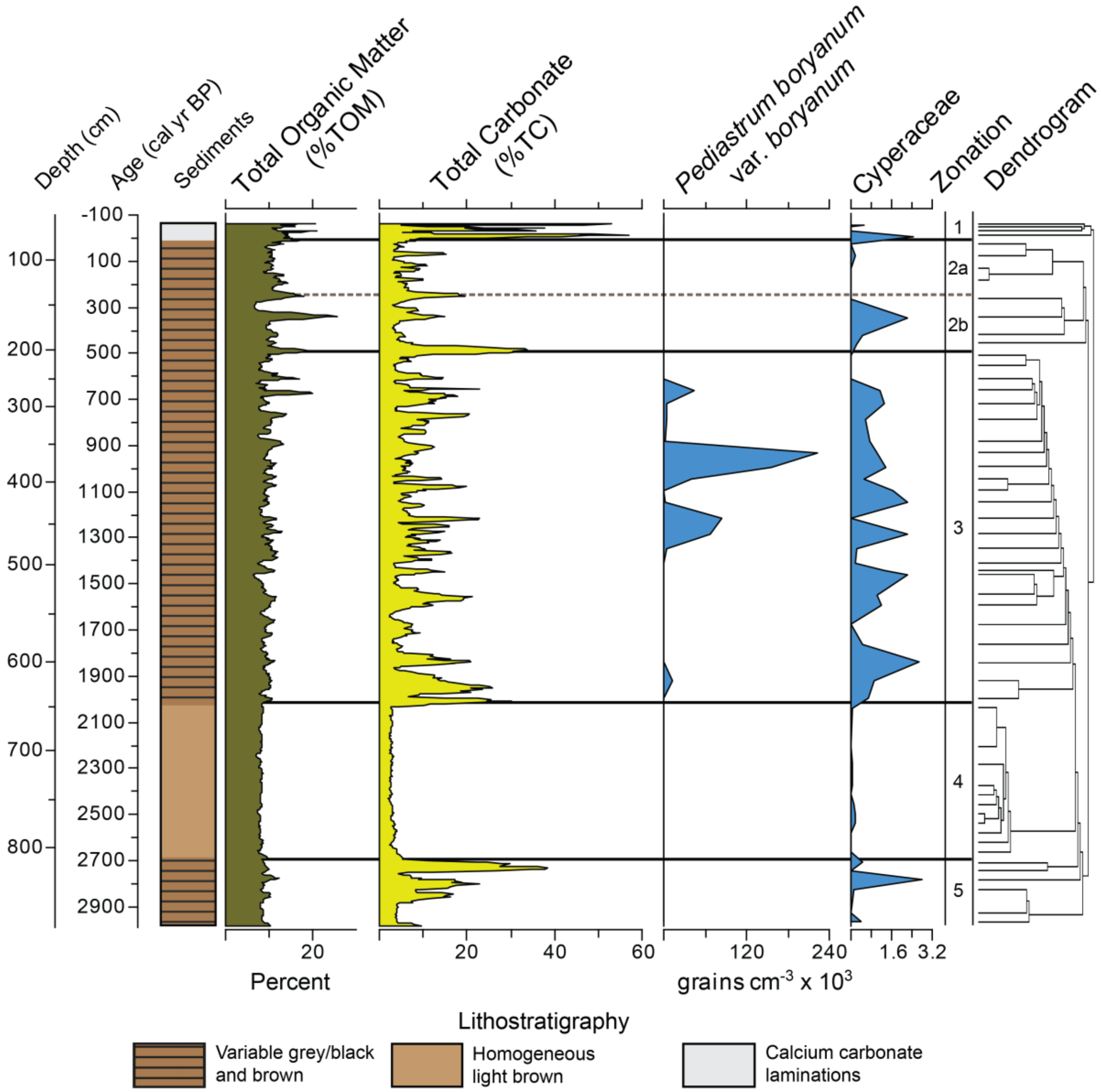

**Figure 5.** Zaca Lake sediments and aquatic palynomorphs. Total Organic Matter (%TOM) and Total Carbonate (%TC) smoothed using a 5 point average. *Pediastrum boryanum var. boryanum* and *Cyperaceae* are plotted as concentrations.

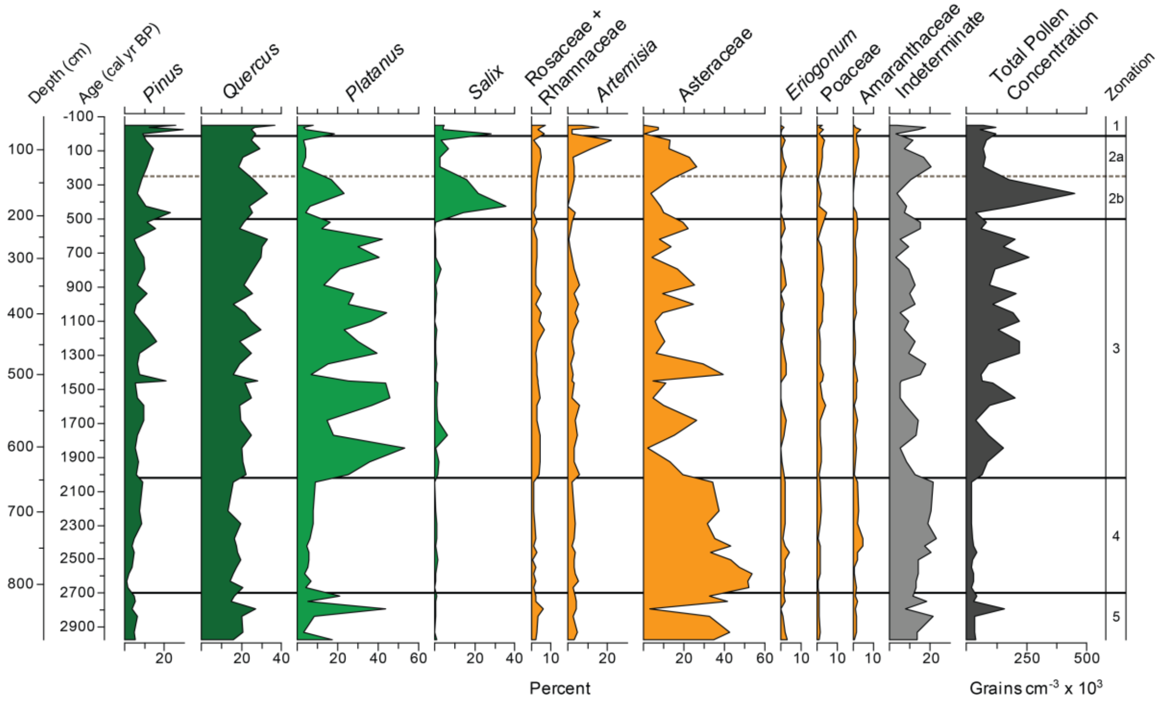

**Figure 6.** Zaca Lake pollen percentages for the ten most common taxa plotted with indeterminate grains and total pollen concentration.

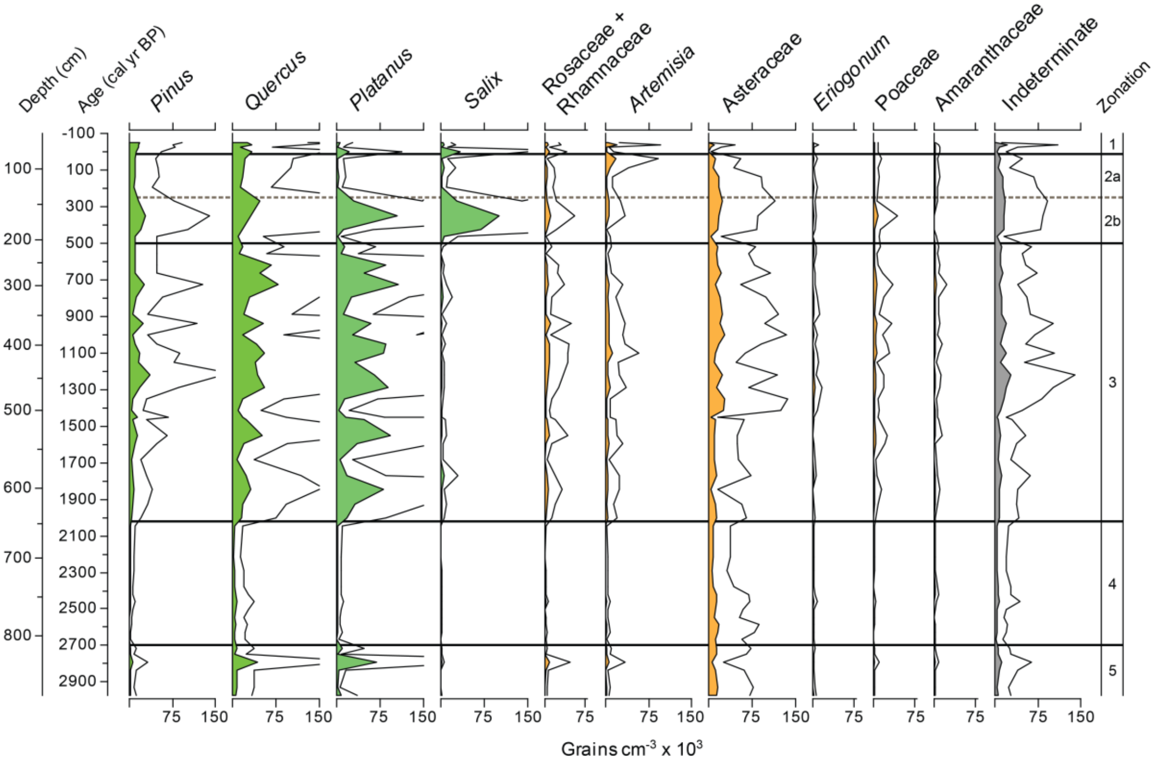

**Figure 7.** Zaca Lake pollen concentration for the ten most common taxa plotted with indeterminate grains. Lines above the pollen percentages represent 3X exaggeration.

A total of 54 strata were counted for pollen (see supplementary information for complete pollen counts). Depth between pollen samples ranged from 5 to 40 cm (16 to 170 years); 48 years between samples from 869 to 691 cm depth (2970 to 2200 cal yr BP), 170 years between samples from 691 to 651 cm depth (2200 to 2040 cal yr BP), 60 years between samples from 651 to 81 cm depth (2040 to 60 cal yr BP [1890 AD]), and 24 years between samples from 81 cm depth to the surface (60 cal yr BP [1890 AD] to the present).

Twenty-three terrestrial pollen taxa were identified. Aquatic palynomorphs included Cyperaceae and the algae *Pediastrum boryanum* var. *boryanum* (Figure 5). *Pinus*, *Quercus, Platanus,* and Asteraceae occur in consistently high percentages (Figures 6 and 7). Additionally, *Salix* and *Artemisia* make up a high percentage in at least one sample.

*Pinus* and *Quercus* pollen are most likely from the two most common tree species in the watershed, coulter pine (*Pinus coulteri*) and coast live oak (*Q. agrifolia*). *Platanus* is California sycamore (*P. racemosa*) the only species of *Platanus* in the region. Numerous species of *Salix* (willow) grow in the region and these have not been identified to the species level. Rhamnaceae and Rosaceae include a number of shrubs common to chaparral in the region, including *Adenostema fasciculatum*, *Heteromoles arbutifolia*, *Ceanothus* spp., *Cercocarpus spp and Prunus spp.*, (Mensing 1993). *Artemisia* is from California sagebrush (*A. californica*). Herbaceous species of Asteraceae are abundant in the region, and commonly associated with disturbed or open habitats. *Eriogonum*

(Polygonaceae) include a diverse set of species in California and the pollen cannot be identified below the genus level. Amaranthaceae and Poaceae are not typically identifiable beyond the family level and appear in low percentages in the pollen record.

The majority of the pollen comes from high pollen producing arboreal taxa (*Pinus* and *Quercus*) or plants growing in close proximity to the lake. Big-cone spruce (*Pseudotsuga macrocarpa*), incense cedar (*Calocedrus decurrens*), and big leaf maple (*Acer macrophyllum*) are restricted to the upper reaches of the watershed today and only show up in very low quantities. Additionally, chaparral are low pollen producers and are likely under-represented.

Zone 5, from 870 to 805 cm depth (2970 to 2700 cal yr BP), was characterized by low total pollen concentration (<45,000 grains $cm^{-3}$), high percentages of Asteraceae (30%), and high percentages of indeterminate grains (15%). *Platanus* was variable (between 3% and 44%); *Pinus* levels were below average (5% vs 9% overall) and *Quercus* levels were average (17% vs 19% overall). The sediments between 870 and 853 cm depth were light brown with low %TC (4%) and %TOM (8 %). The sediments between 852 and 808 cm contained intermittent bands of dark grey to black, light grey to brown, and narrow bands of light brown material high in %TC (above 20%).

Zone 4, from 805 to 645 cm depth (2700 to 2020 cal yr BP) was characterized by very high percentages of both Asteraceae (42% average) and indeterminate grains (17%), and the lowest total pollen concentration in the record. Asteraceae is one of the most resistant pollen types to oxidation and degradation, and the combination of high Asteraceae, high indeterminate, and low concentration is a signature for poor pollen preservation, described more fully below. *Pinus*, *Platanus*, and *Quercus* were all at their lowest levels for the entire record. This was the most uniform section of the core, considering sediment color (light brown material extending >150 cm between 805 and 645 cm depth); %TC (3% average), %TOM (8% average), and total pollen concentration rates were all low.

Zone 3 from 645 to 210 cm depth (2020 to 500 cal yr BP) was characterized by high variability in the percentages of Asteraceae, *Platanus*, and total pollen concentration. *Platanus* also reached its highest average percentage of any zone (29%). *Quercus* and *Pinus* showed increased variability and made up a higher overall percentage than in Zones 4 and 5 (32% vs 23% in zones 4 and 5). %TC was variable with low values (~4%) associated with light brown sediment. *P. boryanum* var. *boryanum* was found between 1350 and 1150, 1070 and 900, and 700 and 650 cal yr BP. Cyperaceae, largely absent from Zone 4 was abundant in Zone 3.

Zone 2b, from 210 to 145 cm depth (500 to 250 cal yr BP), was characterized by the highest levels of *Salix* found in the record, reaching 40%, as well as the highest overall pollen concentration (216,000 grains $cm^{-3}$), indicating well preserved pollen. %TC was moderate to low and %TOM reached its highest levels (20%) in the record around 350 cal yr BP. Zone 2a, from 145 to 60 cm depth (250 to 15 cal yr BP [1935 AD]), was characterized by a period of moderate pollen preservation, with low percentages of *Salix* (4%), moderate Asteraceae (19%) and low *Platanus* (3%). Pollen concentration decreased and *Artemesia* increased to its highest levels (22%) at ~30 cal yr BP (1920 AD). %TC was generally low (4–10%).

Zone 1, from 60 to 0 cm depth (15 cal yr BP [1935 AD] to present), was characterized by extreme variability, with spikes in *Salix*, *Artemesia*, and *Platanus* all found in the top samples of the record. *Pinus* and *Quercus* were more common than in any other zone in the record (19% and 29% zonal average, respectively). Pollen concentration was average or slightly below average. The sediments in zone 1 were characterized by very fine laminations of white, calcium carbonate rich material (%TC values sometimes >50%) alternating with grey or brown material typical of the rest of the core.

## 6. Discussion

### 6.1. Zaca Lake pollen preservation

Large fluctuations in percentages of Asteraceae, *Platanus*, and indeterminate pollen, as well as total pollen concentration suggest that pollen preservation related to dry and wet phases play a major role in the pollen record. Analyzing pollen preservation is an established component of palynological studies (Tweddle and Edwards, 2010). Changes in vegetation (Tipping, 1987), transport (Delcourt and Delcourt, 1980; Wilmshurst and McGlone, 2005) and depositional environments (Hall and Valastro, 1995; Park et al., 2010) have been shown to affect pollen preservation, and understanding the causes and variability associated with preservation is key to interpreting the Zaca Lake record.

An important component of pollen preservation is identification of the type of pollen deterioration. There is no accepted standard for the quantification of pollen deterioration (Twiddle and Bunting, 2010), however, the most common methodology is one first proposed by Cushing (1967) and subsequently modified in studies by Birks (1970), Delcourt and Delcourt (1980), and Lowe (1982). Typically, this methodology divides pollen deterioration into categories, the most common being: corroded, degraded, crumpled, or broken (Twiddle and Bunting, 2010). Typically corrosion and degradation are caused by chemical weathering (oxidation) and result in loss of surface features, so that shape may be maintained, but grains cannot be positively identified. Crumpling and breaking result from mechanical weathering and change the shape of pollen grains, making them difficult to identify. The type of pollen deterioration is important because it can help determine the source, transport mechanisms, and depositional environment of the pollen (Delcourt and Delcourt, 1980; Lowe, 1982; Wilmshurst and McGlone, 2005).

Indeterminate pollen grains in the Zaca Lake sediments have corroded and degraded surfaces (Figure 8A and B), suggesting that the deterioration of pollen grains was primarily caused by chemical weathering. Degraded surfaces on pollen grains have been interpreted as evidence of low water levels in lacustrine environments, even without complete site desiccation. Lowe (1982) found that lake level regressions exposed littoral lake sediments leading to reworking and degradation of pollen grains. Delcourt and Delcourt (1980) found that lower water levels led to increased oxidation of sediments, the primary cause of pollen degradation (Cushing, 1967). Core Z-1C core was taken in 12 m of water and we find no evidence that water level dropped enough in the last 3000 years to expose the core site, therefore degradation is not the result of direct, *in situ* exposure to the atmosphere. However, it is possible that a decrease in water levels could have resulted in a reworking of exposed lake sediments on the lake margins, contributing degraded material to the depocenter. Lower lake levels might also allow for more effective mixing, potentially increasing the oxygenation of lake water at depth.

An alternative explanation of the source of poor pollen preservation is soil in-wash. Pollen initially deposited in soil is often poorly preserved, and increased soil in-

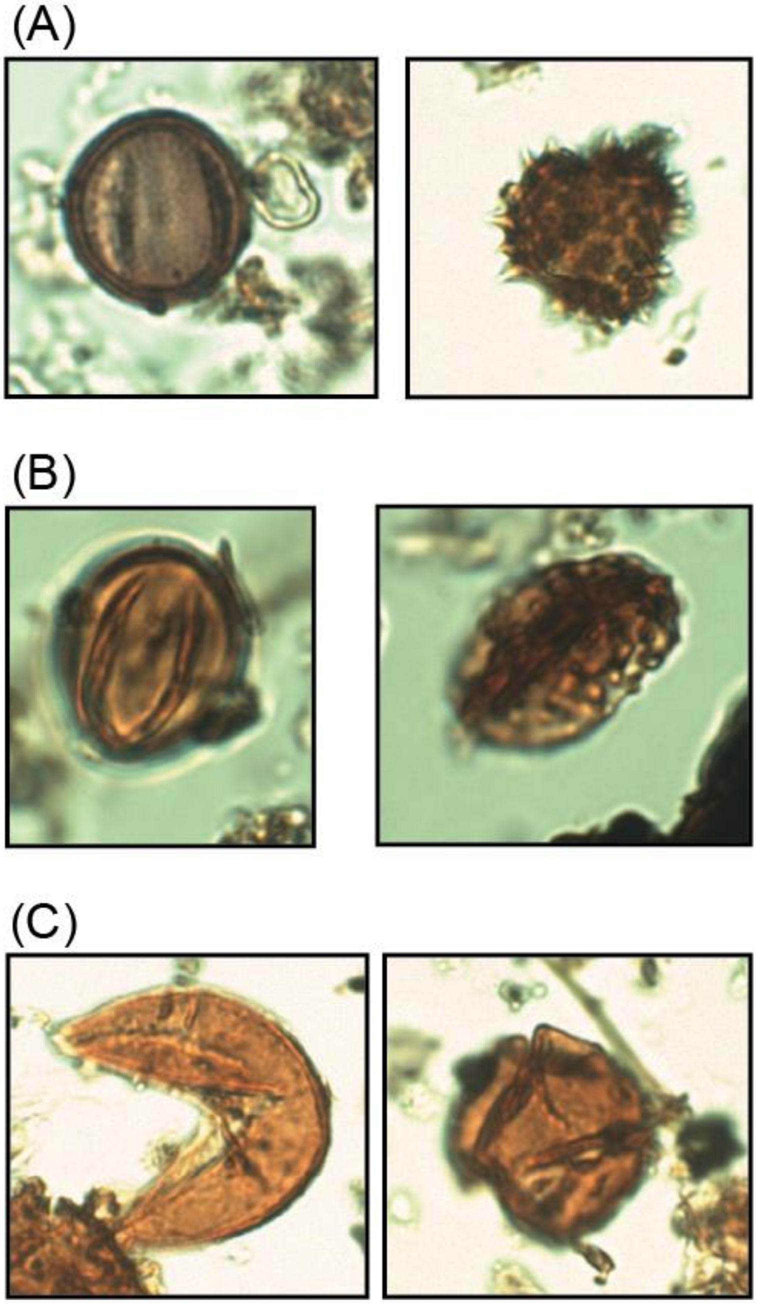

**Figure 8.** Pollen preservation. **A:** Well preserved *Platanus* (left) and Asteraceae (right) pollen grains from the Zaca Lake core. **B:** Pollen grains from the Zaca Lake core (Indeterminate (left), and Asteraceae (right)) which show evidence of severe degradation associated with chemical weathering such as oxidation. Spines in Asteraceae grains allow for positive identification despite severe degradation **C:** Pollen grains (both *Quercus*) from soil which show evidence of crumpling and breaking associated with mechanical weathering.

wash has been identified as a source of poorly preserved pollen in sediment records (Tipping, 1995; Wilmhurst and McGlore, 2005; Tweddle and Edwards, 2010). However, analysis of modern pollen samples from the soil surrounding the lake indicated that the deteriorated pollen grains found in the soil were crumpled or broken (Figure 8C), whereas most deteriorated pollen found in the core show signs of degradation (Figure 8A and B). This suggests that the soil around Zaca Lake is unlikely to be a significant source of indeterminate grains found in the Z1C record, and periods of poor pollen preservation in the Zaca Lake record were more likely a result of lower lake levels than increased soil in-wash.

Variation in structure and composition of pollen grains affects pollen preservation (Hall, S. A., 1981), with some taxa being more resistant to degradation than others. Studies have shown that sporopollenin content and exine thickness are the most important factors for determining resistance to degradation (Havinga, 1967; Campbell, 1999). The two taxa most resistant to degradation are Asteraceae and *Pinus* (Havinga, 1984). Several studies have used high Asteraceae pollen percentage as an indicator of poorly preserved pollen, (Tomescu, 2000; Tweddle and Edwards 2010). Similarly, studies from western North America have noted the increase in *Pinus* percentage in samples with poor pollen preservation (Hall, S. A., 1981; Park et al., 2010; Hall and Valastro, 1995). Pollen grains that can be identified even when damaged or degraded, such as *Pinus*, Amaranthaceae, or Asteraceae account for higher percentages in poorly preserved sediments (Hall, S. A., 1981; Tomescu, 2000). Finally, sections in a record with poorly preserved pollen tend to be characterized by low pollen concentration rates potentially both because of loss of pollen as well as lower pollen productivity during dry periods (Delcourt and Delcount, 1980, Park et al., 2010).

At Zaca Lake the pollen assemblage in poorly preserved sections is characterized by high percentages of Asteraceae, a decrease in the amount of *Platanus*, and low overall pollen concentration. This is not unexpected given the effects of poor preservation. *Platanus* is a grain with a very fine texture and a thin exine that is easily degraded, while Asteraceae is amongst the grains most resistant to destruction and easily identified even if moderately degraded (Havinga, 1984).

What is unexpected is the lack of high percentages of *Pinus*, which is also resistant to degradation and easily identified. This indicates that poor pollen preservation may not be the sole cause of the pollen assemblage found in these sections, and that there may also be changes in plant cover. The high Asteraceae and low *Pinus* and *Platanus* percentages found in poorly preserved sections may be partially a result of a shift from tree species to more drought tolerant annuals during periods of decreased moisture. Other pollen studies in the region from more arid locations have found high Asteraceae percentages even in sediments with well-preserved pollen (Davis, 1992; Cole and Liu, 1994), suggesting that a shift to more Asteraceae at Zaca could also indicate increased aridity.

## 6.2. Vegetation reconstruction and climate interpretation

### 6.2.1. The Late Holocene Dry Period

Terrestrial climatic conditions in coastal Southern California prior to ~1000 BP are not well documented. Most of what is known comes from marine sources, and the relationship between terrestrial and marine records are sometimes difficult to interpret

(Kennett et al., 2007). At Zaca Lake the period between 2700 and 2000 cal yr BP is dominated by herbaceous taxa and poorly preserved pollen (Figure 9), with very low abundances of riparian and tree taxa resulting from reduced tree cover and increased drought-tolerant annuals. This signal is interpreted as indicative of extended dry climate.

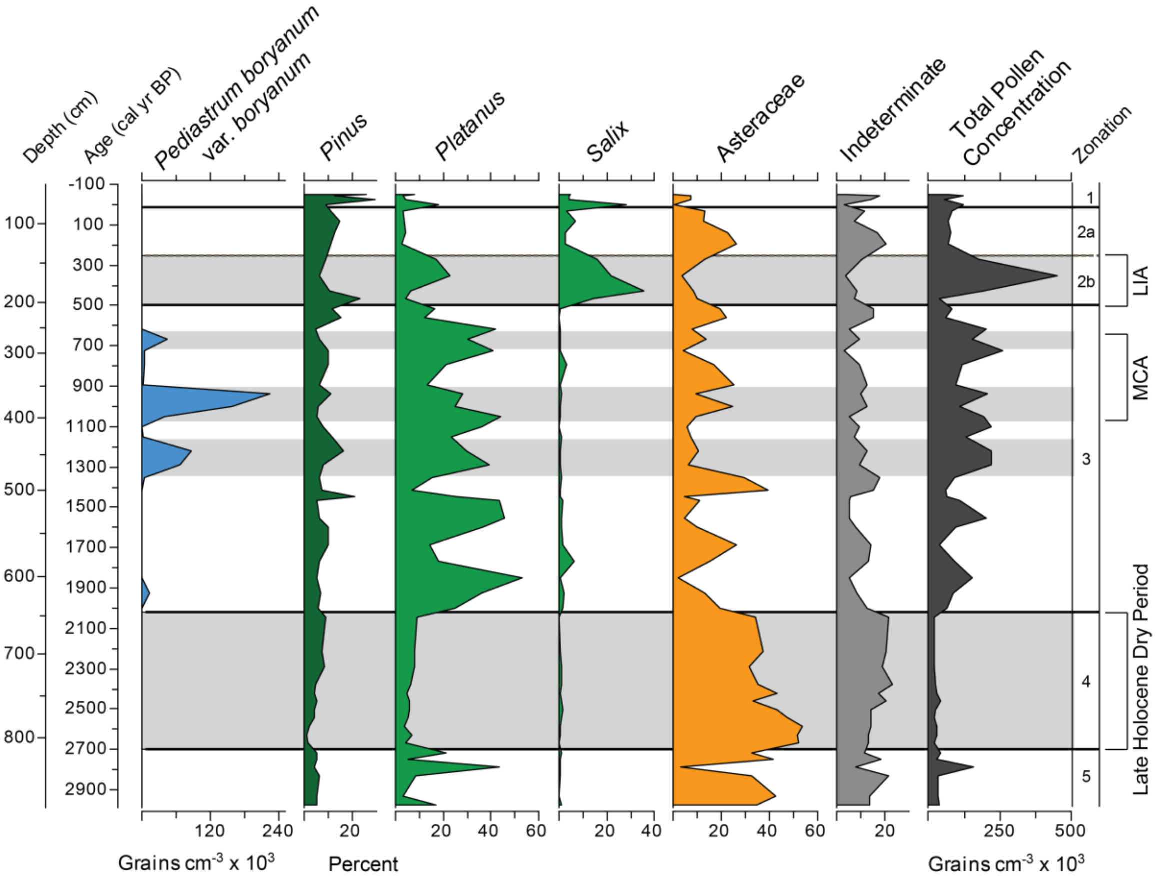

**Figure 9.** Zaca Lake summary diagram. Grey shading represents periods with identified climate signals discussed in the text. 2700–2000 cal yr BP Late Holocene Dry Period, Medieval Climate Anomaly, and Little Ice Age identified in numerous records throughout California.

Several studies in southern California indicate that the period between 3000 and 2000 cal yr BP was characterized by dry conditions. Kirby et al. (2012) interpreted high %TC and low %TOM and C:N ratios at Lower Bear Lake during this period to indicate dry conditions (Figure 10). Kirby et al. (2004) recorded high $\delta^{18}O_{(calcite)}$ values and low magnetic susceptibility between 3000 and 2000 cal yr BP from a littoral sediment core taken at Lake Elsinore; these proxies were interpreted to reflect more evaporative conditions with less run-off. Using a profundal core from Lake Elsinore, Kirby et al. (2010) found generally low % sand between 3200 and 2000 cal yr BP, indicating lower stream runoff and drier conditions. Outside of southern California multiple sites representing a variety of paleoclimate proxy indicators (i.e., lake levels, pollen, tree rings, geomorphology, submerged stumps) identify this as a drought period throughout the central and southern Great Basin (Mensing et al. 2013). Mensing et al. (2013) termed this period the “Late Holocene Dry Period.”

This period also stands out in marine records from SBB. In particular, several records see a substantial shift in conditions at 2000 cal yr BP. Radiolarian assemblages off the west coast of California indicate that the period between 2600 and 2000 cal yr BP represented a period of increased cool water species, which are interpreted as a shift to drier climate (Pisias, 1978). A shift in circulation was identified by a reduction in bioturbation and a greater $^{14}C$ reservoir effect after 2000 cal yr BP (Roak et al., 2003). Barron et al. (2010) also found a shift in conditions at 2000 cal yr BP, to an increased percentage of cold water diatoms, the opposite signal as the one found by Pisias (1978). Foraminifera assemblages shifted at 2000 cal yr BP from taxa found throughout most of the middle Holocene to taxa found during the Younger Dryas (Fisler and Hendy, 2008).

SST suggests generally moderate conditions during the 3000 to 2000 year period and cool temperatures during most of the last 2000 years. Although there is disagreement in the interpretation of marine records as to conditions during the period between 3000 and 2000 cal yr BP, each record shows a clear shift at 2000 cal yr BP.

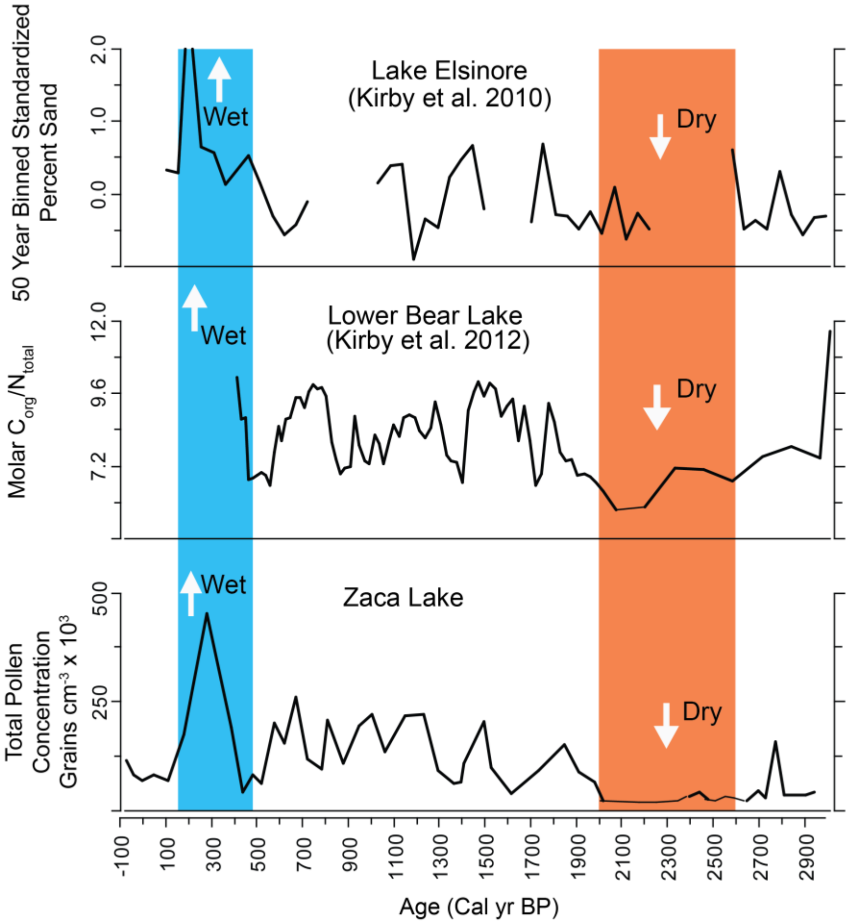

**Figure 10.** Comparison between Zaca Lake and two other records from southern California. Red band represents 2700–2000 cal yr BP dry period identified in the Zaca Lake record. Blue band represents Little Ice Age wet period. Data include a) 50 year binned standardized % sand from Lake Elsinore (Kirby et al. 2010). High sand values indicate periods of increased runoff. b) Molar C/N from Lower Bear Lake (Kirby et al. 2012). Higher values indicate periods of increased runoff and elevated lake levels. C) Overall pollen concentration from Zaca Lake (this study).

### 6.2.2. The Medieval Climate Anomaly

2000 to 500 cal yr BP is characterized by variation in pollen preservation. Samples with well-preserved pollen and a high percentage of *Platanus* represent a deep lake with a healthy riparian zone and minimal oxidation of lake sediments. A key difference compared to the preceding 700 years is greater *Pinus* and *Quercus* percentages, even in periods of poor pollen preservation, indicating increased forest cover. Additionally, higher overall pollen concentration in poorly preserved samples indicate lake levels may not have been as low during dry periods as before 2000 cal yr BP. Overall, the evidence suggests variable conditions after 2000 cal yr BP with a shift to increased moisture.

Substantial effort has been made in the southwestern United States to understand climate during the Medieval Climate Anomaly (MCA) between approximately 1050 and 600 cal yr BP. Tree stumps rooted in modern day Sierra Nevada lakes and rivers have been interpreted as evidence for one or two century-long droughts between ~1050 and 850 cal yr BP and then 700 and 600 cal yr BP, (Stine, 1994; Kleppe et al., 2011; Morgan and Pomerleau, 2012). High concentrations of the colonial algae *Pediastrum boryanum* var. *boryanum* at Zaca Lake between 1070 and 900 and 700 and 650 cal yr BP closely correspond to these periods of inferred droughts, although there are no distinct changes in terrestrial plants.

The appearance of *Pediastrum* is interpreted as indicative of a period of increased temperature, although not significant drought, during the MCA. The ecology of *Pediastrum boryanum* var. *boryanum* is associated with periods of increased temperature (Jankovska and Komarek, 2000). Several tree ring reconstructions with records from the period indicate increased temperature in the Sierra Nevada Range (Graumlich, 1993; Scuderi, 1993). Additionally, trees dating from 1150 to 600 yr BP were growing above modern tree line in the eastern Sierra Nevada suggesting warmer than modern temperatures (Millar et al., 2006).

It is somewhat unclear to what extent the MCA droughts found in the Sierra Nevada Range affected the California coast. Many studies from coastal California, have not found a clear MCA drought signal (Davis, 1992; Cole and Liu, 1994; Kirby et al., 2010; Anderson et al., 2013: Cowart and Byrne, 2013), although insufficient temporal resolution in some of these records may limit the ability to identify changes across such a short time span. There does not appear to be any strong signal of drought in the Zaca pollen record.

There is debate as to the SST conditions between 1200 and 800 cal yr BP in the SBB. High $\delta^{18}O$ values in *Globigerina bulloides* from 1450 to 600 cal yr BP are interpreted as indicative of cool SST (Kennett and Kennett, 2000), as are high percentages of cold water diatoms from 1150 to 550 cal yr BP (Barron et al., 2010). However, the period between 1000–800 cal yr BP was identified as being characterized by warm water species of radiolarian (Pisias, 1978), and between 1150 and 550 cal yr BP higher percentages of warm adapted *Neogloboquadrina incompta* and low percentages of cool adapted *N. pachyderma* were found in a diatom record (Fisler and Hendy, 2008).

### 6.2.3. The Little Ice Age

From 500 to 250 cal yr BP the pollen is characterized by the highest percentages of *Salix* found in the record, which was likely a result of very high lake levels and possibly consistent stream flow. There is a wide, gently sloping alluvial bench extending several hundred meters from the east shore only a few meters above modern lake level, and rising lake levels may have created saturated soils ideal for *Salix* colonization. Additionally, high percentages of *Platanus*, a riparian species, and high pollen concentration with well-preserved pollen support the argument for higher lake levels. Above average levels of *Pinus* and *Quercus*, and low levels of herbaceous species such as Asteraceae suggest that tree cover was higher than during any other period prior to the last 100 years. The apparent increase in lake levels and tree species suggests that this was the wettest period in the last 3000 years.

Evidence from a wide range of sources in southern California suggests that the period from about 500 to 200 cal yr BP, often referred to as The Little Ice Age (LIA) was wet and cool. A precipitation reconstruction from the nearby Transverse Ranges using tree rings of big-cone spruce (*Pseudotsuga macrophylla*) identified 400 to 250 yrs BP as a period of high annual precipitation (Haston and Michaelsen 1994). The period from 600 to 200 cal yr BP corresponds with high percentages of sand resulting from increased runoff at Lake Elsinore (Kirby et al., 2012). A period of abundant *Salix* between 400 and 175 cal yr BP in a pollen record from Wawona Meadow, Yosemite National Park, is interpreted as a LIA signal of increased moisture (Anderson and Stillick, 2013).

### 6.2.4. The historic period

The most recent 100 years in the record (Zone 1) show extreme variability as a result of modern human modification of the landscape. Historical accounts suggest that most of California's oak woodlands were not substantially affected until the American period beginning around AD 1850 (100 cal yr BP) (Mensing, 2006). This appears to be true at Zaca Lake, where the pollen begins showing the impacts of large scale modification starting about 1900 AD. During the historic period there is a sharp increase in *Artemisia*, as well as very high percentages of *Pinus*, a result of a combination of organized planting by the forest service around 1900 AD and fire suppression over the past 100 years (Mensing 1998). The introduction of exotic species to the region by the Spanish in the mid-18th century is an important aspect of the vegetation history of the coast ranges of California. Mensing and Byrne (1998) demonstrated that the invasive Mediterranean annual *Erodium cicutarium* reached Santa Barbara by 1750 AD and its arrival at Zaca Lake shortly thereafter is inferred. In the 20th Century a number of exotic trees were planted around the site, including *Eucalyptus* (Norris and Norris, 1994), and *Cedrus deodara* and their pollen have been found in the record (Mensing, 1998).

### 6.3. Potential climate dynamics between 3000 and 2000 cal yr BP

Mensing et al. (2013) mapped paleoclimatic reconstructions from multiple proxies (lake levels, pollen, geomorphology) across the Great Basin of Western North America for the period between 2800 and 1800 cal yr BP in relation to the dipole pattern of wet vs. dry regions (Figure 11) identified by Wise (2010). Wise (2010) noted a surprisingly narrow boundary separated the dry southwest from the wet northwest, the ENSO dipole pattern, roughly corresponding to 40° N latitude (Fig 9). A persistent dry southwest was associated with ocean-atmosphere conditions typical of a La Niña-like state, characterized by cool sea surface temperatures (SST) in the eastern Pacific.

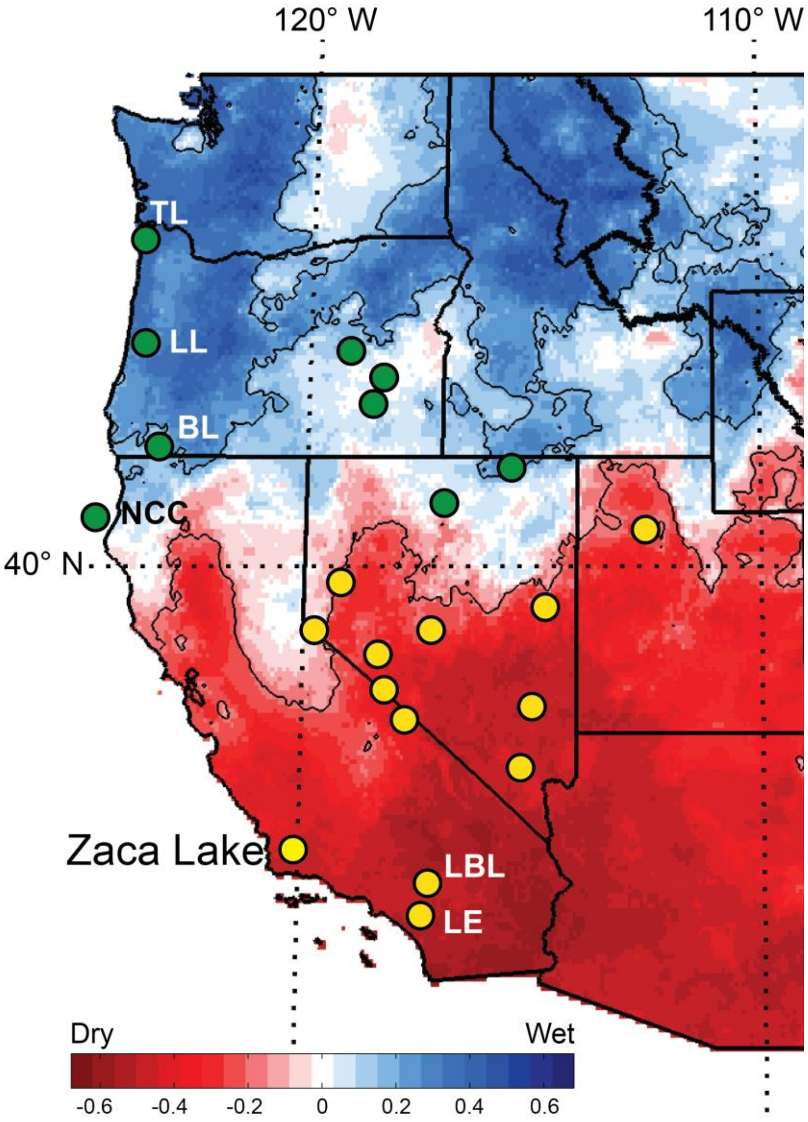

**Figure 11.** Spatial distribution of study sites from the western United States showing dry (yellow circles) and wet (green circles) sites during the period between 2700 and 2000 cal yr BP (unlabeled sited adapted from Mensing et al. 2013). Background shows correlation coefficients between Jun-Nov SOI and Oct-Mar precipitation, 1926-2007 (adapted from Wise 2010). Correlations significant at the .01 level are highlighted and contoured. Labeled sites: BL (Bolan Lake [Briles et al., 2005]); LBL (Lower Bear Lake [Kirby et al., 2012]); LE (Lake Elsinore [Kirby et al., 2010]); NCC (North Coast California [Barron et al., 2013]); TL (Taylor Lake [Long and Whitlock, 2002]).

The Zaca Lake record also indicates persistent drought between 2700 and 2000 cal yr BP and maps onto the dry southwest region (Figure 11)  In addition, two other sites in southern California, Lake Elsinore and Little Bear Lake (Kirby et al., 2010; 2012), indicate drought during this period (Figures 10 and 11). This suggests that if persistent La-Niña like conditions were responsible for creating an extended dry period in the late Holocene, this pattern extended at least from southern California through the central Great Basin.

North of the ENSO dipole boundary in western North America periods of negative ENSO would likely result in increased precipitation, and sites would be expected to indicate wet conditions. Off of the coast of northern California wet conditions persisted between 3000 and 2000 (Barron et al., 2013). They interpret higher levels of *Alnus* and *Quercus* pollen during this period as indicative of increased river runoff associated with increased winter precipitation. Charcoal and pollen from Bolan Lake, Oregon were used to reconstruct fire and climate history, and high levels of *Abies* and low fire frequency between 4500 and 2100 cal yr BP were interpreted as indicative of the wettest period in the Holocene (Briles et al., 2005). Fire and vegetation histories in Oregon from Little Lake (Long et al., 1998) and Taylor Lake (Long and Whitlock, 2002) both found a shift to reduced fire frequency beginning around 2700 cal yr BP, which they interpreted as wetter climate. The evidence from these sites suggest conditions  generally wet climate from 3000 to 2000 cal yr BP north of the 40° N dipole, supporting the hypothesis of Mensing et al. (2013).

Additional evidence from South America also suggests that the period was characterized by low El Niño frequency. Sediment changes in a core from the Andes were interpreted to record changes in the frequency of ENSO events, and the period between 2500 and 1800 cal yr BP was identified as a period of low El Niño frequency (Moy et al., 2002). Percent sand in a lake on the Galapagos Islands increased just before 2000 cal yr BP, indicating an increase in the strength and frequency of El Niño events beginning at that time (Conroy et al., 2008). Finally, an abrupt shift to more frequent El Niño events at about 2000 cal yr BP was identified using a variety of geochemical proxies from a core taken off of the Peruvian coast (Makou et al., 2010).

Overall, climate records from western North America show a period of persistent dry climate between ~2700 and 2000 cal yr BP that is potentially associated with La Niña-type ocean/atmosphere circulation patterns. Drought persisted in the central and southern Great Basin and along the southern California coast and wetter than modern climate was typical north of 40° N. Additionally, evidence for western South America suggests that this period was indeed characterized by reduced El Nino frequency (Moy et al. 2002, Conroy et al. 2008, Makou et al. 2010).

### 6.4. Anthropological applications

Intensification characterizes trajectories of Chumashan sociocultural evolution during the late Holocene (Arnold, 1992, 2004). Population increased, diet breadth expanded, many resources were more heavily exploited, trade increased, there were innovations in technology, health worsened, and sociopolitical organization became more complex and hierarchical. Some authors, including Arnold (2001) and Raab and Larson (1997) have argued that the key period for this pattern of intensification was the Middle-Late Period transition, around 850–800 cal yr BP, and that climate change may have been an important catalyst driving this transition. In that context, it is important to evaluate the pollen record at Zaca Lake within the temporal context of these changes.

Two periods in particular warrant reexamination in the light of the new data. The first is the transition between Middle and Late Periods, around 850-800 cal yr BP. Anthropologists and archaeologists working in the region have long operated under the assumption that climate during this period was characterized by extended drought and pronounced variability (Arnold, et al., 1997, Jones, et al., 1999, Lambert and Walker, 1991, Raab and Larson, 1997). The record from Zaca Lake does not show a clear drying trend during this period, but does suggests potentially higher mean temperatures when compared to modern records. Unfortunately, the Zaca Lake pollen record lacks the adequate temporal resolution to discern the kind of yearly and decadal variation in environmental conditions that might be associated with these changes.

The second area of focus is the period between 2700-2000 cal yr BP, which the Zaca record identifies as a period of persistently dry conditions and which temporally overlaps the proposed transition between the Early and Middle periods in the Chumash cultural record (King, 1990). Little discussion of the role climate may have played during this period is present in the anthropological literature, probably in part because our knowledge of climatic conditions during this period has been limited. Yet the 2700-2000 year drought period has important ramifications for the interpretation of the archaeological record. It coincides with profound changes in lifeways not just for the Chumash of the Santa Barbara region, but for other sociolinguistic groups in California as well. In the Central Valley, and indeed across much of California this period coincides with shifts in diet, from one focused to a large degree on small seeds to one focused more on acorns (Basgall, 1987; Beaton, 1991; Wohlgemuth, 1996). This shift to a more secure but costlier to process food source might be interpreted as a coping mechanism for adverse environmental conditions, increasing population densities or some combination thereof.

Given the Zaca record, the role of climate in models of Chumash cultural evolution warrant reexamination. The models which argue for climate-driven punctuated cultural change and a more recent timing for the development of cultural complexity driven by adverse environmental conditions are generally not supported by the findings a Zaca Lake. In the record from Zaca Lake the period between 1300 and 800 cal yr BP does not appear to be significantly drier than the ~800 years preceding it, certainly not as dry as between 2700 and 2000 cal yr BP. Additionally, numerous other records from central and southern California have failed to identify drought during this period (Cole and Liu, 1994; Kirby et al., 2010; Kirby et al., 2012; Cowart and Byrne, 2013). The Zaca record, however, does support models which take a longer-term view of cultural evolution and the role of climate. The model of environmental conditions impacting culture on a longer term basis (Kennett and Kennett, 2000) seems to be supported by the Zaca record. Additionally, the greater time depth for the development of Chumashan sociocultural complexity argued by King (1990) seems to best fit the record from Zaca. Because of this, the new record from Zaca Lake suggests a model of climate’s role in Chumash cultural evolution that borrows elements from both Kennett and Kennett’s (2000) and King’s (1990) models.

This model sees climate playing an important role in the Early-Middle transition, around 2500 cal yr BP, when a number of important changes in Chumash culture are seen in the record. As previously outlined, these changes include increased diet-breadth, increased exploitation of marine resources, and a shift from interior to coastal settlements. However, unlike the King model and more similar to Kennett and Kennett's (2000) model, this new model identifies adverse climate conditions as playing an important role in these changes.

In light of this interpretation, it is vital that further research be conducted into the possible role climate may have played in the cultural changes during this period. This research likely falls into three categories: archaeological and anthropological research to get a better understanding of the age and extent of cultural change, the development of additional paleoenvironmental records, and further research into the ways environmental change impacts culture (and vice-versa), so that we can better understand what kind of changes we might expect as a result of deleterious environmental conditions.

## 7. Conclusion

A 3000 year record of pollen from Zaca Lake, southern California was constructed. Variations in pollen preservation as well as changes in abundance of major taxa are used to infer climate. It is proposed that when pollen is more degraded this indicates more diagenetic reworking on the lake margins, prior to deposition in the depocenter, and this would occur primarily when conditions are drier than normal and lake levels are lower. Through this approach a multi-centennial drought from 2700 to 2000 cal yr BP is identified in southern California. This dry period corresponds closely with a similar dry period identified by Mensing et al. (2013) in the central and southern Great Basin. The drought found at Zaca confirms that this dry period extended at least from coastal southern California into the central Great Basin of western North America. Additionally, an extended period of La Niña-type ocean/atmospheric circulation and low El Niño frequency may have been a key climate diver. Evidence from the west coast of South America indicates a period of reduced El Niño activity during this period. The spatial distribution of wet and dry signals from sites in North America follows the dipole described by Wise (2010) for the response of climate to La Niña.

Evidence during the period of the Medieval Climate Anomaly suggests that temperatures were warmer than modern, but that this was not a period of extreme drought along southern coastal California. The period corresponding to the Little Ice Age indicates wetter than modern climate and likely the wettest period during the last 3000 years in this region. In the last century, human impacts are noticeable through the appearance of exotic species from the Mediterranean, and increased forest cover associated with reforestation efforts and fire suppression.

Chumash cultural evolution has been linked to the changing environment. Periods of adverse environmental conditions have been interpreted as key drivers of changes in diet, population size and location, leadership structure and complexity, and health. Previous work has tended to focus on the period 1300-800 cal yr BP and the effects of the MCA. The Zaca record suggests that an earlier period, 2700-2000 cal yr BP, may have played a vital role in Chumash cultural evolution. In light of the new record, a new model is proposed which identifies this period of adverse environmental conditions as having had a profound influence on late Holocene Chumash cultural evolution. Additional research needs to be conducted to evaluate this new model.

## 8. References

Anderson, M. K. (2005). *Tending the Wild: Native American Knowledge and the Management of California's Natural Resources* p. 555. University of California Press.

Anderson, R. S., and Byrd, B. F. (1998). Late-Holocene vegetation changes from the Las Flores Creek coastal lowlands, San Diego County, California. *Madroño.* 45:2, 171–182.

Anderson, R. S., Ejarque, A., Brown, P. M., and Hallett, D. J. (2013). Holocene and historical vegetation change and fire history on the north-central coast of California, USA. *The Holocene*. *23*:12, 1797–1810. doi: 10.1177/0959683613505344

Anderson, R. S., and Stillick, R. D. (2013). 800 years of vegetation change, fire and human settlement in the Sierra Nevada of California, USA. *The Holocene*. 23:6, 823–832. doi: 10.1177/0959683612471985

Arnold, J. E. (1992). Complex Hunter-Gatherer-Fishers of Prehistoric California: Chiefs, Specialists, and Maritime Adaptations of the Channel Islands. *American Antiquity*. 57:1, 60–84. doi: 10.2307/2694835

Arnold, J. E. (2007). Credit Where Credit is Due: The History of the Chumash Oceangoing Plank Canoe. *American Antiquity*. 72:2, 196–209. doi: 10.2307/40035811

Arnold, J. E. (2011). Detecting Apprentices and Innovators in the Archaeological Record: The Shell Bead-Making Industry of the Channel Islands. *Journal of Archaeological Method and Theory*. 19, 269–305. doi: 10.1007/s10816-011-9108-1

Arnold, J. E. (editor). (2001). *The Origins of a Pacific Coast Chiefdom: The Chumash of the Channel Islands*. p 317. University of Utah Press, Salt Lake City, UT.

Arnold, J. E. (editor). *Foundations of Chumash Complexity*. Cotsen Institute of Archaeology, University of California, Los Angeles.

Barron, J. A., Heussr, L. E., Addsion, J. A., Bukry, D., Kusler, J. E., and Finney, B. (2013). High-resolution paleoclimatology of the coastal margin of northernmost California during the past 7,400 years.  PP33A-1902, poster, Fall AGU.

Barron, J. A., Bukry, D., and Field, D. (2010). Santa Barbara Basin diatom and silicoflagellate response to global climate anomalies during the past 2200 years. *Quaternary International*. 215, 34–44. doi: 10.1016/j.quaint.2008.08.007

Basgall, M. E. (1987). Resource intensification among hunter-gatherers: acorn economies in prehistoric California. *Research in Economic Anthropology*. 9, 21–52.

Beaton, J. M. (1991). Extensification and intensification in central California prehistory. *Antiquity*. 65:249, 946–952.

Behl, R. J. (1999). Since Bramlette (1946): The Miocene Monterey Formation of California revisited. *Geological Society of America Special paper 338***.** 301-313. doi: 10.1130/0-8137-2338-8.301

Birks, B. (1970). Inwashed Pollen Spectra at Loch Fada, Isle of Skye. *New Phytologist*. 69:3, 807–820. doi: 10.1111/j.1469-8137.1970.tb02464.x

Blaauw, M., and Christen, J. A. (2011). Flexible Paleoclimate Age-Depth Models Using an Autoregressive Gamma Process. *Bayesian Analysis*. 6:3, 457–474. doi: 10.1214/11-BA618

Braje, T. J., Kennett, D. J., Erlandson, J. M., and Culleton, B. J. (2007). Human Impacts on Nearshore Shellfish Taxa: A 7,000 Year Record from Santa Rosa Island, California. *American Antiquity*. 72:4, 735–756. doi: 10.2307/25470443

Briles, C. E., Whitlock, C., and Bartlein, P. J. (2005). Postglacial vegetation, fire, and climate history of the Siskiyou Mountains, Oregon, USA. *Quaternary Research*. 64, 44–56. doi: 10.1016/j.yqres.2005.03.001

Byrne, R., Ingram, B. L., Starratt, S., Malamud-Roam, F., Collins, J. N., and Conrad, M. E. (2001). Carbon-Isotope, Diatom, and Pollen Evidence for Late Holocene Salinity Change in a Brackish Marsh in the San Francisco Estuary. *Quaternary Research*. 55, 66–76. doi: 10.1006/qres.2000.2199

Campbell, I. D. (1999). Quaternary pollen taphonomy: examples of differential redeposition and differential preservation. *Palaeogeography, Palaeoclimatology, Palaeoecology*. 149, 245–256. doi: 10.1080/01916122.1991.9989387

Caponigro, M. A. (1976). T*he diatom stratigraphy and paleolimnology of Zaca Lake, California*. Unpublished M.A. thesis, University of California, Santa Barbara.

Cayan, D. R., Rhoads, J., 1984. Local relationships between United States west coast precipitation and monthly mean circulation parameters. *Monthly Weather Review*. 112, 1276–1282.

Cole, K. L., and Liu, G. W. (1994). Holocene Paleoecology of an Estuary on Santa Rosa Island, California. *Quaternary Research*. 41, 326–335. doi: 10.1006/qres.1994.1037

Cole, K. L., and Wahl, E. (2000). A Late Holocene Paleoecological Record from Torrey Pines State Reserve, California. *Quaternary Research*. 53, 341–351. doi: 10.1006/qres.1999.2121

Colten, R. H. (2001). Ecological and Economic Analysis of Faunal Remains from Santa Cruz Island. In: *The Origins of a Pacific Coast Chiefdom: The Chumash of the Channel Islands*, edited by Arnold, J. E. University of Utah Press, UT 199-219.

Conroy, J. L., Overpeck, J. T., Cole, J. E., Shanahan, T. M., and Steinitz-Kannan, M. (2008). Holocene changes in eastern tropical Pacific climate inferred from a Galápagos lake sediment record. *Quaternary Science Reviews*, 27, 1166–1180. doi: 10.1016/j.quascirev.2008.02.015

Cook, E. R., Woodhouse, C. A., Eakin, M., Meko, D. M., and Stahle, D. W. (2004). Long-Term Aridity Changes in the Western United States. *Science*. 306, 1015–1018. doi: 10.1126/science.1102586

Cowart, A., and Byrne, R. (2013). A Paleolimnological Record of Late Holocene Vegetation Change from the Central California Coast. *California Archaeology*. 5(2), 337–352. doi: 10.1179/1947461X13Z.00000000018

Cushing, E. J. (1967). Evidence for Differential Pollen Preservation in Late Quaternary Sedements in Minnesota. *Review of Palaeobotany and Palynology*. 4, 87–101. doi: 10.1016/0034-6667(67)90175-3

Daly, C., Halbleib, M., Smith, J. I., Gibson, W. P., Doggett, M. K., Taylor, G. H., Curtis, J., and Pasteris, P. P., (2008). Physiographically sensitive mapping of climatological temperature and precipitation across the conterminous United States. *International Journal of Climatology.* 28, 2031–2064. doi: 10.1002/joc.1688

Davis, O. K. (1992). Rapid climatic change in coastal southern California inferred from pollen analysis of San Joaquin Marsh. *Quaternary Research*, 37, 89–100. doi: 10.1016/0033-5894(92)90008-7

Dean, W. E., 1974. Determination of carbonate and organic matter in calcareous sediments by loss on ignition comparison to other methods. *Journal of Sediment. Petrology*. 44, 242-248.

Delcourt, P. A., and Delcourt, H. R. (1980). Pollen Preservation and Quaternary Environmental History in the Southeastern United States. *Palynology*. 4, 215–231. doi: 10.1080/01916122.1980.9989209

Erlandson, J. M. (1997). The Middle Holocene on the Western Santa Barbara Coast. In *Archaeology of the California Coast During the Middle Holocene*, edited by J. M. Erlandson and M. A. Glassow, p 91-110. Cotsen Institute of Archaeology, Universiy of California, Los Angeles.

Erlandson, J. M., and Rick, T. C. (2002). Late Holocene Cultural Developments Along the Santa Barbara Coast. In *Catalysts to Complexity: Late Holocene Societies of the California Coast*, edited by J. M. Erlandson and T. L. Jones. 166-182. Cotsen Institute of Archaeology, University of California, Los Angeles.

Faegri, K., and Iversen, J., 1985. *Textbook of Pollen Analysis*. Fourth ed., New York: Hafner Press.

Feakins, S. J., Kirby, M. E., Cheetham, M. I., Ibarra, Y., & Zimmerman, S. R. H. (2014). Fluctuation in leaf wax D/H ratio from a southern California lake records significant variability in isotopes in precipitation during the late Holocene. *Organic Geochemistry*. 66, 48–59. doi: 10.1016/j.orggeochem.2013.10.015

Field, B., and Baumgartner, T. R. (2000). A 900 year stable isotope record of interdecadal and centennial change from the California Current. *Paleoceanography*. 15:6, 695–708. doi: 10.1029/1999PA000480

Fisler, J. and I. L. Hendy. (2008) California Current System Response to Late Holocene Climate Cooling in Southern California. *Geophysical Research Letters*. 35, 1–5. doi: 10.1029/2008GL033902

Gamble, L. H. (2005). Culture and climate: reconsidering the effect of palaeoclimatic variability among Southern California hunter-gatherer societies. *World Archaeology, 37*(1), 92–108. doi:10.1080/0043824042000329586

Gamble, L. H., Walker, P. L., & Russell, G. S. (2001). An Integrative Approach to Mortuary Analysis: Social and Symbolic Dimensions of Chumash Burial Practices. *American Antiquity*. 66:2, 185–212. doi: 10.2307/2694605

Glassow, M. A. (1970). An evaluation of the archaeological resources at Zaca Lake, Santa Barbara County, California. Santa Barbara County survey report SR-00591.

Glassow, M. A. (1979). An Evaluation of Models of Inezeño Chumash Subsistence and Economics. *Journal of California and Great Basin Archaeology*. 1(1), 155-161.

Glassow, M. A., Gamble, K. H., Perry, J. E., and Russell, G. S. (2006). Prehistory of the Northern California Bight and the Adjacent Transverse Ranges. In *California Prehistory: Colonization, Culture, and Complexity*, edited by Jones, T. L., Klar, K. A. AltaMira Press, MD. 191-213.

Graumlich, L. J. (1993). A 1000-year record of temperature and precipitation in the Sierra Nevada. *Quaternary Research*, *39*, 249–255. doi: 10.1006/qres.1993.1029

Grelaud, M., Schimmelmann, A., and Beaufort, L. (2009). Coccolithophore response to climate and surface hydrography in Santa Barbara Basin, California, AD 1917–2004. *Biogeosciences*. 6, 2025–2039. doi: 10.5194/bg-6-2025-2009

Hall, C. A. (1981). Map of geology along the Little Pine Fault, parts of the Sisquoc, Foxen Canyon, Zaca Lake, Bald Mountain, Los Olivos, and Figueroa Mountain quadrangles, Santa Barbara County, California. U.S. Geologic Survey Miscellaneous Field Studies. Map MF-1285.

Hall, S. A. (1981). Deteriorated Pollen Grains and the Interpretation of Quaternary Pollen Diagrams. *Review of Paleobotany and Palynology*. 32, 193-206. doi: 10.1016/0034-6667(81)90003-8

Hall, S. A., and Valastro, S. (1995). Grassland Vegetation in the Southern Great Plains during the Last Glacial Maximum. *Quaternary Research*. 44, 237–245. doi: 10.1006/qres.1995.1068

Haston, L and Michaelsen, J. (1994). Long-Term Central California Precipitation Variability and Relationships to El Nino-Southern Oscillation. *Journal of Climate*. 7, 1373-1387. doi: 10.1175/1520-0442(1994)007%3C1373:LTCCCP%3E2.0.CO;2

Havinga, A. J., (1967). Palynology and pollen preservation. *Review of Paleobotany and Palynology*. 2, 81–98. doi: 10.1016/0034-6667(67)90138-8

Havinga, A. J., (1984). A 20-year experimental investigation into the differential corrosion susceptibility of pollen and spores in various soil types. *Pollen Spores*. 26, 541–558.

Heiri, O., Lotter, A. F., and Lemcke, G. (2001). Loss on ignition as a method for estimating organic and carbonate content in sediments: reproducibility and comparability of results. *Journal of Paleolimnology*. 25, 101–110. doi: 10.1023/A:1008119611481

Herweijer, C., Seager, R., Cook, E. R., and Emile-Geay, J. (2007). North American Droughts of the Last Millennium from a Gridded Network of Tree-Ring Data. *Journal of Climate*. 20, 1353–1376. doi: 10.1175/JCLI4042.1

Heusser, L. (1978). Pollen in Santa Barbara Basin, California: A 12,000-yr record. *Geological Society of America Bulletin*. 89, 673–678. doi: 10.1130/0016-7606(1978)89<673:PISBBC>2.0.CO;2

Heusser, L. E., and Sirocko, F. (1997). Millennial pulsing of environmental change in southern California from the past 24 k.y.: A record of Indo-Pacific ENSO events? *Geology*. 25:3, 243–246. doi: 10.1130/0091-7613(1997)025<0243:MPOECI>2.3.CO;2

Huguet, C., Schimmelmann, A., Thunell, R., Lourens, L. J., Damsté, J. S. S., and Schouten, S. (2007). A study of the TEX 86 paleothermometer in the water column and sediments of the Santa Barbara Basin, California. *Paleoceanography*. 22, 1-9. doi: 10.1029/2006PA001310

Ibarra, Y., Corsetti, F. A., Cheetham, M. I., and Feakins, S. J. (2014). Were fossil spring-associated carbonates near Zaca Lake, Santa Barbara, California deposited under an ambient or thermal regime? *Sedimentary Geology*, (2014). doi: 10.1016/j.sedgeo.2013.12.005

Jankovska, V., and Komarek, J. (2000). Indicative Value of Pediastrum and Other Coccal Green Algae in Palaeoecology. *Folia Geobotanica*. 35, 59–82. doi: 10.1007/BF02803087

Johnson, J. R. (1988). Chumash Social Organization: An Ethnohistoric Perspective Ph.D. dissertation, University of California, Santa Barbara.

Johnson, J. R. (2001). Ethnohistoric Reflections of Cruzeno Chumash Society. In: *The Origins of a Pacific Coast Chiefdom: The Chumash of the Channel Islands*, edited by Arnold, J. E. University of Utah Press. 53-70.

Jones, T. L., Brown, G. M., Raab, L. M., McVickar, J. L., Spaulding, W. G., Kennett, D. J., York, A., and Walker, P. L. (1999). Environmental Imperatives Reconsidered: Demographic Crises in Western North America during the Medieval Climatic Anomaly. *Current Anthropology*. 20:2, 137-170. doi: 10.1006/qres.1998.2000

Kapp, R. O., Davis, O. K., and King, J. E., (2000). *Ronald O. Kapp's Pollen and Spores*. Second ed. College Station, TX: American Association of Stratigraphic Palynologists.

Keeley, J. E. (2002). Native American Impacts on Fire Regimes of the California Coastal Ranges. *Journal of Biogeography*. 29:3, 303-320. doi: 10.1046/j.1365-2699.2002.00676.x

Kennett, D. J. (2005). *The Island Chumash: Behavioral Ecology of a Maritime Society*. p 298. University of California Press, CA.

Kennett, D. J., and Kennett, J. P. (2000). Competitive and Cooperative Responses to Climatic Instability in Coastal Southern California. *American Antiquity*. 65:2, 379–395. doi: 10.2307/2694065

Kennett, D. J., Kennett, J. P., Erlandson, J. M., and Cannariato, K. G. (2007). Human responses to Middle Holocene climate change on California's Channel Islands. *Quaternary Science Reviews*. 26, 351–367. doi: 10.1016/j.quascirev.2006.07.019

King, C. (1975). Chumash Inter-Village Economic Exchange. *The Indian Historian*. 4(1), 31-43.

King, C. (1990). *A comparative Study of Artifacts Used for Social System Maintenance in the Santa Barbara Channel Region before A.D. 1804*. p. 296 Garland Publishing, New York.

Kirby, M. E., Lund, S. P., Anderson, M. a., and Bird, B. W. (2007). Insolation forcing of Holocene climate change in Southern California: a sediment study from Lake Elsinore. *Journal of Paleolimnology*. 38, 395–417. doi: 10.1007/s10933-006-9085-7

Kirby, M. E., Lund, S. P., Patterson, W. P., Anderson, M. A., Bird, B. W., Ivanovici, L., and Nielsen, S. (2010). A Holocene record of Pacific Decadal Oscillation (PDO)-related hydrologic variability in Southern California (Lake Elsinore, CA). *Journal of Paleolimnology*. 44, 819–839. doi: 10.1007/s10933-010-9454-0

Kirby, M. E., Poulsen C. J., Lund S. P., Patterson, W. P., Reidy, L., and Hammond, D. E. (2004). Late Holocene lake-level dynamics inferred from magnetic susceptibility and stable oxygen isotope data: Lake Elsinore, Southern California (USA). *Journal of Paleolimnology*. 31, 275–293. doi: 10.1023/B:JOPL.0000021710.39800.f6

Kirby, M. E., Zimmerman, S. R. H., Patterson, W. P., and Rivera, J. J. (2012). A 9170-year record of decadal-to-multi-centennial scale pluvial episodes from the coastal Southwest United States: a role for atmospheric rivers? *Quaternary Science Reviews*. 46, 57–65. doi: 10.1016/j.quascirev.2012.05.008

Kleppe, J. A., Brothers, D. S., Kent, G. M., Biondi, F., Jensen, S., and Driscoll, N. W. (2011). Duration and severity of medieval drought in the Lake Tahoe Basin. *Quaternary Science Reviews*. 30, 3269–3279. doi: 10.1016/j.quascirev.2011.08.015

Lambert, P. M. (1993). Health in Prehistoric Populations of the Santa Barbara Channel Islands. *American Antiquity*. 58:3, 509–522. doi: 10.2307/282110

Lambert, P. M. and Walker, P. L. (1991). Pysical anthropological evidence for the evolution of social complexity in coastal Southern California. *Antiquity*. 65:249, 963–973.

Larson, D. O. and Michaelsen, J. (1989). Climate Variability: A Compounding Factor Causing Culture Change among Prehistoric Coastal Populations. Manuscript of file, Department of Anthropology, California State University, Long Beach.

Li, C., Sessions, A. L., Valentine, D. L., and Thiagarajan, N. (2011). D/H variation in terrestrial lipids from Santa Barbara Basin over the past 1400years: A preliminary assessment of paleoclimatic relevance. *Organic Geochemistry*. 42, 15–24. doi: 10.1016/j.orggeochem.2010.09.011

Long, C. J., and Whitlock, C. (2002). Fire and Vegetation History from the Coastal Rain Forest of the Western Oregon Coast Range. *Quaternary Research*. 58, 215–225. doi: 10.1006/qres.2002.2378

Long, C. J., Whitlock, C., Bartlein, P. J., and Millspaugh, S. H. (1998). A 9000-year fire history from the Oregon Coast Range, based on a high-resolution charcoal study. *Canadian Journal of Forest Research*. 28, 774–787. doi: 10.1139/cjfr-28-5-774

Lowe, J. (1982). Three Pollen Profiles from the Teith Valley, Perthshire, Scotland. II. Analysis of Deteriorated Pollen. *New Phytologist*. 90, 371–385. doi: 10.1111/j.1469-8137.1982.tb03268.x

Martin, S. L., and Popper, V. S. (2001). Paleoethnobotanical Investigations of Archaeological Sites on Santa Clara Island. In: *The Origins of a Pacific Coast Chiefdom: The Chumash of the Channel Islands*, edited by Arnold, J. E. University of Utah Press, UT 245-259.

MacArthur, R. H., and Pianka, E. R. (1966). On Optimal Use of a Patchy Environment. *The American Naturalist*. 100:916, 603–609.

MacDonald, G. M., Kremenetski, K. V., and Hidalgo, H. G. (2008). Southern California and the perfect drought: Simultaneous prolonged drought in southern California and the Sacramento and Colorado River systems. *Quaternary International*. 188, 11–23. doi: 10.1016/j.quaint.2007.06.027

Makou, M. C., Eglinton, T. I., Oppo, D. W., and Hughen, K. A. (2010). Postglacial changes in El Niño and La Niña behavior. *Geology*. 38, 43–46. doi: 10.1130/G30366.1

Malamud-Roam, F. P., Ingram, L. B., Hughes, M., and Florsheim, J. L. (2006). Holocene paleoclimate records from a large California estuarine system and its watershed region: linking watershed climate and bay conditions. *Quaternary Science Reviews*. 25, 1570–1598. doi: 10.1016/j.quascirev.2005.11.012

Meko, D. M., Therrell, M. D., Baisan, C. H., and Hughes, M. K. (2001). Sacramento River Flow Reconstructed to A.D. 869 From Tree Rings. *Journal of the American Water Resources Association*. 37:4, 1029–1039.

Mensing, S. A. (1993). *The Impact of European Settlement on Oak Woodlands and Fire: Pollen and Charcoal Evidence from the Transverse Ranges, California*. Unpublished Dissertation, University of California, Berkeley.

Mensing, S. A. (1998) 560 years of vegetation change in the region of Santa Barbara, California. *Madroño*. 45:1, 1-11.

Mensing, S. A. (2006). The History of Oak Woodlands in California , Part II : The Native American and Historic Period. *The California Geographer*. 46, 1–31.

Mensing, S. A., and Byrne, R. (1998). Pre-Mission Invasion of *Erodium cicutarium* in California. *Journal of Biogeography*. 25, 757–762. doi: 10.1046/j.1365-2699.1998.2540757.x

Mensing, S. A., Michaelsen, J., and Byrne, R. (1999). A 560-Year Record of Santa Ana Fires Reconstructed from Charcoal Deposited in the Santa Barbara Basin, California. *Quaternary Research*. 51, 295–305. doi: 10.1006/qres.1999.2035

Mensing, S. A., Sharpe, S. E., Tunno, I., Sada, D. W., Thomas, J. M., Starratt, S., and Smith, J. (2013). The Late Holocene Dry Period: multiproxy evidence for an extended drought between 2800 and 1850 cal yr BP across the central Great Basin, USA. *Quaternary Science Reviews*. 78, 266–282. doi: 10.1016/j.quascirev.2013.08.010

Millar, C. I., King, J. C., Westfall, R. D., Alden, H. A., & Delany, D. L. (2006). Late Holocene forest dynamics, volcanism, and climate change at Whitewing Mountain and San Joaquin Ridge, Mono County, Sierra Nevada, CA, USA. *Quaternary Research*, *66*, 273–287. doi: 10.1016/j.yqres.2006.05.001

Moore, P.D., and Webb, J.A., (1978). *An Illustrated Guide to Pollen Analysis*. New York: Wiley and Sons.

Morgan, C., and Pomerleau, M. M. (2012). New evidence for extreme and persistent terminal medieval drought in California's Sierra Nevada. *Journal of Paleolimnology*. 47, 707–713. doi: 10.1007/s10933-012-9590-9

Moy, C. M., Seltzer, G. O., Rodbell, D. T., and Anderson, D. M. (2002). Variability of El Niño/Southern Oscillation Activity at Millennial Timescales during the Holocene Epoch. *Nature*. 420, 162–165. doi: 10.1038/nature01163.1.

Nalepka, D. and Walanus, A. (2003). Data processing in pollen analysis. *Acta Palaeobotanica* 43, 125-134.

Negrini, R. M., Wigand, P. E., Draucker, S., Gobalet, K., Gardner, J. K., Sutton, M. Q., and Yohe, R. M. (2006). The Rambla highstand shoreline and the Holocene lake-level history of Tulare Lake, California, USA. *Quaternary Science Reviews*. 25, 1599–1618. doi: 10.1016/j.quascirev.2005.11.014

Norris, J., and Norris, L. (1994). *History of Zaca Lake*. Los Olivos, California: Olive Press Publications.

Park, J., Byrne, R., Böhnel, H., Garza, R. M., and Conserva, M. (2010). Holocene climate change and human impact, central Mexico: a record based on maar lake pollen and sediment chemistry. *Quaternary Science Reviews*. 29, 618–632. doi: 10.1016/j.quascirev.2009.10.017

Pisias, N. G. (1978). Paleoceanography of the Santa Barbara Basin During the last 8000 Years. *Quaternary Research*. 10, 366–384. doi: 10.1016/0033-5894(78)90027-3

Pisias, N. G. (1979). Model for paleoceanographic reconstructions of the California Current during the last 8000 years. *Quaternary Research*. 11, 373–386. doi: 10.1016/0033-5894(79)90081-4

Raab, L. M., & Larson, D. O. (1997). Medieval Climatic Anomaly and Punctuated Cultural Evolution in Coastal Southern California. *American Antiquity*. 62:2, 319–336. doi: 10.2307/282513

Reimer, P. J., Bard, E., Bayliss, A., Beck, J. W., Blackwell, P. G., Ramsey, C. B, Buck, J. E., Cheng, H., Edwards, R. L., Friedrich, M., Grootes, P. M., Guilderson, T. P., Haflidason, H., Jajdas, I., Hatté, C., Heaton, T. J., Hoffmann, D. L., Hogg, A. G., Hughen, K. A., Kaiser, K. F., Kromer, B., Manning, S. W., Niu, M., Reimer, R. W., Richards, D. A., Scott, E. M., Southon, J. R., Staff, R. A., Turney, C. S. M., and van der Plicht, J. (2013). Intcal13 and marine13 radiocarbon age calibration curves 0 – 50,000 years cal BP. *Radiocarbon*. 55:4, 1869-1887. doi: 10.2458/azu_js_rc.55.16947

Rick, T. C., Erlandson, J. M., Vellanoweth, R. L., and Braje, T. J., (2005). From Pleistocene Mariners to Complex Hunter-Gatherers : The Archaeology of the California Channel Islands. *Journal of World Prehistory*. 19:3, 169–228. doi: 10.1007/s10963-006-9004-x

Roark, E. B., Ingram, B. L., Southon, J., and Kennett, J. P. (2003). Holocene foraminiferal radiocarbon record of paleocirculation in the Santa Barbara Basin. *Geology*. 31:4, 379. doi: 10.1130/0091-7613(2003)031<0379:HFRROP>2.0.CO;2

Scuderi, L. A. (1993). A 2000-year tree ring record of annual temperatures in the Sierra Nevada mountains. *Science*. 259, 1433–1436. doi: 10.1126/science.259.5100.1433

Stine, S. (1994). Extreme and persistent drought in California and Patagonia during mediaeval time. *Nature*. 369, 546–549. doi: 10.1038/369546a0

Timbrook, J., Johnson, J. R., & Earle, D. D. (1982). Vegetation Burning by the Chumash. *Journal of California and Great Basin Anthropology*. 4:2, 163–186.

Tipping, R. (1987). The origins of corroded pollen grains at five early postglacial pollen sites in western Scotland. *Review of Palaeobotany and Palynology*. 53, 151–161. doi: 10.1016/0034-6667(87)90011-X

Tipping, R. (1995). Holocene landscape change at Carn Dubh, near Pitlochry, Perthshire, Scotland. *Journal of Quaternary Science*. 10, 59–75. doi: 10.1002/jqs.3390100107

Tomescu, A. (2000). Evaluation of Holocene pollen records from the Romanian Plain. *Review of Palaeobotany and Palynology*. 109, 219–233. doi: 10.1016/S0034-6667(99)00056-1

True, D. L. (1990). Site Locations and Water Supply: A Perspective from Northern San Diego County, California. *New World Archaeology* 4, 37-60.

Tweddle, J. C., and Edwards, K. J. (2010). Pollen preservation zones as an interpretative tool in Holocene palynology. *Review of Palaeobotany and Palynology*. 161, 59–76. doi: 10.1016/j.revpalbo.2010.03.004

Twiddle, C. L., and Bunting, M. J. (2010). Experimental investigations into the preservation of pollen grains: A pilot study of four pollen types. *Review of Palaeobotany and Palynology*. 162, 621–630. doi: 10.1016/j.revpalbo.2010.08.003

Walker, P. L., and Erlandson, J. M. (1986). Dental Evidence for Prehistoric Dietary Change on the Northern Channel Islands, California. *American Antiquity*. 51:2, 375–383. doi: 10.2307/279951

Wohlgemuth, E. (1996). Resource intensification in prehistoric California: Evidence from archaeobotanical data. *Journal of California and Great Basin Anthropology*. 18:1, 81–103.

Wilmshurst, J. M., and McGlone, M. S. (2005). Corroded Pollen and Spores as Indicators of Changing Lake Sediment Sources and Catchment Disturbance. *Journal of Paleolimnology*. 34, 503–517. doi: 10.1007/s10933-005-5476-4

Wise, E. K. (2010). Spatiotemporal variability of the precipitation dipole transition zone in the western United States. *Geophysical Research Letters*. 37, 1-5. doi: 10.1029/2009GL042193