SHELLFISH AND ANCIENT HUMAN ECOLOGY: AN ARCHAEOLOGICAL STUDY FROM SAN MIGUEL ISLAND, CALIFORNIA

by

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A THESIS

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Archaeologist and ecologists are increasingly recognizing historical data as an important source in analyzing human ecological relationships. Archaeology provides a means for investigating such relationships and islands provide ideal landscapes for researching human impacts on marine ecosystems. My thesis is based on a 10,000 year-old record of shellfish harvesting from San Miguel Island, California and analyzes possible human impacts on California mussel (*Mytilus californianus*), black abalone (*Haliotis cracherodii*), and red abalone (*H. rufescens*) populations. I discuss the environmental setting, archaeological background, and pertinent ecology of San Miguel Island, California as it pertains to shellfish and humans. Utilizing shell length measurements, I examine the human-environment relationship that existed between island peoples and shellfish communities. I suggest that shellfish harvesting pressures by the Chumash Indians and their antecedents over the past 10,000 years impacted shellfish communities by reducing the overall size of shells through time on San Miguel Island, California.

> Wilderness is not an easy-to-observe ecological condition as much as it is the interplay between the constantly changing state of nature and the constantly changing state of the human mind.
>
> - Charles Redman (1999:203)

INTRODUCTION

Studies of human environmental impacts in coastal settings are of great interest to resource managers, conservationists, and other scientists working to develop sustainable resource management. Management plans are based on ecological baselines, essential reference points in evaluating the health of our ecosystems and in assessing the elusive "natural" state (Jackson et al. 2001). Unfortunately, our baselines have been developed from ecological or historical records that rarely span more than the last few decades, long after the devastating effects of commercial overfishing, coastal development, and environmental degradation. Consequently, ecologists, resource managers, and visitors often evaluate the health of coastal environments without knowing how they used to look, a phenomenon referred to as the "shifting baseline syndrome" (Pauly 1995).

The reexamination of our notions of "pristine" and "natural" have come, in part, from the work of archaeologists who have shown that humans have exploited a variety of marine environments for much longer than previously believed (Erlandson 2001). Research of ancient human ecology is, then, a reaction to contemporary observations of and questions about environmental impacts. Archaeologists have concluded that all humans impact their environment, but large, sedentary human populations generally have greater ecological impacts (Erlandson and Rick 2005). Deep historical perspectives, provided by archaeologists, paleoecologists, and other scientists, can help outline a plan for the "remediation and restoration" of marine ecosystems (Jackson et al. 2001:636) and answer questions concerning human-environmental interactions. Is environmental degradation by humans a recent phenomenon? Does population growth inevitably lead to devastated environments and species extinctions? Or, did some ancient humans develop economic practices that sustained large populations as well as natural ecosystems?

When first contacted by Europeans, Native American groups were living as part of an actively managed environment. The natural state of "wilderness" ecosystems, as we imagine them today, has largely been crafted by humans over thousands of years (Kay and Simmons 2002; Redman 1999). Through long-term settlement, anatomically modern humans (*Homo sapiens sapiens*) have caused significant environmental impacts across the globe. Humans are efficient predators and, as researchers have recently noted, relatively small human populations can have significant impacts on their environment (Alroy 2001; Kay and Simmons 2002; Redman 1999). In an effort to trace these impacts through time and search for solutions to contemporary environmental management problems, ecologists, archaeologists and other researchers have collaborated in studies investigating long-term human-environmental relationships. Islands are ideal settings for examining this relationship because their fragile ecosystems are highly susceptible to impact (Erlandson et al. 2004). The Channel Islands of southern California, in particular, provide a long and well-preserved record of human occupation from which to examine ancient human ecology.

In this paper, I examine ancient human ecology using a 10,000-year record of shellfish harvesting from San Miguel Island, California (Erlandson et al. 2004). I examine how specific shellfish communities varied through time and how humans may have influenced this variation. I suggest that shellfish harvesting pressures by Native

Americans over the past 10,000 years impacted shellfish communities by reducing the average size of shells through time on San Miguel Island.

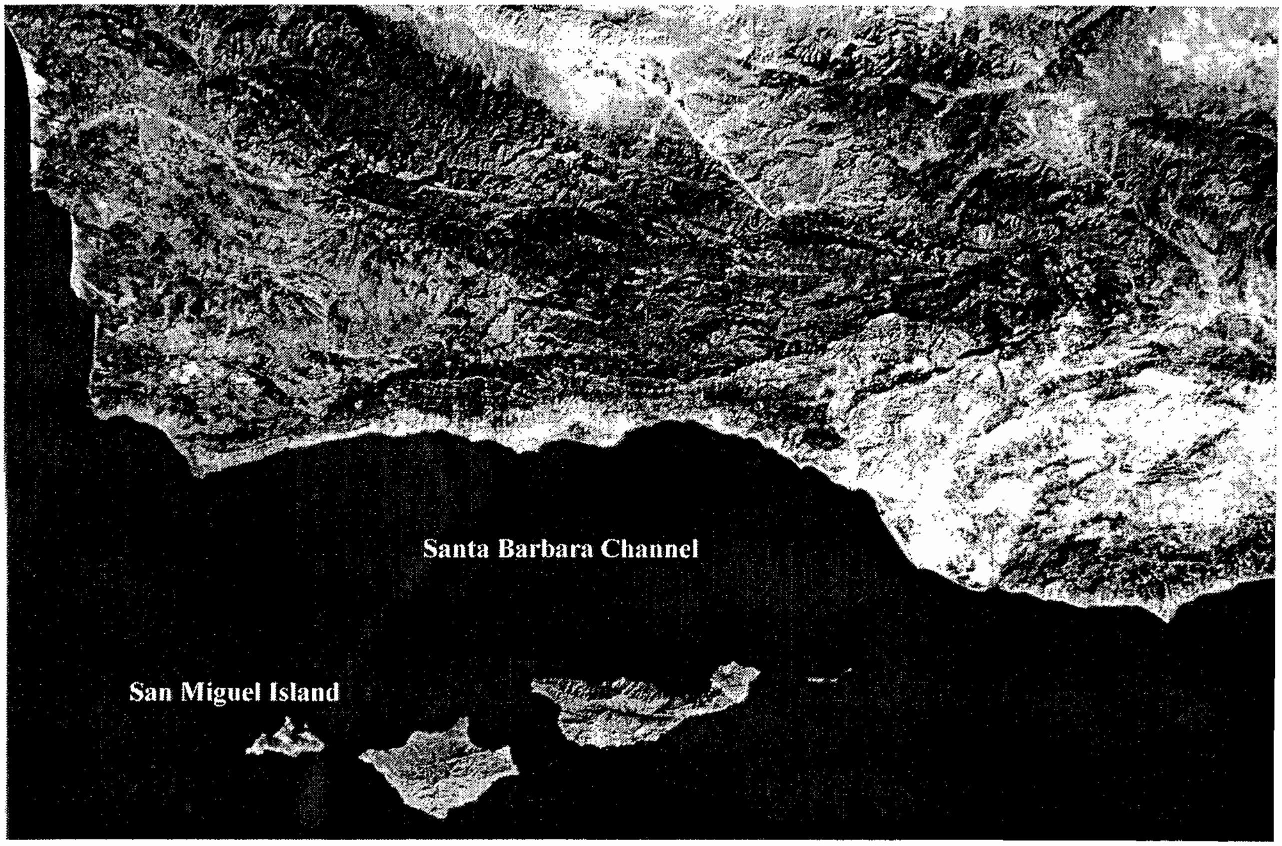
Researchers are increasingly recognizing historical data as an important source of information in analyzing human ecological relationships (Erlandson and Rick 2005; Jackson et al. 2001; Pauly et al. 1998; Rogers-Bennett et al. 2002). My thesis contributes to the growing body of research on human impacts on marine fisheries and may provide new insights into the dynamic synergy that exists between humans and marine environments. This work may also inform questions of ecological sustainability and aid resource managers in developing sustainable practices in marine fisheries and coastal environments.

ANTIQUITY OF COASTAL SUBSISTENCE

Resource availability acts as a limiting factor in the growth and distribution of hunter-gatherer populations. Osborn (1977) argued that marine resource exploitation was not an effective means for sustaining human populations and maritime living was not adopted by humans until relatively late in prehistory. Archaeologists have since challenged Osborn's (1977) claim with data from the Northwest Coast, southwestern Florida, and coastal areas of Africa, Europe, and southern California. Marine resources, especially fish and shellfish, were the primary subsistence foundations for relatively large hunter-gatherer populations in many coastal areas (Erlandson 2001). Current research concerning the evolution of maritime cultures deals with the antiquity of and extent to which humans were using, exploiting, and/or managing their marine environments. Contrary to Osborn's (1977) claim, the oceans have long provided a subsistence foundation for humans across the globe. Examples of prehistoric and historic shellfish cultivation come from coastal communities around the world, including the Netherlands, parts of the Mediterranean, and the Philippines. Medieval cultivators of the French Biscay Coast grew mussels in nets suspended in water (Thomas and Mannino 2001).

The dietary importance of marine foods through time along the California Coast and Channel Islands is well documented and supported by numerous researchers (Colten 1998; Erlandson 1988, 1994; Erlandson et al. 2004; Glassow 1992; Rick 2004; Vellanoweth 2001). Most marine resources were available year-round for islanders, making intertidal and near shore fauna an important source of subsistence (Jones 2002). In winter, frequent storms may have limited some local fishing but resources were available at other nearby locations. Research has shown that shellfish were the key dietary resource among the early occupants of San Miguel Island. Through time, the dietary importance of shellfish decreased and Native Americans intensified fishing strategies and sea mammal hunting (Glassow 1992; Kennett 2005; Rick 2004; Rick and Erlandson 2003; Vellanoweth 2001). Sea otters were valued for their furs, which were traded by islanders to the mainland. Archaeological data from San Miguel Island indicate that humans hunted sea otters from at least 9,000 years ago (Erlandson et al. 2005). However, faunal data suggest that marine mammals were not a major component of most prehistoric islanders' diet and that fish were the most utilized food resource during the Late Holocene (Colten and Arnold 1998).

Figure 1. *Southern California and the Northern Channel Islands*



ENVIRONMENTAL AND CULTURAL BACKGROUND

California's Channel Islands are located in the Pacific Ocean off the coast of southern California. Eight separate islands are divided into northern and southern clusters. The southern group includes Santa Barbara, San Nicolas, Santa Catalina and San Clemente islands. The northern consists of Anacapa, Santa Cruz, Santa Rosa and San Miguel islands (Figure 1). Of the Northern Channel Islands, San Miguel is the second smallest with a total land area of 37 km^2. It is also the westernmost, located about 42 km off the Santa Barbara Coast.

Environmentally distinct from the southern California mainland, the Channel Islands have few terrestrial resources but are rich in marine resources (Rick et al. 2001).

The waters around San Miguel Island are home to an abundance of marine shellfish (abalones, mussels, limpets, sea urchins, etc.), fishes, birds, cetaceans (whales, dolphins, and porpoises), and other sea mammals (seals, sea lions, sea otters). Nutrient rich upwellings in the Santa Barbara Channel support large, productive kelp forests and rocky and sandy coastlines provide for variable near shore habitats.

In historic times, two distinct cultural groups occupied the Channel Islands, the Chumash and Gabrielino Indians. The Gabrielino were Shoshonean peoples who migrated south and west from the Great Basin. They occupied the Southern Channel Islands and adjacent coast, centered on what is now the city of Los Angeles. The Chumash occupied the Santa Barbara Coast and the adjacent Northern Channel Islands (Arnold 1992). Some of the earliest maritime peoples of North America and antecedents of the Chumash occupied the Northern Channel Islands beginning at least 12,000 to 13,000 years ago (Erlandson et al. 1996; Johnson et al. 2000). These people developed maritime subsistence strategies that utilized a variety of resources in coastal, estuarine, and terrestrial environments. Early and Middle Holocene occupants experienced population growth, environmental change, and the development of maritime technology (Arnold 2001; Rick 2004). By the Late Holocene, the Chumash had developed into a complex maritime society with hierarchical political and social organization (Arnold 2000; Jones 2002). Coastal adaptations such as the *tomol* (plank canoe) and fishhooks likely developed during this time period. A sophisticated shell bead trading network connected islanders with mainland peoples, supporting diverse subsistence strategies and craft specialization (Kennett 2005). Shell beads were used as currency among the Chumash and may have been one of the major commodities produced by islanders and exported to the mainland (Arnold 2001).

By the time Juan Rodriguez Cabrillo, a Spanish explorer, sailed into the Santa Barbara Channel in AD 1542, the Chumash lived in numerous relatively large villages with as many as 1,000 occupants. Estimates of total Chumash population levels approach 15,000, recorded at the time of European contact as one of the densest hunter-gatherer groups in the world (Arnold 1992).

Contacts by European explorers continued intermittently for several centuries after Cabrillo's expedition, leaving few written records of historical Chumash society. Archaeological evidence suggests that early European contact may also have left behind Old World epidemic diseases such as smallpox and measles, possibly devastating Chumash populations during this Protohistoric period (Erlandson and Bartoy 1995). The effects of disease intensified in the late 1700s as Spanish missionaries settled on the California mainland. By AD 1820 the Chumash were removed from the Northern Channel Islands and relocated to mainland missions. Occupation of southern California continued and expanded under Mexican (AD 1822-1848) and American (AD 1848-present) control.

The demographic collapse of Native populations and subsequent reductions in Native fishing, hunting, and gathering likely contributed to significant changes in marine and terrestrial ecosystems. Ecological changes may have included, at least temporarily, the recovery of major prey species such as fish, shellfish, pinnipeds and land mammals (Erlandson et al. 2004). For about 30-years after the Chumash were dislocated from the islands, and commercial hunting of sea otters decimated their populations, shellfish rebounded (Davis et al. 1992). Modern abalone and sea urchin fisheries grew out of this period of shellfish abundance.

Valuable resources, particularly sea otters and abalone, attracted traders and merchants to the Santa Barbara Channel area. The 18th century fur trade, led by Russian, Spanish, English, and American merchants, resulted in intensive sea otter hunting. Government control over hunting and the fur trade was limited, especially around the remote Channel Islands, and by AD 1850 California sea otters were nearly extinct (Erlandson et al. 2005). Historical accounts indicate that commercial abalone fishing and export was controlled primarily by Chinese immigrant fishermen and merchants. From the 1850s to 1880s the Chinese utilized the intertidal zone for intensive abalone collection and later Japanese immigrants introduced dive fishing. The Chinese fishing industry declined after the U.S. Congress passed the Scott Act in AD 1888, prohibiting Chinese workers from entering the country, and a ban on abalone exports in 1913. In 1915 the first abalone cannery was established in Cayucos, California and recreational abalone fishing was also popularized. Laws restricting abalone fishing developed in 1930 with the decline of abalone populations (Rogers-Bennett et al. 2002). In addition to the changes caused by intensive sea otter hunting and abalone fishing, historic ranching degraded Channel Islands terrestrial environments. The consequent erosion of San Miguel Island sand dunes may have reduced the extent of the rocky intertidal and subtidal habitat favored by abalones.

With the use of sophisticated technology and an increasingly global market, southern California's modern fishing industry grew to an annual abalone harvest of nearly 2,000 metric tons by AD 1879 (Davis et al. 1992). Despite the abundance of nineteenth and early twentieth-century landings, marine fisheries around the world are now in a state of crisis. Fishery management practices have significantly altered marine ecosystems and contributed to the collapse of abalone populations in southern California (ARMP 2003; Davis et al. 1992). The collapse of fisheries around the world provides contemporary and candid examples of ecosystem sensitivity and human overestimates of shellfish abundance.

The U.S. Navy and the National Park Service (NPS) have led efforts to restore the historically degraded terrestrial and marine environments of the Channel Islands. Except for parts of Santa Cruz Island owned by the Nature Conservancy, the Northern Channel Islands are now incorporated into Channel Islands National Park and managed by the U.S. Department of the Interior. The recently established Abalone Recovery and Management Plan (ARMP 2003) designates no-take zones throughout the Channel Islands National Marine Sanctuary, protecting many marine and near-shore abalone populations.

ARCHAEOLOGICAL SETTING

Several thousand archaeological sites have been recorded on the Northern Channel Islands. San Miguel alone contains over 675 sites, including many large shell middens. A midden is a refuse deposit left by humans and can be used by archaeologists as a stratigraphic record of human resource procurement. Shell middens, comprised mostly of human food debris, can provide information about human diet, changing subsistence patterns, and general times of occupation. Dating these stratified shell middens, archaeologists have recorded a nearly continuous occupation of San Miguel Island spanning the past 10,000 years (Figure 2) (Erlandson et al. 2004, 2005).

Figure 2. *Cultural Chronology of the Santa Barbara Channel Region*

Geologic Time	C14 Years (BP/BC/AD)	Santa Barbara Channel Area	Climatic Trends
Late Holocene	100-400 BP/ ~AD1542-850	Historic/Protohistoric Cultures	Unstable Cool Dry
		Late Period	
		Transitional Period	
	1500 BP/AD 500	Middle Period	Warm Wet
	3350 BP	Early Period *Early Milling Stone*	
Middle Holocene			Warm Dry
	5000 BP/3000BC		Cool Wet
	6650 BP		Warm Dry
Early Holocene	8000 BP/6000BC		
		Paleocoastal Period	Cool Wet
	10000BP/ 8000BC		
Terminal Pleistocene		*Clovis Pattern*	

*Adapted from Erlandson (1997); Jones (1992); and Kennett and Kennett (2000).

On San Miguel Island, the earliest archaeological evidence of human occupation comes from a shell midden at the Daisy Cave site (CA-SMI-261) dating to about 11,500 years ago (Erlandson et al. 1996).

Archaeological data suggest that human population levels in southern California were low during the Terminal Pleistocene and Early Holocene, but increased significantly during the Middle Holocene. The frequency of human burials in the Santa Barbara area, for example, increases during this time, suggesting that population was also increasing (Lambert 1994). Frequencies of radiocarbon dates from the Middle and Late Holocene suggest that an increasing number of archaeological sites were occupied over time (Glassow 1999; Lambert 1994). On San Miguel, variation in the size and number of archaeological sites and their corresponding dates allows estimates of relative human population levels at various times. While these estimates are imprecise, the increasing number of dated sites suggests that population increased during the Middle and Late Holocene.

The archaeological record also provides evidence of technological development and diversification of hunting and fishing strategies during the Middle and Late Holocene, from heavy reliance on intertidal shellfish to an increased reliance on fishing. These developments, as well as major sociopolitical changes, may have been stimulated, in part, by environmental changes and terrestrial and marine resource stresses.

Cultural evolution on the Channel Islands reflects human adaptation to a dynamic marine environment and adaptations may have included changing subsistence strategies based on the availability of key resources (Glassow 1992). Channel Island archaeologists are examining local evidence to explain changes in subsistence strategies, with lines of analysis that include environmental change, population pressure, resource stress, and technological innovation. Emergent sociopolitical complexity of the Late Holocene may be interpreted as a type of human response to environmental challenges. For example, resource stress may have encouraged the development of more complex social systems to meet increasing subsistence demands, especially by about AD 1000 to 1300 (Arnold 1992; Jones 2002; Kennett and Kennett 2000). By the Late Holocene, the Channel Islands had sustained a relatively dense population of marine hunter-gatherers for thousands of years...but at what cost?

ECOLOGICAL SETTING

Paleoenvironmental and Climatic Change

Environmental changes in the southern California Bight area have affected the structure, abundance, and diversity of plant and animal communities. Paleoenvironmental data identify numerous climatic changes that likely affected habitat availability and the productivity of marine resources. Data from the Early Holocene point to rapidly rising postglacial sea levels until about 7,000 years ago (Erlandson 1994: 34). In many parts of California, this transition resulted in lowland flooding and the formation of bays and estuaries. Productivity of near shore habitats may have increased while terrestrial habitats generally decreased. Rising sea levels stabilized during the Middle Holocene and climate generally became warmer and drier (Jones 1992; Erlandson 1997; Vellanoweth 2001). Climate in the Late Holocene exhibits much greater instability. Recent data from the Northern Channel Islands identify an interval from AD 450-1300 when marine and terrestrial environments varied considerably (Kennett and

Kennett 2000). Based on oxygen isotopic analysis of a Santa Barbara Basin sediment core and California mussel shells, Kennett and Kennett (2000) suggested that this interval was marked by cold, unstable marine conditions, high marine productivity, and dry terrestrial climate. Researchers have also identified a possible interval of high sea surface temperatures from AD 1150-1300 that might be connected with long-term oceanic temperature changes, multiple El Niño/Southern Oscillation-like events, and temperature change on a global scale (Colten and Arnold 1998).

El Niño/Southern Oscillation (ENSO) events occur when the tropical Pacific Ocean-atmospheric system is disrupted, affecting weather patterns around the globe. Along the coast of California, ENSOs tend to produce warmer sea surface temperatures and diminish the California Current, reducing marine productivity. While the effects of prehistoric ENSO events on marine ecosystems are not well known, analysis from recent ENSO events may prove useful when studying the impact of sea surface temperature on marine fauna. For example, researchers recently documented increased mortality and reduced reproductive success among pinnipeds in the eastern Pacific, suggesting that sea temperature changes may have impacted prehistoric populations (Colten and Arnold 1998). Contemporary data also suggest that El Niño-like events may have affected the availability of marine fish and shellfish communities on which the Chumash depended.

Kelp Forests and Sea Otters

The biologically diverse and abundant kelp forests of the Santa Barbara Coast and Northern Channel Islands once supported highly productive fisheries, contributing to high Chumash population densities (Erlandson et al. 2005). Kelp forests grow in shallow, rocky habitats along temperate and cool-water coastlines worldwide and provide complex and productive environments for a variety of mammals, fishes, and invertebrates. North Pacific kelp forest ecosystems contain sea otters and a variety of shellfish and fish. Sea otters (*Enhydra lutris*) are important predators, controlling the density and distribution of herbivorous kelp feeders such as abalones (*Haliotis* spp.) and sea urchins (*Strongylocentrotus* spp.). They preferentially feed on large abalone, sea urchins, and crabs, shifting alternatively to mussels and fish. By feeding on sea urchins, sea otters act as apex predators, preventing urchins from overgrazing kelp (ARMP 2003; Jackson et al. 2001). Deforested kelp states, known as sea urchin barrens, can result from intense feeding by urchins due to human predation on sea otters (Steneck et al. 2002). In southern California, sea otters, spiny lobsters (*Panulirus interruptus*), and a fish known as the California sheephead (*Semicossyphus pulcher*) historically preyed on sea urchins, and abalones competed for kelp. The near extinction of sea otters due to the historic fur trade temporarily supported highly productive commercial fishing of remarkably large populations of abalone and sea urchins. Some California kelp forests began to collapse after the intense commercial exploitation of other urchin predators and competitors, including sheephead, spiny lobsters, and abalone in the 19th and 20th centuries (Jackson et al. 2001; Steneck et al. 2002).

Shellfish

Shellfish are especially sensitive indicators of stress on marine ecosystems. Many species are highly susceptible to overexploitation pressures (Erlandson and Yesner 1992; Rogers-Bennett et al. 2002). Abalone, in particular, are relatively slow growing, easily processed, and yield high amounts of meat, making them susceptible to overexploitation by humans. Various non-anthropogenic factors also determine and affect abalone stocks, including development, predation, food and substrate availability, and mortality. Examining these factors provides a baseline for determining the extent to which prehistoric people may have exploited abalone in the Northern Channel Islands.

Over 70 species of abalone are found in marine environments around the world. Red abalone (*Haliotis rufescens*) and black abalone (*H. cracherodii*) are found in rocky intertidal and subtidal kelp forest habitats in southern California. Southern California abalones are some of the largest in the world, with red abalone shells often exceeding 290mm in length (Lindberg 1992). Young abalone eat coralline algae while adults feed on drifting giant kelp (*Macrocystis pyrifera*). Abalones are passive feeders, generally waiting for kelp to pass by them. Urchins, however, are active foragers and more successful competitors for kelp under limited food conditions (ARMP 2003; Davis et al. 1992). Environmental variation in sea temperature, food availability, salinity, and oxygen concentrations can all affect abalone growth and development (Day and Fleming 1992). Under favorable conditions, red and black abalones can reach sexual maturity in roughly two years, but it takes from twelve (red) to twenty-five years (black) to reach current minimal legal sizes for commercial harvesting (ARMP 2003).

Major non-human predators for California abalones are other invertebrates (sea stars, rock crabs, octopi), fish (sheephead, moray eel), and sea otters. Environmental factors such as increased sea temperature, oxygen depletion, storm events, salinity changes, toxic chemicals, and diseases also cause abalone mortality. Because kelp forests are so vital to abalone populations, any event that reduces kelp will indirectly impact abalone. Storms and warm, low-nutrient water from ENSO events significantly reduce kelp abundance, resulting in a cascading decline of higher trophic levels, including shellfish and their predators. Reduced giant kelp abundance in the 1982-4 El Niño years contributed to decreased abalone growth and population collapse on the California Channel Islands and more frequent ENSO events may be contributing to the severe decline of abalone populations (ARMP 2003; Day and Fleming 1992; Shepherd and Breen 1992).

For abalones, sea urchins are primary competitors for both food and space. Competition between these species has helped shape abalone populations. While sea urchins may outcompete abalone during times of resource stress, they also seem to be critical for the survival of abalone. For example, a beneficial relationship may exist between juvenile abalone and the protective spine canopy provided by sea urchins (Rogers-Bennett and Pearse 2001; ARMP 2003).

The California mussel (*Mytilus californianus*) is readily accessible and abundant compared to abalone species. Mussels attach to the hard substrate of rocky shorelines, where they aggregate to form large multi-layered beds in the intertidal zone (Kozloff 1993:135). California mussels are filter feeders that can grow up to 200 mm long. Causes of mortality include predation by sea stars and other animals, large waves from storms, and similar environmental factors that affect abalone (Kozloff 1993).

Changes in growth rates, size, age, and abundance of shellfish populations may reflect a variety of changes in kelp forest environments. In assessing human impacts on shellfish beds, we must be careful to evaluate these natural ecological fluctuations. Nonetheless, San Miguel islanders actively harvested mussels, black abalone, and red abalone for subsistence. Human harvesting may have acted as a predation pressure on shellfish as human population levels increased. Red and perhaps black abalone were also used by the Chumash and their ancestors to make fish hooks, ornaments, and containers. A number of Late Holocene sites, in particular, contain fragments of larger abalone shells that have been heavily processed for technological purposes (Rick 2004). This presents a potential bias in my study, as some larger shells may be missing from the archaeological record, especially for Late Holocene sites.

HUMAN IMPACTS ON ECOLOGICAL COMMUNITIES

> While it may be true, as Kay [2002:259-260] has argued, that it is condescending and morally indefensible to claim that indigenous peoples were not capable of significant environmental impacts, it would be equally condescending to suggest that such people were incapable of recognizing the ecological impacts they had or developing practices that encouraged conservation or sustainable yields. As archaeologists and anthropologists, we find it difficult to believe that ecological awareness and conservation strategies are solely the province of literate or modern human societies (Erlandson and Rick 2005:5).

Without denying the significance of natural ecological changes, it is critical to recognize the role humans have played in altering the environment. Human overfishing of apex predators such as sea otters has caused trophic cascades in kelp forest ecosystems in California, the Aleutians, and the Gulf of Maine (Jackson et al. 2001; Steneck et al. 2002). Aboriginal Aleuts preyed heavily on sea otters beginning around 2,500 years ago, effectively increasing the size and abundance of sea urchins. The near extinction of sea otters from the historic fur trade resulted in the collapse of kelp forests and extensive sea urchin barrens in Alaska (Jackson et al. 2001). Less dramatic changes may be evident in the archaeological record on San Miguel Island, where a series of red abalone middens and sea urchin lenses may indicate a human alteration of nearshore ecosystems (Erlandson et al. 2005). Still, Santa Barbara Channel kelp forests remain today, even though humans have significantly reduced the numbers of predators like sea otters, sheephead, and lobsters, and have overfished abalone and sea urchin populations. Steneck et al. (2002) argued that the more ecologically diverse and redundant ecosystem of southern California makes kelp forests more resistant to collapse compared with Alaskan kelp forests.

METHODS

My project is one component of a larger multi-disciplinary project that employs a historical ecological framework for investigating and understanding long-term human-environment relationships on the Channel Islands. Archaeological data come from San Miguel Island but research and analysis utilizes relevant information, current theories, and archaeological and ecological records from the Channel Islands, the Pacific Coast of the Americas, and marine environments around the globe.

Several lines of evidence exist for measuring human impacts to marine ecosystems. For archaeologists examining shell middens, reduction in abundance, size, and/or age of shells through time may suggest increased fishing pressure (Mannino and Thomas 2001, 2002; Erlandson and Rick 2005). It is often assumed that human foragers would have tended to select larger shells for their greater meat yield, so the larger available shells are expected to dominate shell midden sequences (Mannino and Thomas 2001). Thus, large average shell sizes may indicate limited human impact, while a decline in shell size may indicate intensified predation pressure. Variation in shell sizes over time may indicate that humans were changing subsistence strategies or managing their environment in some way.

Other indirect and non-anthropogenic factors should also be considered when examining changes in shellfish sizes. Some of these natural ecological changes include increased predation by non-human predators, oceanic temperature fluctuations, ENSOs or storm events, sea level changes, and other natural processes discussed earlier. Such changes may reduce or enhance the populations of species upon which humans depend, and may also make species more vulnerable to human-induced pressures. Because detailed ecological monitoring rarely encompasses more than a few decades, the full range of natural variability in nearshore ecosystems may not be understood. Based on current research, it is difficult to assess the extent to which natural (non-anthropogenic) processes affected the San Miguel Island kelp forest ecosystem at any given time over the past 10,000 years, partly because human hunters and foragers have played such an integral role in this ecosystem. For these and other reasons, it is advisable to interpret archaeological data cautiously, focusing on the identification of regional trends rather than patterns found within single sites.

In a preliminary study, Erlandson et al. (2004) found little evidence for significant changes in the average size of California mussels on San Miguel Island over time. To search for evidence of human impacts on San Miguel Island shellfish beds, I analyzed a larger body of data on the size of major shellfish species from twenty-one archaeological sites spanning the past 10,000 years. The data were collected over the past eight years from various shell middens and recorded according to species, sample weight, and length of specimens. Data were collected from both excavation and surface samples, with measurements recorded primarily by graduate and undergraduate students from the Anthropology Department at the University of Oregon. Jon Erlandson, Torben Rick, Todd Braje, and René Vellanoweth carried out pertinent collections and excavations on San Miguel Island. My analysis utilized the available length and height measurements of whole shell specimens and was limited to California mussels, black abalone, and red abalone. I analyzed data from a total of 8,969 shells, including 7,530 California mussels, 1,106 black abalones, and 333 red abalones. I also used a Channel Islands radiocarbon database maintained by University of Oregon archaeologists to estimate San Miguel Island site ages, or individual stratigraphic levels within them (Table 1). Throughout my analysis, all dates are expressed in calendar years before present (CYBP), with the "present" defined as AD 1950. I also grouped average length measurements for each species of shellfish into Early, Middle, and Late Holocene, based on the average radiocarbon date of site strata. The Early Holocene is defined as 11,000-7,500 BP, the Middle Holocene as 7,500-3,000 BP, the Late Holocene as 3,000-150 BP and the Historic as 150 BP- present. Several historic assemblages from Chinese abalone processing sites, dated between about AD 1850 and 1900, were also included in my analysis. In total, 1,176 shells dated to the Early Holocene, 1,536 to the Middle Holocene, 5,847 to the Late Holocene, and 410 to the Historic. Glassow's population growth model (1999) for the Santa Barbara Channel area was used to estimate Chumash population variability through time.

Shellfish size was used as an indicator in examining the extent to which humans were harvesting shellfish. For all three shellfish species, I compared average shell length by site and stratum through time. I expected a decreasing trend in average shell length

Table 1. *Data on San Miguel Island Shellfish Assemblages*

Species	Site (CA-)	Date (CYBP)	Period	Number (shells)	Avg Length	Avg Height	Max (L)	Min (L)	Std. Dev.
H. cracherodii	SMI-SC-61	150	Historic	21	132	42	160	107	16.9
H. cracherodii	SMI-SC-62	150	Historic	64	121	35	164	79	20.2
H. cracherodii	SMI-SC-A19	150	Historic	149	132	48	162	86	14.4
H. cracherodii	SMI-553	150	Historic	58	136	42	176	92	18.4
H. cracherodii	SMI-558	150	Historic	88	127.2	46.8	162	31	18.2
H. cracherodii	SMI-237/H	150	Historic	19	151	51	169	138	6.6
H. cracherodii	SMI-232	1200	Late	123	69.7	18.9	131	29	20.4
H. cracherodii	SMI-261	3290	Middle	14	80.2	N/A	115	27	24.5
H. cracherodii	SMI-396	4600	Middle	321	108.9	33.5	165	44	23.4
H. cracherodii	SMI-SC-22	5210	Middle	12	81.2	25	153	45	35.5
H. cracherodii	SMI-261	6710	Middle	21	88	N/A	117	44	19.2
H. cracherodii	SMI-SC-64	6930	Middle	7	76	17	106	62	15.3
H. cracherodii	SMI-SC-65	7300	Middle	7	78	23	144	50	30.8
H. cracherodii	SMI-607	8530	Early	13	77.8	N/A	106	51	20.1
H. cracherodii	SMI-261	8687	Early	15	75	N/A	112	26	23.9
H. cracherodii	SMI-261	8900	Early	55	82	N/A	127	41	20.2
H. cracherodii	SMI-261	9000	Early	86	72.3	N/A	117	18	18.1
H. cracherodii	SMI-608	9000	Early	11	64.2	N/A	120.3	26.7	26.1
H. cracherodii	SMI-261	9300	Early	8	69	N/A	96	47	15.8
H. cracherodii	SMI-522	9800	Early	12	88.2	N/A	153	45	35.5
H. rufescens	SMI-SC-61	150	Historic	1	193	62	193	193	0
H. rufescens	SMI-553	150	Historic	10	192	55	218	167	17.5
H. rufescens	SMI-232	1200	Late	37	97.5	22.6	156	46	28.9
H. rufescens	SMI-481	1220	Late	64	43.9	N/A	74	24	10.2
H. rufescens	SMI-261	3360	Middle	7	77	N/A	112	48	24.6
H. rufescens	SMI-396	4600	Middle	145	167.8	45.4	235	44	34.3
H. rufescens	SMI-SC-22	5210	Middle	10	124	29.4	200	50	47.3
H. rufescens	SMI-557	6160	Middle	39	164	50	205	101	29.3
H. rufescens	SMI-261	6710	Middle	4	126	N/A	143	96	21.7
H. rufescens	SMI-SC-64	6930	Middle	6	194	46	205	176	11.8
H. rufescens	SMI-SC-65	7300	Middle	10	152	44	190	92	32.2
M. californianus	SMI-163	150	Late	2690	38	N/A	100.3	5.1	11.3
M. californianus	SMI-163	300	Late	422	30	N/A	94.1	4.8	17.8
M. californianus	SMI-470	360	Late	670	33.2	N/A	109	4.8	19.5
M. californianus	SMI-9A	490	Late	148	45	N/A	140	16	15.1
M. californianus	SMI-232	1200	Late	673	33	N/A	92	6	16.8
M. californianus	SMI-481	1220	Late	933	44	N/A	145	7	18.9
M. californianus	SMI-603	2450	Late	87	37	N/A	76.1	13.3	12.4
M. californianus	SMI-261	3360	Middle	71	47	N/A	86	15	14.4
M. californianus	SMI-603	4070	Middle	140	42	N/A	81.6	17.9	10.6
M. californianus	SMI-603	4340	Middle	367	43	N/A	121.4	8.1	13.4
M. californianus	SMI-603	4380	Middle	71	30	N/A	92.5	4.2	24.2
M. californianus	SMI-396	4600	Middle	175	53	N/A	156	17	18.8
M. californianus	SMI-SC-22	5210	Middle	39	46.1	N/A	90	16	15.9
M. californianus	SMI-605	6550	Middle	100	37	N/A	91.8	6.6	24.7
M. californianus	SMI-261	6710	Middle	16	75	N/A	93	57	10.9
M. californianus	SMI-603	7500	Middle	319	23	N/A	101.5	4.7	20.4
M. californianus	SMI-603	8000	Early	128	30.6	N/A	83.5	5.9	22.1
M. californianus	SMI-607	8530	Early	27	66	N/A	114	21	21.2
M. californianus	SMI-261	8687	Early	253	50	N/A	123	5	20.1
M. californianus	SMI-261	8900	Early	42	56	N/A	118	24	20.3
M. californianus	SMI-261	9000	Early	7	63	N/A	86	42	17.5
M. californianus	SMI-261	9300	Early	68	43	N/A	141	7	28.9
M. californianus	SMI-522	9800	Early	123	51	N/A	135	7	19.2

*All dates expressed as averages, all measurements in mm. Historic dates are estimates based on historic abalone fishing records.

over time. For example, shellfish from the Early Holocene should be relatively large, when human population levels and shellfish resource needs were comparatively low. Shellfish sizes should generally decrease through the Middle Holocene and into the Late Holocene, when human populations were larger and more sedentary, necessitating increased predation on shellfish resources. Maritime technology became more effective during this time and humans began more intensive hunting and fishing practices. Finally, shellfish were expected to be relatively large during certain times of the historic period, when Old World diseases affected Channel Islanders, the Chumash were relocated to Spanish Missions on the mainland, and sea otters were hunted to extinction by the historic fur trade.

In analyzing average shell length by site and stratum through time, I produced comparative graphs for each shellfish species. I also graphed individual shell length by site and stratum through time, allowing the examination of data ranges, identification of possible intra-site outliers, variation, and number of individual shells.

In an effort to analyze the environmental impacts of prehistoric peoples, I conducted all statistical analysis on shell size variation from 10,000 years ago up to the Historic period (excluding measurements from sites dating to the historic). The statistical significance of changes in shell sizes through time was examined using a regression test for each species. All statistical analyses were done in JMP and R (Sall and Lehman 2001; R 2004). For black abalones, data from the Historic period demonstrate the potential abundance of shellfish in an artificial state relatively free from human and sea otter predation. In this way, the Historic data may be used as a control to analyze the extent of prehistoric human impacts on shellfish populations. Independently examining data from the Historic period in my analysis is also useful in comparing the impacts the Chumash to those of the colonial and contemporary eras.

RESULTS

Generally, as human populations and predation pressures increase through time, I expected to see a decline in average shellfish size. My analysis generally supports these expectations. For California mussels and red abalones, there appears to be a general decline in shell sizes over time. Black abalones appear to temporarily recover and increase in size in the Historic period. Shell sizes before this time, while generally decreasing, show considerable variation (Figures 3-8). It appears that humans were targeting specific resources, such as shellfish and depleting these resources over time. However, the data seem to indicate periods of predation pressure as well as recovery. Too much emphasis should not be placed on any single point (mean length measurement) in time. Instead, the purpose of such a long-term study is to look for general trends. It is important to remember that temporary ecological shifts due to short-term environmental or climatic changes, such as El Niño events, may not be visible in the archaeological record. This may prove advantageous when analyzing larger changes and ecological relationships through time. As Mannino and Thomas (2001:1110) pointed out, archaeological samples are advantageous in filtering out short-term fluctuations and exposing long-term trends. My results point to a long-term trend of reduced mean shell sizes in San Miguel Island midden deposits over time, interpreted to be the consequence of human predation.

California Mussel

Mean shell sizes of California mussels generally decline through the depositional sequence (p-value = <2.2e-16) (Figure 3). This pattern is very significant because of the large amount of supporting data that consistently span the past 10,000 years (N=7530). Average mussel shell length in seven Early Holocene components is 51.4 mm, and five of the seven assemblages average 50 mm or larger. Average mussel shell length in nine Middle Holocene components is 44 mm, and seven of the nine assemblages average 47 mm or smaller. The gradual pattern of mussel decline through time is less clear between about 7,500-5,500 years ago, due to the comparatively large mean shell length (75 mm) of mussels from Stratum C at Daisy Cave (CA-SMI-261), a relatively brief occupation located on an isolated stretch of the northeast coast. This point is considered an outlier and consists of a relatively small number of shells (N=16). Mean shell lengths for seven points dating to the Late Holocene do not exceed 45 mm, a significant decline from Early Holocene mean shell lengths. While generally decreasing in length through time, mussel sizes from each site vary considerably (Figure 4). For example, the largest and smallest mean values for mussels, 75 mm and 23 mm respectively, both fall between 7,500 and 6,700 years. My study of mussels did not include shells dating to the Historic period, but provide a good indicator of long-term, pre-colonial human predation pressure.

Black Abalone

Black abalones are reasonably well represented in the San Miguel Island sequence, including the Historic period, but relatively few measurements are available from the Late Holocene. Mean shell sizes do not demonstrate a generally decreasing trend and do not significantly decline through time (p-value = 0.088). Mean shell sizes of black abalone increase slightly in the Middle Holocene, then decrease back to Early Holocene levels in the Late Holocene (Figure 5). Average black abalone shell size in seven Early Holocene components is 75.5 mm, and five of the seven assemblages average 77.8 mm or smaller. Average shell size in six Middle Holocene components is 85.4 mm, and all but one of the assemblages average 88 mm or smaller. Figures 5 and 6 demonstrate that Middle Holocene shell sizes vary widely but appear to be slightly larger, overall, than Early Holocene shells. Most evidence for larger Middle Holocene shell sizes comes from a single site (CA-SMI-396) that may be an outlier, although the assemblage provides the most number of shells (N=321). Larger shell sizes in the Middle Holocene may be due to the depletion of sea otters or other more favorable growth conditions. The only Late Holocene component with a sizable assemblage of black abalones dates to about 1200 CYBP and has an average size of about 70 mm. In contrast, the average black abalone shell size in six Historic period components is 133.2 mm. Historic mean shell sizes are comparatively and significantly higher, providing strong evidence that the Chumash and their antecedents heavily harvested black abalone until the Historic period.

Red Abalone

Red abalones are relatively rare in Early Holocene sites, so my analysis can only address variation over the last 7,500 years. Mean shell sizes of red abalone significantly and dramatically decrease from the early Middle Holocene to the Late Holocene (p-value = <2.2e-16) (Figure 7). Mean shell lengths dating to the Late Holocene do not exceed

97.5 mm, whereas all but one mean shell length dating to the Middle Holocene exceeds 124 mm. The one outlying component is from a later Middle Holocene site (CA-SMI-261) and is comprised of just seven shells (Figure 8). Average red abalone shell size from this site is 77 mm, significantly lower than the other six Middle Holocene averages and closer to Late Holocene averages. Technological selection of red abalone shells may explain a portion of this dramatic decline. This is particularly true for Late Holocene sites, where most of the larger shells harvested from San Miguel Island may have been processed for technological use or exported off the island. Many of these larger shells, consequently, may be absent from our archaeological samples. Historic red abalone shells are limited in number (n=11), but the mean shell size is very high, averaging 192.5 mm. At least one Middle Holocene assemblage is comparable to Historic shell lengths and all the assemblages from 7,500-4,000 years ago exceed 120 mm in mean length. I expected to see significant human subsistence pressures on red abalone as human population levels rose in the Middle Holocene (Glassow 1999; Lambert 1994), but the existing data do not fit this expectation. Instead, they may provide evidence for shellfish management by Middle Holocene Channel Islanders. As Erlandson et al. (2005) suggested, the "explosion" of red abalone middens in the Middle Holocene may be due to the depletion of sea otters by Native American hunters:

> When combined with knowledge of sea otter behavior and ecology, archaeological data provide evidence for the possible management of near shore habitats by Native Americans, who may have limited sea otter populations to increase the productivity of shellfish and near shore fish populations (Erlandson et al. 2005:1).

Glassow (1999) alternatively suggested that changes in sea-surface temperature contributed to this explosion of red abalone middens. The generally stable climate of the

Middle Holocene may support evidence for shellfish abundance and productivity but such paleoclimatic effects should also be visible in the Late Holocene, when marine productivity was high due to cold sea surface temperatures (Kennett and Kennett 2000). The relatively large and abundant red abalone shells from Middle Holocene sites, then, do not appear to be solely the result of paleoclimatic change but also of human alterations to the kelp forest ecosystem.

CONCLUSIONS

As keystone predators, humans have impacted and shaped San Miguel Island shellfish communities over the past 10,000 years. Mussel and red abalone shell sizes decline significantly through the depositional sequence, supporting my hypothesis that human predation pressure through time reduced overall shellfish size. Patterns of red abalone exploitation may provide evidence that humans limited sea otter populations to increase the productivity of shellfish populations. Except for the Historic period, black abalone results show no systematic decline in shell size through time, but provide some limited support for a Middle Holocene rebound in abalone populations.

Climatic changes may lead to reduced or enhanced availability of species on which humans depend or make animals more vulnerable to human induced pressures. On San Miguel Island, however, humans may have been the dominant force in shaping shellfish communities through the Holocene. Based on current research, it is difficult to assess the extent to which natural (non-anthropogenic) processes affected the San Miguel Island kelp forest ecosystem at any given time over the past 10,000 years, partly because human hunters and foragers have played such an integral role in this ecosystem. A multi-disciplinary approach and closer working relationships between ecologists, biologists, geologists, archaeologists, and other researchers would provide a more comprehensive understanding of the complex ecological relationships that exist in kelp forests and the role humans played and continue to play in marine ecosystems worldwide.

Further research on San Miguel and the other Channel Islands includes continuing collection, excavation, and analysis of shells from prehistoric and historic archaeological sites. A further line of analysis should include analysis of average shell ages, data that may provide some independent corroboration of my study of changes in mean shell sizes through time.

Erlandson et al. (2005) recently argued that the Chumash may have actively managed their environment by enhancing shellfish productivity on San Miguel Island. Shellfish size data from California mussels, red abalones, and black abalones may support this argument, suggesting that the Chumash maintained sustainable shellfish harvests while supporting a large and sedentary population. Such population levels may have been reached because of resource abundance and diversity (Jackson et al. 2001) and the Chumash may have sought to maintain the abundance of shellfish by selectively and increasingly preying on sea otters. In this way, the Chumash may have used a relatively sustainable strategy of "fishing up" the marine food web. Early Holocene San Miguel islanders subsisted primarily off foods from lower trophic levels, such as shellfish. Through time, and as populations grew and technology advanced, resources from higher trophic levels, such as larger fishes and sea mammals were increasingly utilized. Compared to the Historic period, the ecological impact of fishing up the marine food web for over 10,000 years appears to have been relatively small. Shellfish populations were consistently preyed upon, as demonstrated by this study, but the kelp forest ecosystem remained intact and abundant enough to support a large-scale fishing industry as late as the 20th century.

This particular Native American subsistence pattern contrasts with contemporary trends of "fishing down marine food webs", as exemplified by marine hunting and fishing strategies from historic and modern eras (Pauly 1995; Pauly et al. 1998). It includes first, the removal of apex predators such as tuna and swordfish, then of smaller fishes and fauna from increasingly lower trophic levels, such as shellfish. The result is a cascading collapse of the trophic system and, ultimately, of the entire marine ecosystem (Jackson et al. 2001). As Pauly et al. (1998:863) explain:

> Globally, trophic levels of fisheries landings appear to have declined in recent decades at a rate of about 0.1 per decade, without the landings themselves increasing substantially. It is likely that continuation of present trends will lead to widespread fisheries collapses...whether or not they are due to a relaxation of top-down control. Therefore, we consider estimations of global potentials based on extrapolation of present trends or explicitly incorporating fishing-down-the-food-web strategies to be highly questionable.

Fishing down marine food webs is intimately connected to the "shifting baseline syndrome" because of its impact on increasingly depleted marine species (Pauly 1995; Pauly et al. 1998). Modern fishery management strategies based on "recent historical baselines are often fundamentally flawed because they fail to account for the abundance of key species prior to heavy fishing or hunting by indigenous peoples or early commercial harvests" (Erlandson and Rick 2005:1). In demonstrating that humans have impacted Channel Island shellfish communities for the past 10,000 years, my study provides an example of how such baselines are flawed. Utilizing information about the effects of indigenous subsistence strategies, such as the Chumash pattern of fishing up the marine food web, may aid management decisions about the future of large-scale subsistence fishing, or at least provide a comparative baseline for the magnitude of current human impacts on the environment.

Local subsistence adaptations may be viewed as part of regional and even global trends in human evolution. Perhaps further examination of hunter-gatherer subsistence strategies on the Channel Islands and around the world will provide insights into modern environmental management.

Figure 3

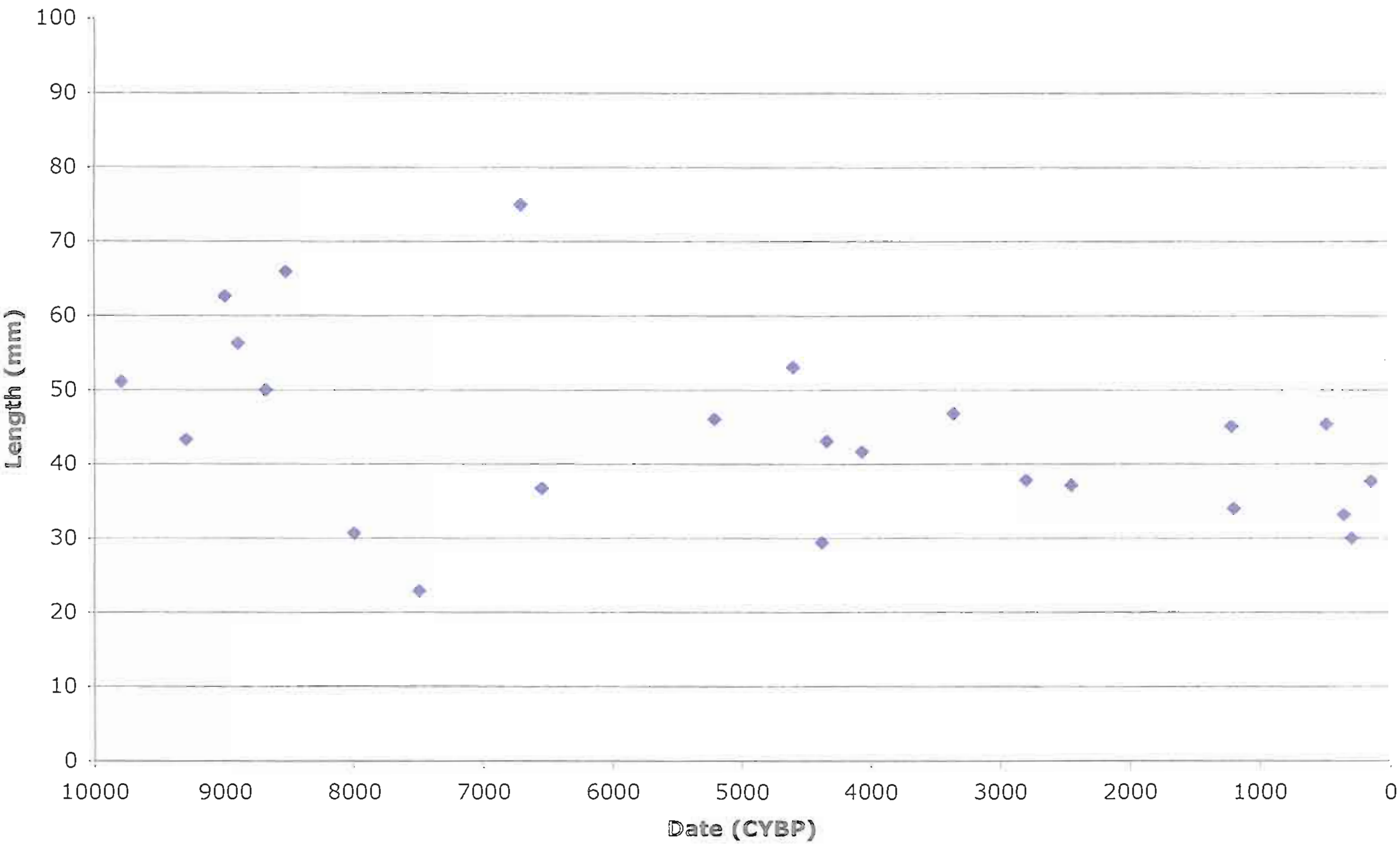

Mussel Length through Time
Length (mm)
100
90
80
70
60
50
40
30
20
10
0
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
Date (CYBP)

Figure 4

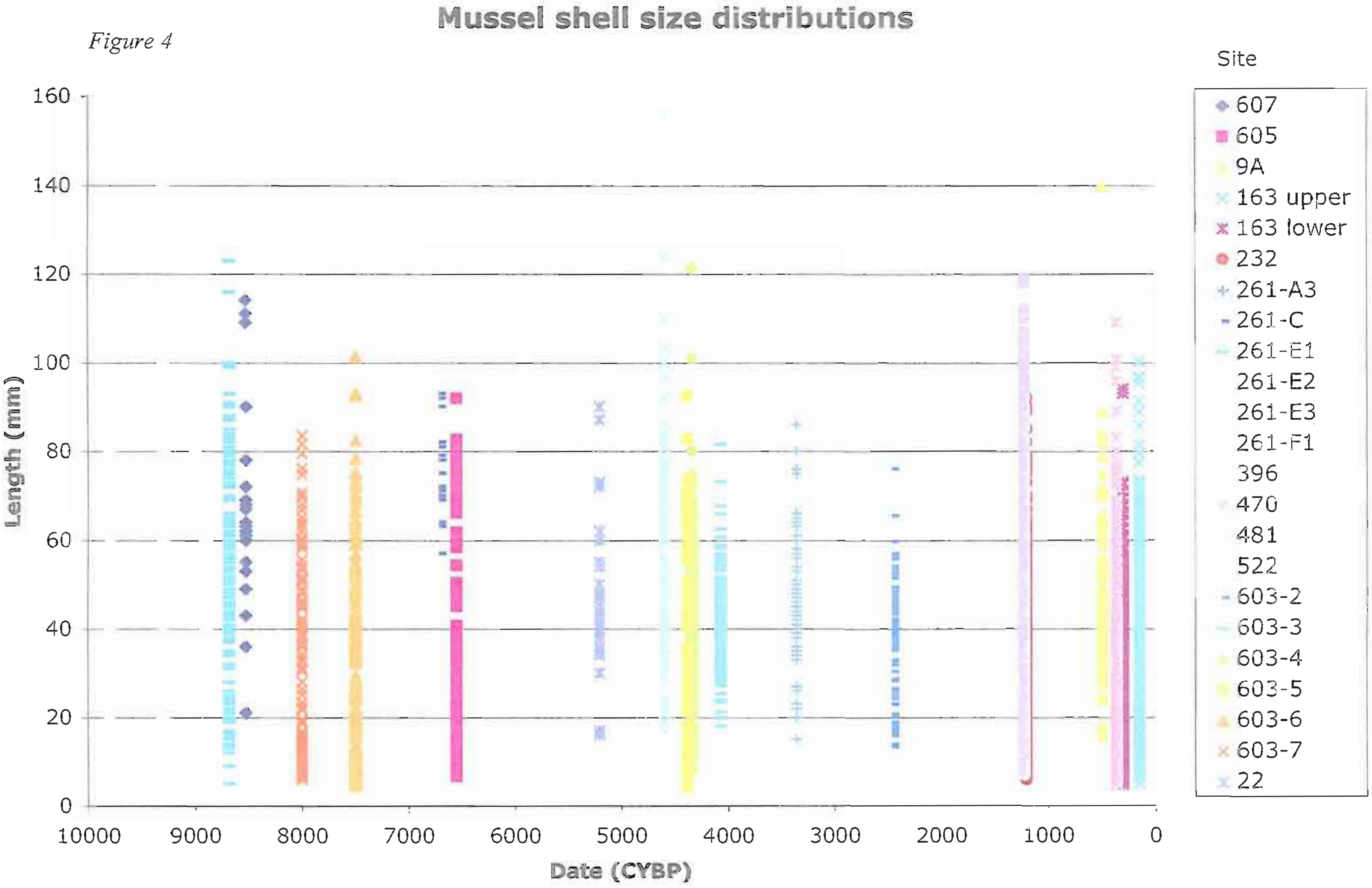

Mussel shell size distributions
Site
607
605
9A
163 upper
163 lower
232
261-A3
261-C
261-E1
261-E2
261-E3
261-F1
396
470
481
522
603-2
603-3
603-4
603-5
603-6
603-7
22
Length (mm)
160
140
120
100
80
60
40
20
0
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
Date (CYBP)

Figure 5

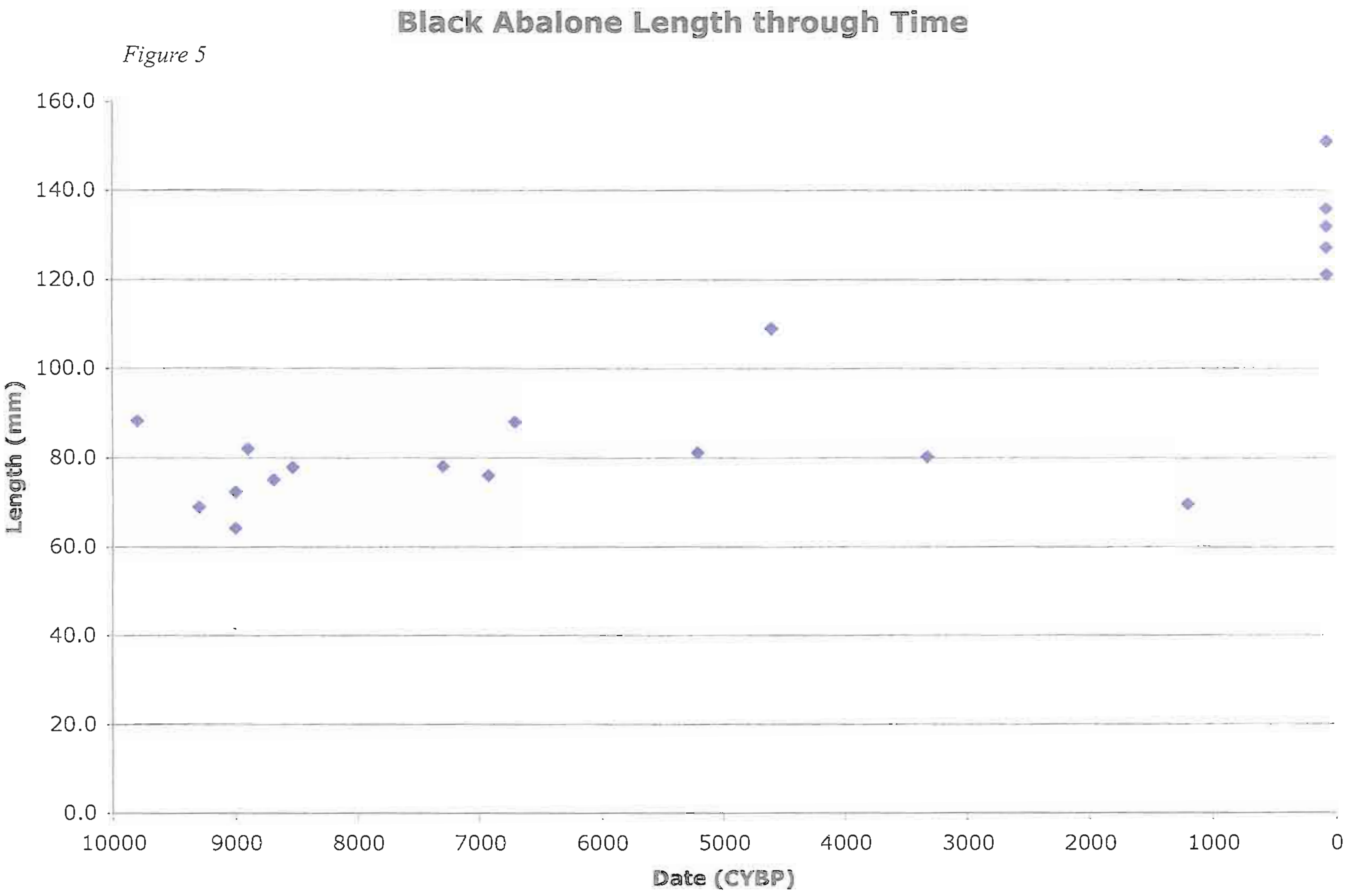

Black Abalone Length through Time
Length (mm)
160.0
140.0
120.0
100.0
80.0
60.0
40.0
20.0
0.0
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
Date (CYBP)

Figure 6

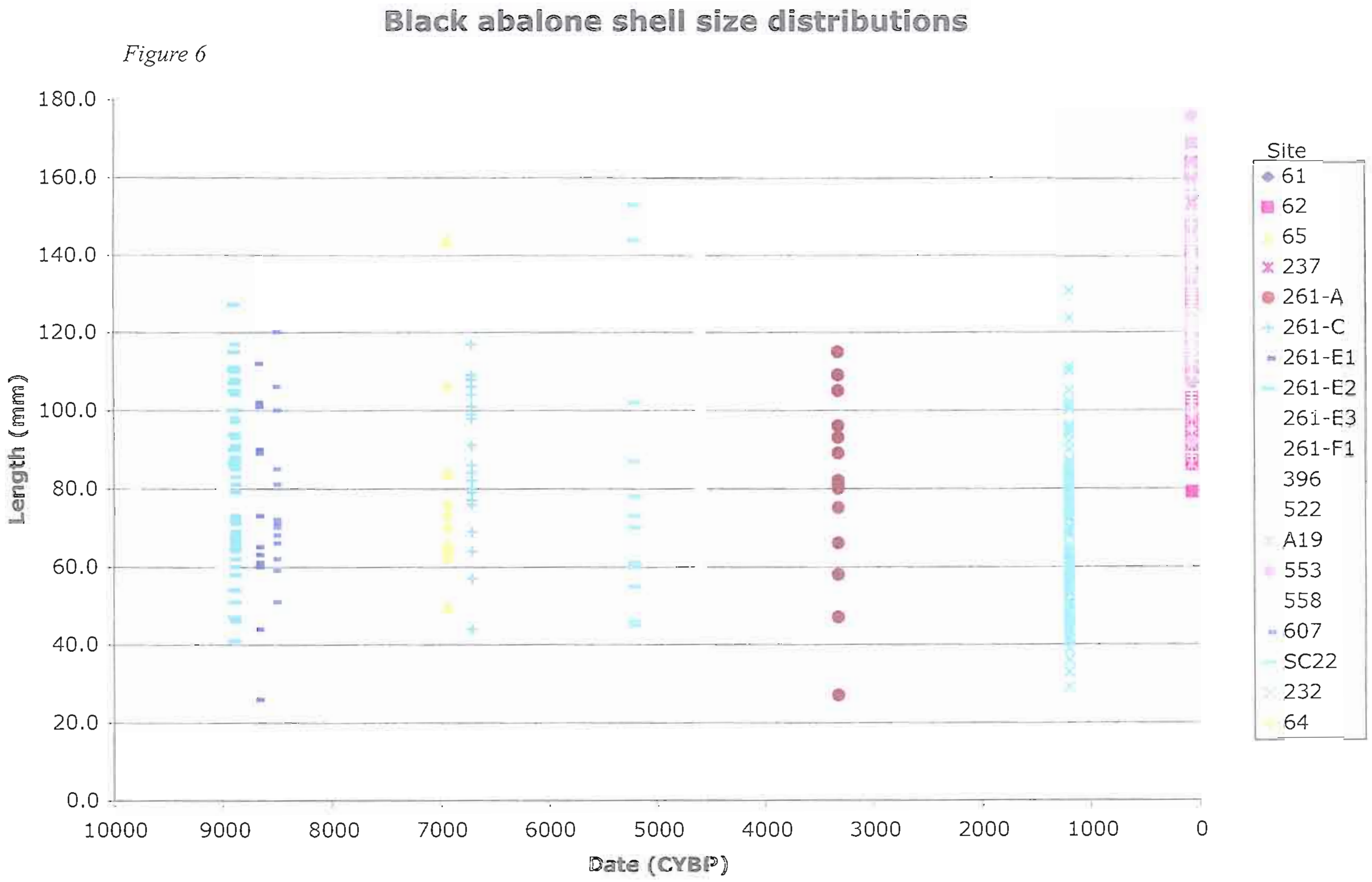

Black abalone shell size distributions
Length (mm)
180.0
160.0
140.0
120.0
100.0
80.0
60.0
40.0
20.0
0.0
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
Date (CYBP)
Site
61
62
65
237
261-A
261-C
261-E1
261-E2
261-E3
261-F1
396
522
A19
553
558
607
SC22
232
64

Figure 7

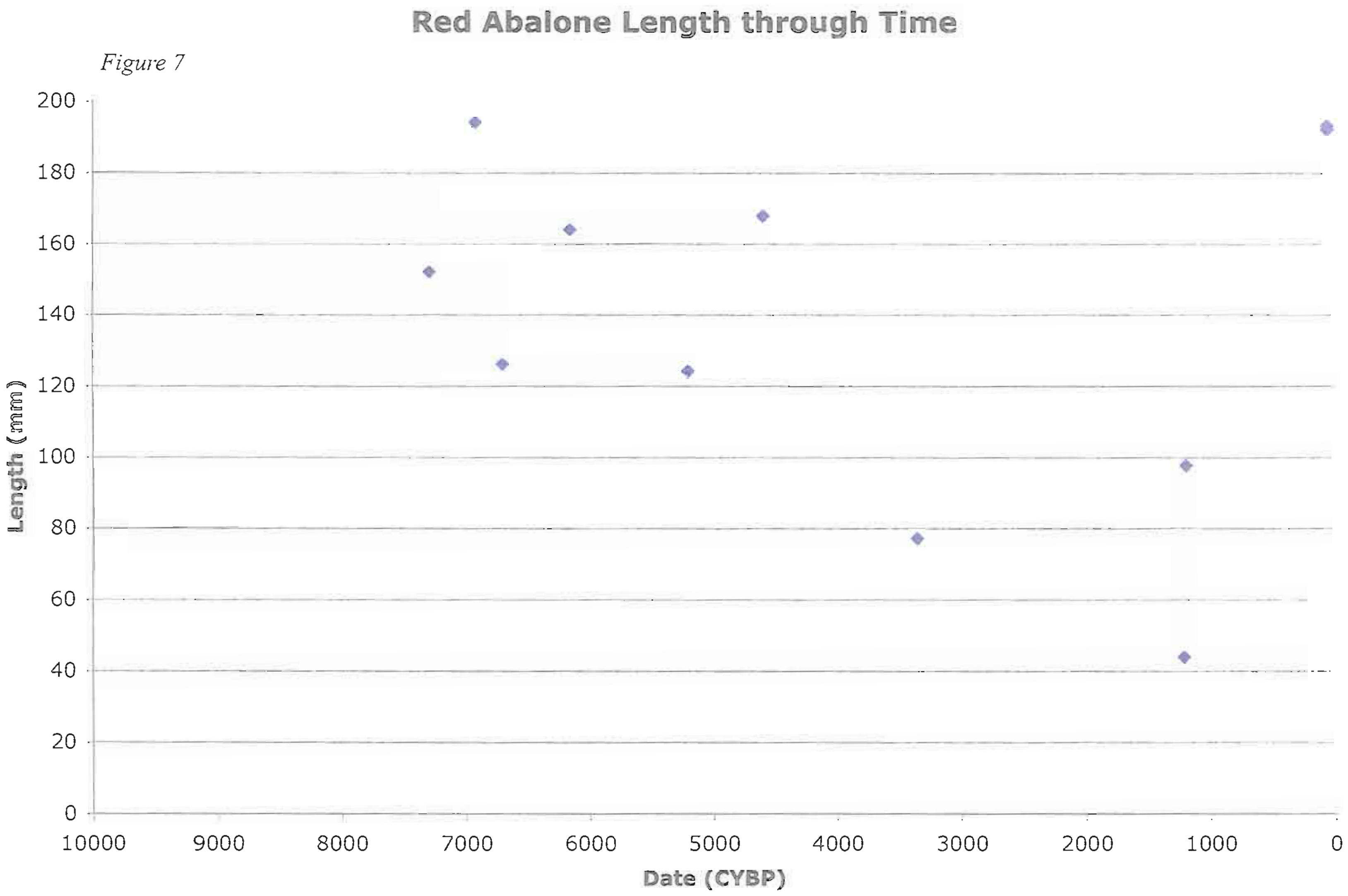
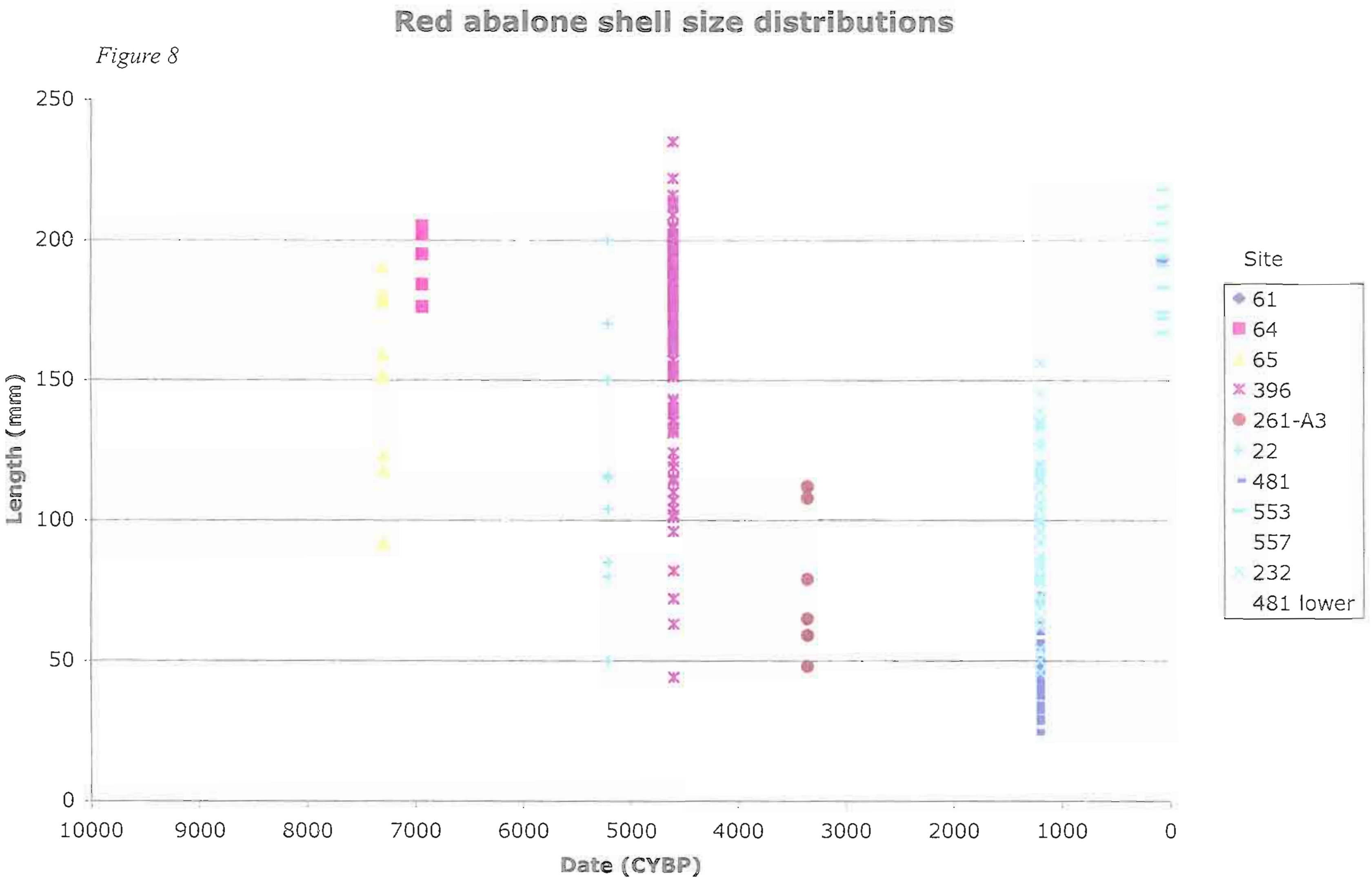

Red Abalone Length through Time
Length (mm)
200
180
160
140
120
100
80
60
40
20
0
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
Date (CYBP)

Figure 8


Red abalone shell size distributions
Length (mm)
250
200
150
100
50
0
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
Date (CYBP)
Site
61
64
65
396
261-A3
22
481
553
557
232
481 lower

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REFERENCES CITED

Abalone Recovery and Management Plan (ARMP)

2003 Electronic document, http://www.dfg.ca.gov/mrd/armp/figures.html, accessed February 23, 2005.

Alroy, J.

2001 A Multispecies Overkill Simulation of the End Pleistocene Megafaunal Mass Extinction. *Science* 292:1893-1896.

Arnold, Jeanne E.

1992 Complex Hunter-Gatherer-Fishers of Prehistoric California: Chiefs, Specialists, and Maritime Adaptations of the Channel Islands. *American Antiquity* 57:60-84.

2000 The Origins of Hierarchy and the Nature of Hierarchical Structures in Prehistoric California. In *Hierarchies in Action: Cui Bono?*, edited by Michael W. Diehl, pp. 221-240. Center for Archaeological Investigations, Southern Illinois University, Carbondale.

2001 The Chumash in World and Regional Perspectives. In *The Origins of a Pacific Coast Chiefdom: The Chumash of the Channel Islands*, edited by Jeanne E. Arnold, pp. 1-19. University of Utah Press, Salt Lake City.

Colten, Roger H., and Jeanne E. Arnold

1998 Prehistoric Marine Mammal Hunting on California's Northern Channel Islands. *American Antiquity* 63:679-701.

Davis, Gary E., Daniel V. Richards, Peter L. Haaker, and David O. Parker

1992 Abalone Population Declines and Fishery Management in Southern California. In *Abalone of the World: Biology, Fisheries and Culture*, edited by S.A. Shepherd, Mia J. Tegner, and S.A Guzman del Proo, pp. 237-249. *Proceedings of the 1st International Symposium on Abalone*, Fishing News Books, Cambridge, MA.

Day, R.W., and A.E. Fleming

1992 The Determinants and Measurement of Abalone Growth. In *Abalone of the World: Biology, Fisheries and Culture*, edited by S.A. Shepherd, Mia J. Tegner, and S.A Guzman del Proo, pp. 141-168. *Proceedings of the 1st International Symposium on Abalone*, Fishing News Books, Cambridge, MA.

Erlandson, Jon M.

1988 Role of Shellfish in Prehistoric Economies: A Protein Perspective. *American Antiquity* 53:102-109.

1994 *Early Hunter Gatherers of the California Coast*. Plenum Press, New York.

1997 The Middle Holocene Along the California Coast. In *Archaeology of the California Coast During the Middle Holocene*, edited by Jon M. Erlandson and Michael A. Glassow, pp. 1-10. Institute of Archaeology, University of California, Los Angeles.

2001 The Archaeology of Aquatic Adaptations: Paradigms for a New Millennium. *The Journal of Archaeological Research* 9(4):287-350.

Erlandson, Jon M., and David R. Yesner
1992 The Prehistory of the California Coast: Prospects and Perspectives. In *Essays on the Prehistory of Maritime California*, edited by Terry L. Jones, pp. 267-276. University of California, Davis Publications, Davis, CA.

Erlandson, Jon M., and Kevin Bartoy
1995 Cabrillo, the Chumash, and Old World Diseases. *Journal of California and Great Basin Anthropology* 17(2):153-173.

Erlandson, Jon M., Douglas J. Kennett, B. Lynn Ingram, Daniel A. Guthrie, Don P. Morris, Mark A. Tveskov, G. James West, and Phillip L. Walker
1996 An Archaeological and Paleontological Chronology for Daisy Cave (CA-SMI-261), San Miguel Island, California. *Radiocarbon* 38(2):355-373.

Erlandson, Jon M., Torben C. Rick, and Rene L. Vellanoweth
2004 Human Impacts on Ancient Environments: A Case Study from California's Northern Channel Islands. In *Voyages of Discovery: The Archaeology of Islands,* edited by Scott M. Fitzpatrick, pp. 51-83. Praeger, Westport, CT.

Erlandson, Jon M., and Torben C. Rick
2005 Archaeology, Marine Ecology, and Human Impacts on Marine Environments. In *Archaeology, Historical Ecology, and Human Impacts in Marine Ecosystems*, edited by Torben C. Rick and Jon M. Erlandson. University of California Press. (in review)

Erlandson, Jon M., Torben C. Rick, James A. Estes, and Michael H. Graham
2005 Sea Otters, Shellfish, and Humans: A 10,000 Year Record from San Miguel Island, California. *Proceedings of the Sixth California Islands Conference*, edited by D. Garcelon and C. Schwemmer, pp.1-20. Institute for Wildlife Studies and National Parks Service.

Glassow, Michael A.
1992 The Relative Dietary Importance of Marine Foods Through Time in Western Santa Barbara County. In *Essays on the Prehistory of Maritime California*, edited by Terry L. Jones, pp. 115-128. University of California, Davis Publications, Davis CA.

1999 Measurement of Population Growth and Decline During California Prehistory. *Journal of California and Great Basin Anthropology* 21(1): 45-66.

Jackson, Jeremy B.C., Michael X. Kirby, Wolfgang H.Berger, Karen A. Bjorndal, Louis W. Botsford, Bruce J. Bourque, Roger H. Bradbury, Richard Cooke, Jon Erlandson, James A. Estes, Terence P. Hughes, Susan Kidwell, Carina B. Lange, Hunter S. Lenihan, John M. Pandolfi, Charles H. Peterson, Robert S. Steneck, Mia J. Tegner, Robert R. Warner

2001 Historical Overfishing and the Recent Collapse of Coastal Ecosystems. *Science* 293:561-748.

Johnson, J.R., T. Stafford Jr., H. Ajie, and D.P. Morris

2000 Arlington Springs Revisited. *Proceedings of the Fifth California Islands Symposium*, edited by D. Brown, K. Mitchell and H. Chaney, pp. 541-545. Santa Barbara Museum of Natural History, Santa Barbara, CA.

Jones, Terry L.

1992 Settlement Trends Along the California Coast. In *Essays on the Prehistory of Maritime California*, edited by Terry L. Jones, pp. 1-37. Davis Publications, Davis, CA.

2002 Late Holocene Cultural Complexity on the California Coast. In *Catalysts to Complexity: Late Holocene Societies of the California Coast*, edited by Jon M. Erlandson and Terry L. Jones, pp. 1-12. Cotsen Institute of Archaeology, University of California, Los Angeles.

Kay, Charles E., and Randy T. Simmons

2002 *Wilderness and Political Ecology: Aboriginal Influences and the Original State of Nature*. University of Utah Press, Salt Lake City.

Kennett, Douglas J.

2005 *The Island Chumash: Behavioral Ecology of a Maritime Society*. University of California Press, Berkeley.

Kennett, Douglas J., and James P. Kennett

2000 Competitive and Cooperative Responses to Climatic Instability in Coastal Southern California. *American Antiquity* 65:379-395.

Kozloff, Eugene N.

1993 *Seashore Life of the Northern Pacific Coast*. University of Washington Press, Seattle.

Lambert, P.
1994 *War and Peace on the Western Front: A Study of Violent Conflict and its Correlates in Prehistoric Hunter-gatherer Societies of Coastal Southern California.* Ph.D. dissertation, Department of Anthropology, University of California, Santa Barbara.

Lindberg, David R.
1992 Evolution, Distribution and Systematics of Haliotidae. In *Abalone of the World: Biology, Fisheries and Culture*, edited by S.A. Shepherd, Mia J. Tegner, and S.A Guzman del Proo, pp. 3-18. *Proceedings of the 1st International Symposium on Abalone*, Fishing News Books, Cambridge, MA.

Mannino, Marcello A., and Kenneth D. Thomas
2001 Intensive Mesolithic Exploitation of Coastal Resources? Evidence from a Shell Deposit on the Isle of Portland (Southern England) for the Impact of Human Foraging on Populations of Intertidal Rocky Shore Molluscs. *Journal of Archaeological Science* 28:1101-1114.

2002 Depletion of a Resource? The Impact of Prehistoric Human Foraging on Intertidal Mollusc Communities and its Significance for Human Settlement, Mobility and Dispersal. *World Archaeology* 33(3):452-474.

Osborn, A.O.
1977 Strandloopers, Mermaids, and Other Fairy Tales: Ecological Determinants of Resource Utilization – the Peruvian Case. In *For Theory Building in Archaeology*, edited by L.R. Binford, pp. 157-205. Academic Press, New York.

Pauly, Daniel
1995 Anecdotes and the Shifting Baseline Syndrome of Fisheries. *Trends in Ecology and Evolution* 10(10):430.

Pauly, Daniel, Villy Christensen, Johanne Dalsgaard, Rainer Froese, and Francisco Torres Jr.
1998 Fishing Down Marine Food Webs. *Science* 279:860-863.

R Development Core Team
2004 *R: A Language and Environment for Statistical Computing.* R Foundation for Statistical Computing, Vienna, Austria.

Redman, Charles L.
1999 *Human Impact on Ancient Environments.* University of Arizona Press, Tucson.

Rick, Torben C., Jon M. Erlandson, and Rene L. Vellanoweth
2001 Paleocoastal Marine Fishing on the Pacific Coast of the Americas: Perspectives from Daisy Cave, California. *American Antiquity* 66:595-613.

Rick, Torben C., and Jon M. Erlandson
2003 Archaeology, Ancient Human Impacts on the Environment, and Cultural Resource Management on Channel Islands National Park, California. *CRM Journal* 25(3):86-89.

Rick, Torben C.
2004 *Daily Activities, Community Dynamics, and Historical Ecology on California's Northern Channel Islands*. Ph.D. dissertation, Department of Anthropology, University of Oregon.

Rogers-Bennett, Laura, and J.S. Pearse
2001 Indirect Benefits of Marine Protected Areas for Juvenile Abalone. *Conservation Biology* 15(3):642-647.

Rogers-Bennett, Laura, Peter L. Haaker, Tonya O. Huff, and Paul K. Dayton
2002 Estimating Baseline Abundances of Abalone in California for Restoration. *CalCOFI Rep* 43:97-111.

Sall, J. and A. Lehman
2001 *JMP Start Statistics*, Pacific Grove, CA. Duxbury Press.

Shepherd, S.A., and P.A. Breen
1992 Mortality in Abalone: Its Estimation, Variability and Causes. In *Abalone of the World: Biology, Fisheries and Culture*, edited by S.A. Shepherd, Mia J. Tegner, and S.A Guzman del Proo, pp. 276-304. *Proceedings of the 1st International Symposium on Abalone*. Fishing News Books, Cambridge, MA.

Steneck, Robert S., Michael H. Graham, Bruce J. Bourque, Debbie Corbett, Jon M. Erlandson, James A. Estes, and Mia J. Tegner
2002 Kelp Forest Ecosystems: Biodiversity, Stability, Resilience and Future. *Environmental Conservation* 29(4):436-459.

Thomas, Kenneth D., and Marcello A. Mannino
2001 The Exploitation of Invertebrates and Invertebrate Products. In *Handbook of Archaeological Sciences*, edited by D.R. Brothwell and A.M. Pollard, pp. 427-440. John Wiley and Sons,

Vellanoweth, Rene L.
2001 *Coastal Archaeology of Southern California: Accounts from the Holocene*. Ph.D. dissertation, Department of Anthropology, University of Oregon.